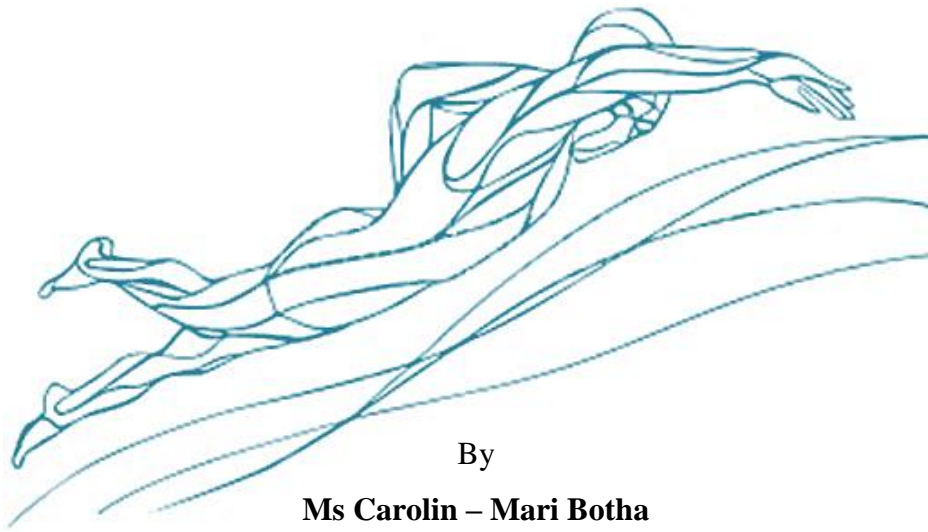




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**THE MEASUREMENT CHARACTERISTICS OF UPPER-QUARTER POSTURE IN  
FEMALE ADOLESCENTS: A COMPARISON BETWEEN COMPETITIVE  
FREESTYLE SWIMMERS AND NON-SWIMMERS**



By

**Ms Carolin – Mari Botha**

A dissertation submitted in fulfilment of requirements of the degree  
**MSc (Sport Science)**

in the Department of Physiology, Division of Biokinetics and Sport Science at the

UNIVERSITY OF PRETORIA  
FACULTY OF HEALTH SCIENCES

**Supervisor: Mrs TCdS Camacho**

**Co-supervisor: Dr F Rossouw**

**7 November 2018**



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# DEDICATION

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*To my loving parents, Prof Ben and Lindi Botha:*

*You are the reason I want to further my studies. Thank you for setting me up for success and motivating me to achieve greatness.*

*When I grow up I want to be more like you.  
As for every successful child there is a parent that already paved the way.*



# ACKNOWLEDGEMENTS

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**I would like to express my sincere appreciation to the following people and institutions for their role in assisting me to successfully complete this study**

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**Late Prof PE Kruger** (Director of the Institute for Sports Research, University of Pretoria) for initiating this project and believing in me. Your presence is truly missed.

**Dr Pieter WA Meyer** (Department of Immunology, Senior Specialist and Statistics, University of Pretoria) for statistical analysis. Your assistance and guidance are greatly appreciated.

**Dr Pippa Marais**, for language editing. Your meticulous eye for perfection is unparalleled.

The **participants** of the study - my sincerest gratitude for your willingness that brought this study to its success.



# ABSTRACT

**TITLE:** The measurement characteristics of upper-quarter posture in female adolescents: a comparison between competitive freestyle swimmers and non-swimmers

**CANDIDATE:** Ms Carolin-Mari Botha

**SUPERVISOR:** Mrs Tanya Chantelle de Sousa Camacho

**CO-SUPERVISOR:** Dr Francè Rossouw

**DEGREE:** MSc (Sport Science)

**Background & Aim:** Upper-quarter postural changes and their associated injury is a growing concern in female adolescent competitive swimmers. Postural changes in female adolescent competitive freestyle swimmers is hypothesized to develop because of high training loads, physiological and mechanical demands of freestyle swimming and its associated intrinsic and extrinsic risk factors. Studies comparing upper-quarter postural changes between highly competitive adolescent swimmers to adolescent non-swimmers have not been conducted. Therefore, the aim of this was to prospectively identify the incidence of upper-quarter postural differences in female adolescent competitive freestyle swimmers, by comparing their upper-quarter postural measurement characteristics to the upper-quarter postural measurement characteristics of female adolescent non-swimmers.

**Methods:** A total of 116 female adolescents were recruited for this study. Overall, 71 participants (35 evaluation group; 36 control group, mean age =  $15\pm 3$  yrs) complied with the inclusion criteria. Cervical and shoulder range of motion, dynamic stability through the Y-Balance test, photographic postural analysis, and shoulder and scapular muscular strength measures were conducted on both groups. A prospective observational and comparative cross-sectional study design was used. Data was analysed using the STATA 13 software application. Quantitative data collected were subjected to descriptive and inferential statistics. The One-way ANOVA was performed using the Kruskal-Wallis test for non-parametric data for more than 2 groups or the Mann-Whitney test when 2 groups were compared. The Wilcoxon signed rank test was used to gauge differences within groups. Statistical significance was determined by P-value equal to or less than 0.05.



**Results:** Analysis showed significant differences ( $p \geq 0.05$ ) between the EVAL and CON groups for all variables measured, except for cervical lateral flexion. When comparing the difference between groups, the EVAL group achieved lower mean scores for range of motion measures in horizontal shoulder adduction, shoulder flexion, -extension, and -internal rotation, and cervical forward flexion. Additionally, the EVAL group scored lower mean values for static upper-quarter cervical angle, protraction and retraction angle; and muscular strength measures in shoulder extension and scapular retraction, than the CON group. The EVAL group achieved higher mean scores for range of motion measures in shoulder abduction, -external rotation, cervical extension, -lateral flexion, and -lateral rotation; the mean absolute value for the Y-balance test; static upper-quarter head tilt and thoracic angles; and muscular strength measures in shoulder flexion; -external rotation; -internal rotation; -abduction; and -adduction, scapular elevation, -depression, and -protraction measures, than the CON group. Furthermore, the mean scores attained by the EVAL group for horizontal shoulder adduction (right & left = 10 deg, difference), shoulder internal rotation (right = 8 deg & left = 9 deg, difference), -extension (right = 8 deg & left = 9 deg, difference), and -flexion (right & left = 23 deg, difference) range of motion and static upper-quarter head tilt, cervical, and thoracic angles, deviated from the normative values.

**Conclusion:** The significant differences in the upper-quarter characteristics noted between the EVAL and CON groups indicate that the female adolescent competitive freestyle swimmers were at greater risk of attaining a forward head – rounded shoulder posture. Subsequently, a number of the EVAL group's measures deviated from the norm, therefore leading to the presumption that they were also at risk of injury and pain associated with the forward head – rounded shoulder posture. The results propose that the extrinsic risk factors associated with competitive swimming, may have had an influence on the upper-quarter posture of the female adolescent competitive freestyle swimmers of this study. These findings highlight the interplay between the intrinsic - and extrinsic risk factors of swimming. It is, therefore, recommended that sport scientists and coaches screen for postural changes and implement preventative strength and conditioning training sessions for their female adolescent competitive freestyle swimmers. Moreover, future research should aim at investigating the influence of the extrinsic risk factors on upper-quarter posture of both male and female adolescent competitive swimmers.

**Key words:** forward head-rounded shoulder posture; range of motion; muscular strength; postural angles; female adolescent competitive freestyle swimmers; female adolescent non-swimmers.



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# LIST OF ABBREVIATIONS

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<b>ANOVA</b>	Analysis Of Variance
<b>BMI</b>	Body Mass Index
<b>C1-C7</b>	Cervical vertebrae 1 to 7
<b>cm</b>	centimetres
<b>cm<sub>h</sub></b>	centimetres height
<b>cm<sub>l</sub></b>	centimetres length
<b>cm<sub>w</sub></b>	centimetres width
<b>CON</b>	Control Group
<b>deg</b>	degrees
<b>EL</b>	Extremity Length
<b>EVAL</b>	Evaluation Group
<b>GH</b>	Glenohumeral joint
<b>GIRD</b>	Glenohumeral Internal Rotation Deficit
<b>iqr</b>	interquartile range
<b>kg</b>	kilogram
<b>kg/m<sup>2</sup></b>	kilogram force per square meter
<b>kgf</b>	kilogram force
<b>L1-L12</b>	Lumbar vertebrae 1 to 12
<b>MCD</b>	Minimal Clinical Difference
<b>mm</b>	millimetre
<b>MRI</b>	Magnetic Resonance Imaging
<b>MSc</b>	Master of Science
<b>p50</b>	Mean
<b>PPAM</b>	Photographic Posture Analysis Method
<b>ROM</b>	Range Of Motion
<b>SC</b>	Sternoclavicular joint
<b>SEM</b>	Standard Error of Measurement
<b>SSA</b>	Swimming South Africa



<b>ST</b>	Scapulothoracic
<b>STATA</b>	Statistics and Data
<b>SUR</b>	Scapulothoracic Upward Rotation
<b>T1-T12</b>	Thoracic vertebrae 1 to 12
<b>YBT-UQ</b>	Upper-Quarter Y Balance Test
<b>yrs</b>	years



# CHAPTER 1

## INTRODUCTION

---

### 1.1 Introduction and Motivation for the study

Swimming is a popular sport in South Africa and annually growing in numbers of competitive swimmers. It has been estimated that over 248 thousand individuals swim recreationally, with an additional 399 thousand individuals competing in high school teams, 301 thousand registered members of Swim South Africa (SSA) competing in club teams, and 22 thousand competitive swimmers who participate in leagues (Sport & Recreation South Africa, 2016; Swimming South Africa, 2017). Within the group of registered club swimmers, 43.5% of the members are female between the ages of 13-18 years (Sport & Recreation South Africa, 2016; Swimming South Africa, 2017). These female swimmers compete on an elite level and are exposed to very high training demands. Club swimmers between the ages of 13-18 years have been reported to complete approximately nine swimming training sessions per week (twice per day), swimming an average distance of 5500-6400 meters per session (Weldon & Richardson, 2001; Hibberd & Myers, 2013). This training volume is maintained for approximately 11 months of the year (Weldon & Richardson, 2001; Hibberd & Myers, 2013).

Research has indicated that swimmers perform an average of 17 freestyle strokes per 25 meters, equating to an average of 1870-2176 shoulder revolutions per arm per session (Pink & Tibone, 2000; Kluemper *et al.*, 2006; Craig & Richard, 2012; Hibberd & Myers, 2013). When comparing the number of shoulder revolutions performed by freestyle swimmers to athletes participating in other overhead sports, such as tennis and javelin, the number of shoulder revolutions performed by freestyle swimmers is exorbitantly higher. It has been reported that professional tennis players or baseball pitchers perform approximately 1000 shoulder revolutions per week and a college javelin thrower approximately 300 shoulder revolutions per week (Weldon & Richardson, 2001; Hibberd & Myers, 2013).



A number of studies have reported that female athletes who specialise in freestyle swimming at an early age and who participate at an elite level are at an increased risk of attaining postural malalignments (Lewis *et al.*, 2005; Atalar *et al.*, 2009). It has been hypothesized that the muscular characteristics of a swimmer's upper-quarter adapts to the physiological and mechanical demands that are placed on them during high volumes of swim training. The high physiological and mechanical demands placed on the swimmer predispose the swimmer to the development of postural malalignments, especially in the upper-quarter (Stirn *et al.*, 2011; Laudner *et al.*, 2015).

Over time, the physical and structural changes that occur result in adaptive shortening or lengthening of the associated musculature (Stirn *et al.*, 2011; Laudner *et al.*, 2015). Muscles that undergo adaptive shortening become tight and strong, placing the opposing muscles in a lengthened and weakened position (Kendall *et al.*, 1983; Stirn *et al.*, 2011). Muscular imbalances in the upper-quarter not only lead to strength imbalances in the shoulder girdle but also undesirable postural and joint articulation changes commonly seen in female adolescent swimmers (Virag *et al.*, 2014). The most common postural changes observed in female adolescent swimmers are a forward head and rounded shoulders with an increased curvature of the thoracic spine (kyphosis) (Lynch *et al.*, 2010; Virag *et al.*, 2014). These postural changes may lead to mechanical compensation when performing the freestyle stroke, inhibiting performance and predisposing the swimmer to injury (Peterson *et al.*, 1997; Lynch *et al.*, 2010; Virag *et al.*, 2014).

Identifying the physical adaptations and the risk factors associated with upper-quarter postural deviations is imperative for the understanding of how participation in freestyle swimming affects the posture of upper-quarter in swimmers. When performing freestyle swimming, 90% of the propulsive force required to move the swimmer through the water is generated from the upper-quarter (Pink & Tibone, 2000; Garcia-Massó & Colado, 2010; Craig & Richard, 2012). This places a significant demand on the shoulder and back musculature, creating imbalances that may lead to a forward head, rounded shoulder posture (Thigpen *et al.*, 2010; Craig & Richard, 2012). The primary movements in freestyle swimming are shoulder adduction and internal rotation (Cools *et al.*, 2008; Morrissey *et al.*, 2008; Virag *et al.*, 2014; Matthews *et al.*, 2017). As a result of these movement patterns, swimmers develop excessive shoulder internal-rotation and adduction strength, which is



related to the overdevelopment of active muscles such as the latissimus dorsi, pectoralis major and triceps brachii muscle groups (Morrissey *et al.*, 2008; Paine & Voight, 2013; Matthews *et al.*, 2017). Potential modifiable intrinsic risk factors, reported by Thigpen *et al.*, 2010, include: (i) excessive anterior orientation of the head or glenohumeral joint relative to the vertical plumb line of the body, (ii) excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa, (iii) posterior capsular tightness, (iv) increased midthoracic spine kyphosis, and (v) hyperextension at the atlanto-occipital articulations and a flattening of the midcervical spine lordosis.

The high training load that demands a great deal from the musculoskeletal structures of the upper-quarter of swimmers is a potential extrinsic risk factor (Kluemper *et al.*, 2006; Stirn *et al.*, 2011). Kluemper *et al.* (2006) reported that adolescents who undertake a number of training sessions in one microcycle (seven day plan) experience a negative influence on the rate of physical development. Puberty is considered to be a developmental phase characterised by rapid growth of all the segments of the spine (growth plate closure), general joint laxity and significant muscular growth (Bak & Fauno, 2007). It is precisely during this period that a great number of athletes take part in intense training and begin their active swimming careers, which leads to the possibility of developing postural changes (Bak & Fauno, 2007).

Therefore, according to the reviewed literature, postural changes in female adolescent swimmers are hypothesized to develop because of high training loads, physiological and mechanical demands of freestyle swimming and its associated intrinsic and extrinsic risk factors on the upper-quarter. However, to the researchers' knowledge, studies comparing these postural differences observed in elite competitive adolescent swimmers with adolescent non-swimmers have not been investigated. The purpose of this study was, therefore, to prospectively identify the incidence of upper-quarter postural differences in female adolescent competitive freestyle swimmers, by comparing their upper-quarter postural measurement characteristics to the upper-quarter postural measurement characteristics of female adolescent non-swimmers. Identifying the differences in upper-quarter postural measurement characteristics between female adolescent competitive freestyle swimmers and non-swimmers helped to highlight whether the observed differences in upper-quarter postural characteristics were of concern and whether they would predispose the female



adolescent swimmers to upper-quarter injuries in the future. Moreover, the observed differences helped to determine whether further research on intervention programmes that focus on the prevention or improvement of poor upper-quarter posture in female adolescent competitive freestyle swimmers was warranted.

Data collection and analysis in this area of sports science research, worked towards alleviating the dearth in knowledge concerning the long-term effects of swim training on the postural development of female adolescent competitive freestyle swimmers. The findings of this study may be used to educate coaches, sport scientists and female swimmers about the postural changes that occur with competitive freestyle swimming from a young age and therefore re-emphasise the importance of correct swimming technique, training loads, and strength and conditioning exercise programmes for this population.

## **1.2 The Research Question**

For this study, the following research questions were asked:

1. ‘What are the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers and female adolescent non-swimmers?’
2. ‘What are the differences in the upper-quarter postural measurement characteristics between female adolescent competitive freestyle swimmers and female adolescent non-swimmers?’

## **1.3 The Research Aim**

The aim of this study was to determine whether significant ( $p \leq 0.05$ ) differences existed in the upper-quarter postural measurement characteristics between female adolescent competitive freestyle swimmers and female adolescent non-swimmers.

## **1.4 Objectives and Hypothesis**

The objectives of the study were to:

1. assess the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers and of female adolescent non-swimmers by measuring the cervical and shoulder range of motion measurements, static upper-quarter posture through photographic analysis, dynamic upper-quarter performance by



means of the Y balance test, and muscular strength of the shoulder and scapula by means of a MicroFET device; and

2. compare the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers to female adolescent non-swimmers by assessing the cervical and shoulder range of motion measurements, static upper-quarter posture through photographic analysis and dynamic upper-quarter performance by means of the Y balance test, and muscular strength of the shoulder and scapula by means of a MicroFET device.

## 1.5 Research Design and Approach

A prospective observational and comparative, cross-sectional study design was used for this study. Shoulder posture alignment, flexibility and muscular strength of female adolescent competitive freestyle swimmers were compared with the shoulder posture alignment, flexibility and muscular strength of female adolescent non-swimmers. A quantitative research approach was followed by the collection of data in the form of the scores (numerical) obtained and organised into statistics (Thomas & Nelson, 2001; Brink *et al.*, 2012).

## 1.6 Research Procedures and Strategy

The following research procedures and strategies were followed:

1. Identification of the research question, -aim, -objectives, and -design.
2. Compilation of the MSc research proposal.
3. Presentation of the MSc research proposal to the research committee of the Department of Physiology, Division of Biokinetics and Sport Science at the University of Pretoria, Faculty of Health Sciences.
4. Submission and presentation of the MSc research proposal to the MSc Research Committee of the Faculty of Health Sciences, University of Pretoria for approval (Approved) (ANNEXURE A).
5. Submission of the MSc research proposal to the Ethics Committee of the Faculty of Health Sciences, University of Pretoria, for approval (Approved) (ANNEXURE B).
6. Commencement of data collection
  - a. Permission for use of setting for data collection (Approved) (ANNEXURE C)
  - b. Permission for use of equipment for data collection (Approved) (ANNEXURE D)



- c. Participant selection:
  - i. Pre-screening questionnaire to determine inclusion and exclusion of the study (ANNEXURE E & F);
  - ii. Signing of informed and assent forms;
  - iii. Evaluation (EVAL) group (35 female adolescent competitive freestyle swimmers), control (CON) group (36 female adolescent non-swimmers);
- d. Measurements
  - i. Pre-testing information session with participants and parents/guardians;
  - ii. Testing session – included body composition (height and body mass), upper-quarter range of motion, upper-quarter dynamic and static posture, and muscular strength;
7. Data analysis
  - i. The data collected was captured by the researcher and analysed by Dr Pieter Meyer at the University of Pretoria (ANNEXURE G).
8. Results and discussion.
9. Research conclusion.
10. Final submission.

To enhance the understanding and knowledge about the influence of competitive freestyle swimming on the upper-quarter posture of female adolescent swimmers, the physiological and mechanical demands of competitive freestyle swimming and their associated risk factors on posture are discussed in greater detail in chapter 2.



# CHAPTER 2

## LITERATURE REVIEW

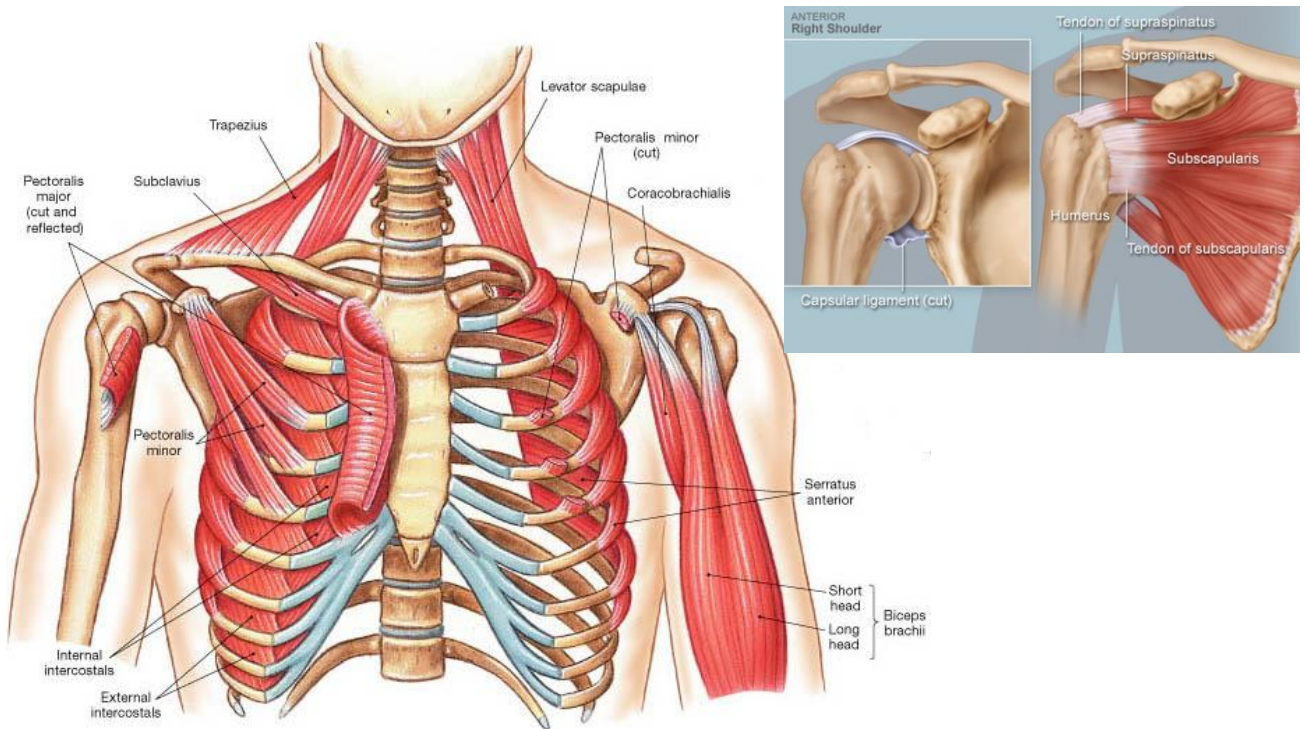
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### 2.1 Introduction

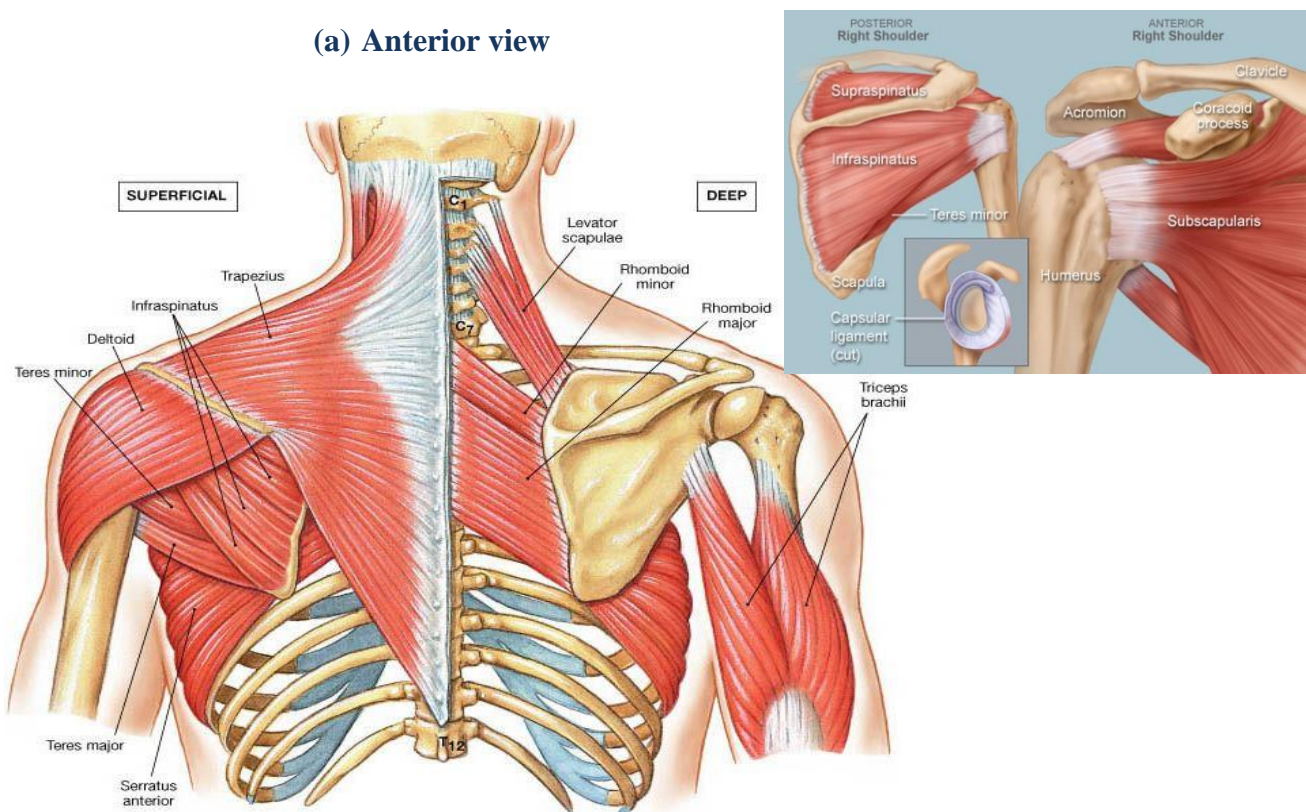
Competitive swimmers are notorious for having poor posture that can be observed as a forward head and rounded shoulders with an increased curvature of the thoracic spine (kyphosis) (Lewis *et al.*, 2005; Atalar *et al.*, 2009; Lynch *et al.*, 2010; Virag *et al.*, 2014). This chapter provides a comprehensive overview of the physical impact swimming has on the upper-quarter posture of a female adolescent swimmer. To have a better understanding of how these postural characteristics develop in these swimmers, a thorough explanation of the shoulder complex anatomy is provided along with how freestyle swimming mechanics affect the postural characteristics of the upper-quarter structures.

### 2.2 Anatomy of the upper-quarter structures associated with freestyle swimming

Structures of the upper-quarter act as a mechanical unit that is interconnected by numerous soft tissue links, or articulations, which are functionally interdependent on one another (Greenfield *et al.*, 1990; Matthews *et al.*, 2017). The simple act of adjusting one's swimming goggles involves movement at the head, spine, shoulder, elbow, hand, and fingers (Matthews *et al.*, 2017). To perform any movement while swimming requires an adequate range of motion in various joints (arthrokinematics), proper muscular control and muscle length changes (Matthews *et al.*, 2017). These factors, in combination with muscular strength, play a significant role in determining individual differences in flexibility and mobility, predisposition to postural deviations, and the distinction between normal and pathological movement (Lynch *et al.*, 2010; Matthews *et al.*, 2017). The upper-quarter regions significantly affected when performing the freestyle stroke include the shoulder complex, scapular structures, and vertebral column (Greenfield *et al.*, 1990; Lynch *et al.*, 2010; Matthews *et al.*, 2017). Figure 2.1 illustrates the musculature of these upper-quarter regions that are affected by freestyle swimming.



(a) Anterior view



(b) Posterior view

Figure 2.1 The anatomical structures involved in freestyle swimming (a) Anterior view (b) Posterior view (Martini, 2007:1054)



## 2.2.1 Skeletal structures of the upper-quarter

The skeleton consists of individual and fused bones of which 144 bones are situated in the upper-quarter – 80 in the axial skeleton and 64 in the upper extremities (Saladin, 2015). These bones are supported and supplemented by articulating joints, ligaments, tendons, muscles and cartilage (Saladin, 2015). Table 2.1 presents the skeletal components of the upper-quarter associated with freestyle swimming.

*Table 2.1 Skeletal structures of the upper-quarter* (Laudner *et al.*, 2015; Saladin, 2015; Juul-Kristensen *et al.*, 2017)

Regions	Bones	Joints and associated ligaments
Shoulder	Clavicle	<b>Sternoclavicular joint</b> Interclavicular ligament Costoclavicular ligament Sternoclavicular ligament Coracoclavicular ligament
	Scapula	<b>Acromioclavicular joint</b> Acromioclavicular ligament Coracoacromial ligament
	Humerus	<b>Glenohumeral joint</b> Coracohumeral ligament Glenohumeral ligament Transverse ligament
Spinal	Cervical and thoracic vertebrae	<b>Atlanto-axial joint</b> <b>Atlanto-occipital joint</b> Nuchal ligament Transverse ligament of the atlas



### 2.2.1.1 The shoulder region

The shoulder complex predominately functions to support the arm and its connection to the axial skeleton (Paine & Voight, 2013). It consists primarily of three bones, namely the clavicle, scapula and humerus, (Paine & Voight, 2013) and three joints, namely the sternoclavicular joint (SC), acromioclavicular joint (AC) and the glenohumeral joint (GH) (Laudner *et al.*, 2015).

The clavicle assumes a gentle S-shape in the axial plane and extends from the manubrium of the sternum to the acromion of the scapula (Hibberd & Myers, 2013; Paine & Voight, 2013; Laudner *et al.*, 2015). The clavicle serves as a rigid support from which the scapula and humerus suspend (Hibberd & Myers, 2013); an arrangement that keeps the upper limb away from the thorax in order for the arm to have maximum range of movement (Paine & Voight, 2013). The medial end of the clavicle articulates with the sternum at the SC joint and the lateral end articulates with the scapula at the AC joint (Laudner *et al.*, 2015). The SC joint consists of the interclavicular ligament that connects the sternal end of the clavicles via attachment to the manubrium of the sternum. It reinforces the SC joint capsule superiorly and supports the weight of the humerus and restricts elevation of the sternum when the lateral end of the clavicle is depressed (Johnston, 1937; Laudner *et al.*, 2015).

The costoclavicular ligament connects the superior surface of the first rib to the medial, inferior surface of the clavicle. It reinforces the SC joint capsule laterally and supports the weight of the humerus and restricts the elevation and lateral movement of the clavicle (Johnston, 1937; Paine & Voight, 2013; Laudner *et al.*, 2015). The costoclavicular ligament also monitors the anterior and posterior movement of the clavicle in the horizontal plane (Laudner *et al.*, 2015). The sternoclavicular ligament covers the SC joint to connect the clavicle to the manubrium of the sternum. It prevents anterior and posterior clavicular dislocation and supports the weight of humerus (Paine & Voight, 2013; Laudner *et al.*, 2015). The coracoclavicular ligament is composed of conoid and trapezoid ligaments and attaches the coracoid process to the clavicle inferiorly. It prevents superior dislocation from the AC joint and stabilises the clavicle horizontally to restrict anterior and posterior scapular movement (Paine & Voight, 2013; Laudner *et al.*, 2015).



The scapula is a triangular flat bone that posteriorly overlies ribs 2 to 7 (Westerick *et al.*, 2012; Hibberd & Myers, 2013). It consists of three borders, namely the superior, medial and lateral border and three angles, namely the superior, inferior and lateral angles (Westerick *et al.*, 2012; Paine & Voight, 2013). The most complex region of the scapula is the lateral angle which consists of the acromion that forms the apex of the shoulder and articulates with the clavicle at the AC joint; the coracoid process that provides attachment for tendons of the biceps brachii and other muscles of the arm; and the glenoid cavity that articulates with the head of the humerus to form the GH joint (Westerick *et al.*, 2012; Paine & Voight, 2013; Laudner *et al.*, 2015).

The acromioclavicular joint consist of the (i) acromioclavicular ligament that connects the acromion of the scapula to the lateral end of the clavicle. It reinforces the joint capsule for greater range of movement and prevents anteroposterior instability of the clavicle and separation from the scapula (Paine & Voight, 2013; Laudner *et al.*, 2015). The (ii) coracoacromial ligament attaches the coracoid process to the acromion and forms the supraspinatus sulcus and prevents inferior displacement of the acromion and coracoid from the distal clavicle (Westerick *et al.*, 2012; Hibberd & Myers, 2013; Paine & Voight, 2013).

The humerus is a long bone that runs from the shoulder to the elbow and connects the scapula, the radius and the ulna (Milner & Boldsen, 2012). It consists of a hemispherical head that is generally tilted at an average of 30° relative to the transepicondylar axis of the distal humerus (Hibberd & Myers, 2013; Paine & Voight, 2013; Laudner *et al.*, 2015). The smooth surface of the humeral head articulates with the glenoid cavity of the scapula at the GH joint (Paine & Voight, 2013; Laudner *et al.*, 2015). Allowing for full range of motion, the glenoid cavity is relatively shallow (Milner & Boldsen, 2012).

The glenohumeral joint consist of the (i) coracohumeral ligament that connects the humerus to the coracoid process of the scapula (Paine & Voight, 2013; Laudner *et al.*, 2015). It provides tension anteriorly when performing shoulder extension and posteriorly when performing shoulder flexion (Milner & Boldsen, 2012; Paine & Voight, 2013; Laudner *et al.*, 2015). It also controls superior displacement of the humeral head and external rotation of the humerus which aids in prevention of dislocation. The (ii) glenohumeral ligament connects the humerus to the glenoid fossa of the scapula and consists of three bands: superior, middle, and inferior (Milner & Boldsen, 2012; Paine & Voight, 2013). All three bands are involved with external shoulder rotation; however, the middle and inferior bands are also involved with



shoulder abduction to prevent anterior dislocation of the humerus (Paine & Voight, 2013; Laudner *et al.*, 2015). The (iii) transverse ligament spans across the bicipital groove of the humerus and encloses the intertubercular groove to maintain the biceps tendon long head within the bicipital groove (Paine & Voight, 2013; Laudner *et al.*, 2015).

Milner & Boldsen (2012) have reported that the average circumference of the humeral head presented in females is approximately 42mm, proposing that the GH joint is prone to dislocation. Distal to the humeral head is the shaft of the humerus which contains bony landmarks such as the deltoid tuberosity and radial groove. They serve as attachment sites for associated muscles (Milner & Boldsen, 2012).

### **2.2.1.2 The spinal region**

The upper-quarter vertebral column consists of the cervical (C1-C7) and the thoracic (T1-T12) spine which display a secondary and primary curvature respectively (Becker, 1986; Hrysomallis & Goodman, 2001; Thigpen *et al.*, 2010). The components of the cervical spine are seven vertebrae that begin at the bottom of the skull and end at the upper back (Becker, 1986; Hrysomallis & Goodman, 2001). These vertebrae primarily protect the spinal cord, support the head and allow great range of movement (Becker, 1986; Hrysomallis & Goodman, 2001). The first two vertebrae, (C1 – atlas; C2 – axis) in the cervical spine are responsible for the rotation of the head. Vertebrae C5-C7 are responsible for flexion and extension of the head (Becker, 1986; Hrysomallis & Goodman, 2001).

There are two lateral atlanto-axial joints which are formed by the articulation between the inferior facets of the lateral masses of C1 and the superior facets of C2. The medial atlanto-axial joint is formed by the articulation of the dens of C2 with the articular facet of C1 and enables the rotation of the head (Thigpen *et al.*, 2010). The atlanto-occipital joint consists of an articulation between the spine and the cranium and is situated between the superior facets of the lateral masses of the atlas and the occipital condyles at the base of the cranium (Thigpen *et al.*, 2010). These are condyloid type synovial joints, and permit flexion at the head (Hrysomallis & Goodman, 2001; Thigpen *et al.*, 2010). The transverse ligament of the atlas connects the lateral masses of the atlas, and in doing so anchors the dens in place (Thigpen *et al.*, 2010).



In vertebrae C2 through C6, the spinous processes exhibit a bifid at the tip which provides attachment for the nuchal ligaments of the back and neck (Becker, 1986). The nuchal ligament is a continuation of the supraspinous ligament and attaches to the tips of the spinous processes from C1-C7 to provide the proximal attachment for the rhomboids and trapezius (Becker, 1986; Thigpen *et al.*, 2010). The spinous process of vertebrae C7 is long and thick and nearly horizontal in direction and is also known as the vertebrae prominence because of a featured landmark that can be easily palpated (Becker, 1986). Distal to C7 the 12 thoracic vertebrae are intermediate in size and show an anatomical transition to the lumbar vertebrae (L1) (Becker, 1986). They are distinguished by the facets on the sides of the vertebral bodies for articulation with the heads of the corresponding ribs (Becker, 1986; Hrysonmallis & Goodman, 2001; Thigpen *et al.*, 2010). The thoracic vertebrae primarily function to support the rib cage and protect the vital organs (Becker, 1986; Thigpen *et al.*, 2010).

## 2.2.2 Muscles of the upper-quarter

The action a muscle initiates can be determined by its location of origin and insertion (Young, 2002; Garcia-Massó & Colado, 2010; Stirn *et al.*, 2011). The muscles' ability to generate force to the external environment, such as water when swimming, is determined by the number of myofibrils – chain of sarcomeres, which can operate in parallel (Garcia-Massó & Colado, 2010).

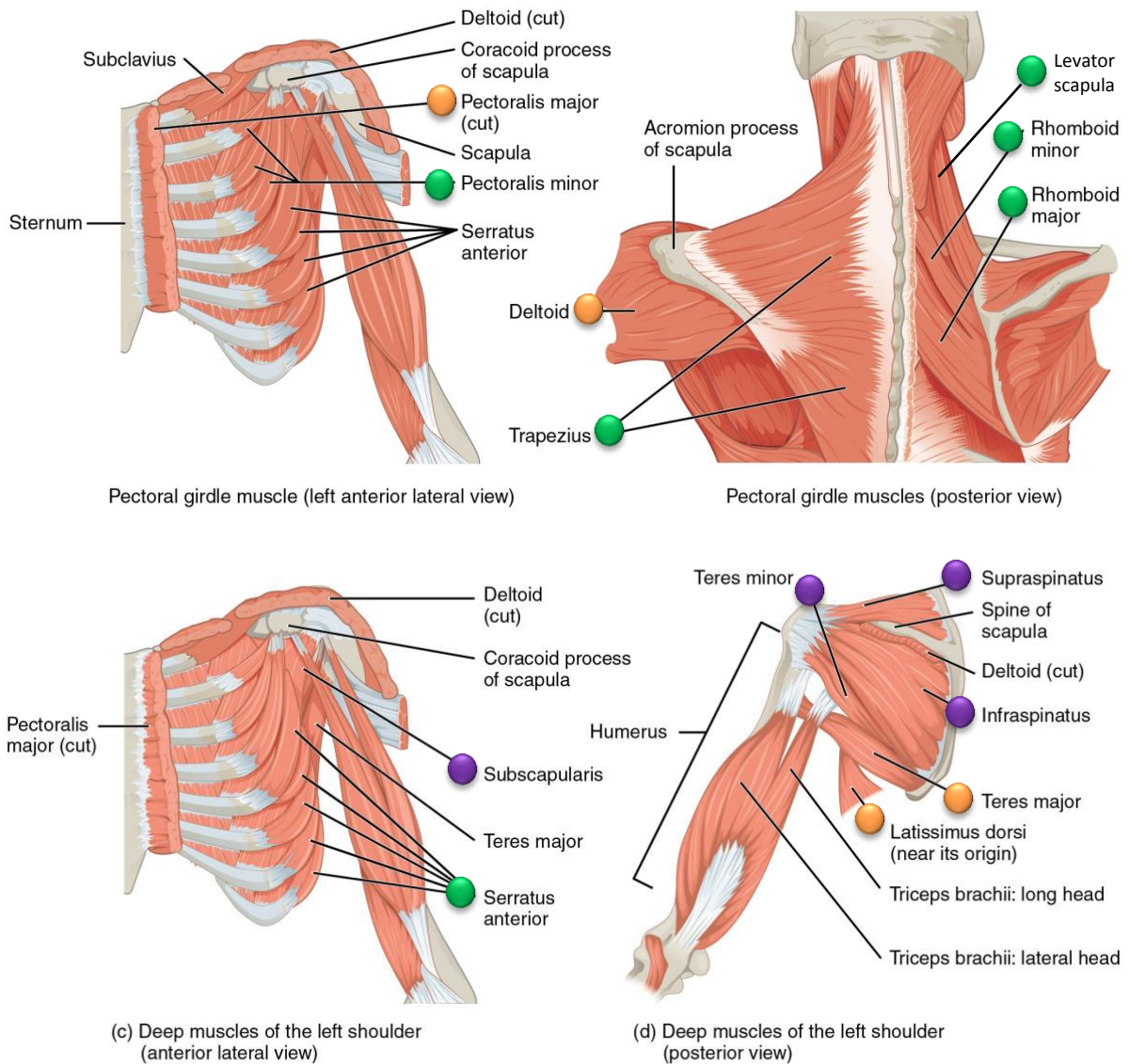
Table 2.2 categorises the upper-quarter muscles into four groups, namely the scapular pivoters, the shoulder protectors, the humeral positioners, and the spinal rotators (Morrissey *et al.*, 2008; Paine & Voight, 2013). Figure 2.2 highlights the individual upper-quarter musculature that is associated with the first three categories. These groups provide a better understanding of the muscular involvement related to the freestyle swimming phases.



*Table 2.2 Muscles of the upper-quarter* (Young, 2002; Garcia-Massó & Colado, 2010; Stirn *et al.*, 2011)

Categories	Muscles
● <b>Scapular pivoters</b>	Anterior muscle group Pectoralis Minor Serratus Anterior
	Posterior muscle group Trapezius Levator Scapulae Rhomboid Minor Rhomboid Major
● <b>Shoulder protectors</b>	Rotator cuff muscles Supraspinatus Infraspinatus Teres Minor Subscapularis
● <b>Humeral positioners</b>	Axial muscles Pectoralis Major Latissimus Dorsi
	Scapular muscles Deltoid Teres Major Coracobrachialis
● <b>Spinal rotators</b>	Cervical region Iliocostalis cervicis Longissimus capitis; -cervicis Spinalis capitis; -cervicis Semispinalis capitis; -cervicis Splenius capitis; -cervicis Sternocleidomastoid Scalenes
	Thoracic region Iliocostalis thoracis Longissimus thoracis Spinalis thoracis Semispinalis thoracis

To enhance the understanding of the role of these above-mentioned muscles in the mechanics of freestyle swimming, it is fundamental to understand the anatomy and function of these muscles.



**Figure 2.2 Muscles of the upper-quarter – scapular pivotors; shoulder protectors; humeral positioners** (Martini, 2007:1152)

### 2.2.2.1 The scapular pivotors

The scapular pivotors – involved in elevation and depression of the scapula - are the trapezius, rhomboid major and rhomboid minor, serratus anterior and pectoralis minor (Cools *et al.*, 2008; Morrissey *et al.*, 2008; Laudner *et al.*, 2015). This section discusses the muscles acting on the shoulder complex that originates on the axial skeleton and inserts on the clavicle, humerus and/or scapula (Young, 2002; Garcia-Massó & Colado, 2010; Stirn *et al.*, 2011). These muscles can be categorised into the anterior and posterior group and primarily function to move the scapula in various ranges of motion (Young, 2002; Garcia-Massó &



Colado, 2010; Stirn *et al.*, 2011). From an anteriorly deep view the pectoralis minor is connected into the superior margin of ribs 3 to 5 and inserts into the medial border of the coracoid process of the scapula (Garcia-Massó & Colado, 2010). It functions to depress the apex of the shoulder and together with the serratus anterior draws the scapula laterally during scapular protraction (Morrissey *et al.*, 2008). Laterally to the pectoralis minor, the serratus anterior arises from ribs 1 to 8 and converges on the medial border of the scapula (Garcia-Massó & Colado, 2010). Activated during shoulder abduction, the serratus anterior contributes to scapular rotation to elevate the apex of the shoulder, protraction and the stabilisation of the scapula against the rib cage (Paine & Voight, 2013).

The trapezius is situated posteriorly and has three functional regions, namely the superior, middle and inferior fibers with multiple origin and insertion sites (Pink & Tibone, 2000; Garcia-Massó & Colado, 2010; Paine & Voight, 2013). The upper portion of the trapezius muscle is responsible for elevating and upwardly rotating the scapula (Paine & Voight, 2013; Laudner *et al.*, 2015). The middle portion aids in the retraction of the scapula, and the lower portion contributes to the depression and downward rotation of the scapula (Paine & Voight, 2013).

Deep to the trapezius, the levator scapulae originates from the transverse processes of C1-C4 vertebrae and inserts to the medial superior border of the scapula (Garcia-Massó & Colado, 2010). It primarily functions to rotate the scapula and depresses the shoulder apex; however, when the shoulder is fixed it helps to laterally rotate and flex the head (Garcia-Massó & Colado, 2010). The rhomboid minor arises from the nuchal ligament and spinous processes of C7-T1 vertebrae and inserts at the medial border of the scapula (Garcia-Massó & Colado, 2010). It works in conjunction with the middle portion of the trapezius muscle in retracting and downwardly rotating the medial border of the scapula (Paine & Voight, 2013). Inferiorly situated to rhomboid minor is the rhomboid major (Garcia-Massó & Colado, 2010). It connects the scapula with the vertebrae of the spinal column by arising from spinous process of the vertebrae T2-T5 and inserting to the medial border of the scapula (Garcia-Massó & Colado, 2010). When activated, the rhomboid major helps to stabilise and rotate the scapula with respect to the glenoid cavity (Garcia-Massó & Colado, 2010).



### 2.2.2.2 The shoulder protectors

The shoulder protector group, also known as the rotator cuff muscles, include the supraspinatus, infraspinatus, teres minor, and subscapularis muscles (Young, 2002; Paine & Voight, 2013). This section discusses the origin, insertion and function of the shoulder protector group. The supraspinatus lies along the superior part of the scapula in the supraspinous fossa and attaches to the greater tuberosity of the humerus (Paine & Voight, 2013). The rotator cuff consists of four muscles acting in unison to modulate the movement of the deltoid and prevent displacement of the humeral head (Young, 2002). The supraspinatus arises from the supraspinous fossa of the scapula and inserts into the greater tubercle of the humerus (Young, 2002; Stirn *et al.*, 2011). It reinforces the deltoid in the abduction of the arm, decreasing the subacromial space and resists inferior displacement of the humeral head when the arm is in neutral (Pink & Tibone, 2000; Garcia-Massó & Colado, 2010).

Inferior to the spine of the scapula, the infraspinatus originates from the infraspinous fossa of the scapula and inserts onto the greater tubercle of the humerus (Young, 2002). Partially covered by the infraspinous is the teres minor that originates from the lateral border and adjacent posterior surface of the scapula (Young, 2002). It inserts on the greater tubercle of the humerus and posterior surface of the joint capsule (Young, 2002). Together they modulate the action of the deltoid to prevent superior displacement of the humeral head when the arm is abducted and act to laterally rotate the humerus (Young, 2002).

Anteriorly the subscapularis originates from the subscapular fossa and inserts into the lesser tubercle of the humerus and anterior surface of the joint capsule (Stirn *et al.*, 2011). It prevents the superior displacement of the humeral head when the arm is abducted and rotates the humerus medially (Stirn *et al.*, 2011). As the name implies, the rotator cuff muscles act as primary stabilisers and control rotation about the glenohumeral joint (Pink & Tibone, 2000; Shultz *et al.*, 2010). The shoulder joint sacrifices stability in favour of mobility and therefore it depends on the rotator cuff musculature to act as stabilisers and protectors (Pink & Tibone, 2000; Garcia-Massó & Colado, 2010). Dynamic stabilisation of the GH joint relies on the force coupling relationship of the deltoid and rotator cuff muscles as the ligaments are



relatively lax and cause the shoulder to be unstable (Cools *et al.*, 2008; Garcia-Massó & Colado, 2010).

### 2.2.2.3 The humeral positioners

As the name implies, the humeral positioners can be distinguished by their function to change the position of the humerus to move the arm (Morrissey *et al.*, 2008; Garcia-Massó & Colado, 2010). Muscles acting on the arm can be categorised into the axial muscles and scapular muscles by referring to their origin and insertion landmarks (Young, 2002; Morrissey *et al.*, 2008; Paine & Voight, 2013). The pectoralis major arises from two sites and inserts on the lateral border of the intertubercular sulcus of the humerus (Stirn *et al.*, 2011). The clavicular head originates from the anterior surface of the sternal half of the clavicle and functions to flex the humerus (Young, 2002; Stirn *et al.*, 2011). Distal to this site, the sternocostal head arises from the lateral margin of the sternum, attaches to the superior 7 costal cartilages and the aponeurosis of the external oblique muscle (Young, 2002). When activated, it adducts and medially rotates the humerus (Young, 2002; Morrissey *et al.*, 2008; Paine & Voight, 2013). Posteriorly, the latissimus dorsi originates from the spinous processes of T7-L5, the inferior four ribs, iliac crest and the thoracolumbar fascia (Young, 2002; Morrissey *et al.*, 2008). It stretches proximally to the sides (Young, 2002; Morrissey *et al.*, 2008; Paine & Voight, 2013), is partially covered by the trapezius and inserts onto the floor of the intertubercular sulcus of the humerus (Stirn *et al.*, 2011). The latissimus dorsi is responsible for lateral flexion of the lumbar spine, internal rotation of the GH joint and most arm movements of extension, adduction, and horizontal abduction (Young, 2002; Morrissey *et al.*, 2008; Paine & Voight, 2013).

The deltoid gives the shoulder its distinctive shape as it originates from the lateral third of the clavicle, acromion and spine of the scapula and inserts at the deltoid tuberosity of the humerus (Young, 2002). Arising from three sites, the anterior fibres flex and medially rotate the humerus; lateral fibres abduct the humerus; and posterior fibres extend and laterally rotate the humerus (Morrissey *et al.*, 2008; Garcia-Massó & Colado, 2010). The deltoid partially covers the teres major muscle which is situated superior to the latissimus dorsi as it originates from the inferior angle of the scapula (Young, 2002; Paine & Voight, 2013). It inserts at the medial lip of the intertubercular sulcus of the humerus and assists with

extension and internal rotation of the humerus (Young, 2002). Anteriorly, the coracobrachialis originates from the coracoid process of the scapula and inserts at the medial aspect of the humeral shaft (Young, 2002). It acts to flex and medially rotate the arm and restricts deviation of the arm from the frontal plane during shoulder abduction (Young, 2002; Morrissey *et al.*, 2008; Paine & Voight, 2013). Collectively these three muscles function to change the position of the humerus and contribute to the great range of motion associated with the glenohumeral joint (Morrissey *et al.*, 2008; Garcia-Massó & Colado, 2010).

### 2.2.2.4 The spinal rotators

Muscles of the back primarily extend, laterally flex and rotate the vertebral column (Milenković *et al.*, 2012). This section discusses the specific back muscles activated during freestyle swimming which are addressed in the next section. Figure 2.3 highlights the individual muscles of the cervical and thoracic region.

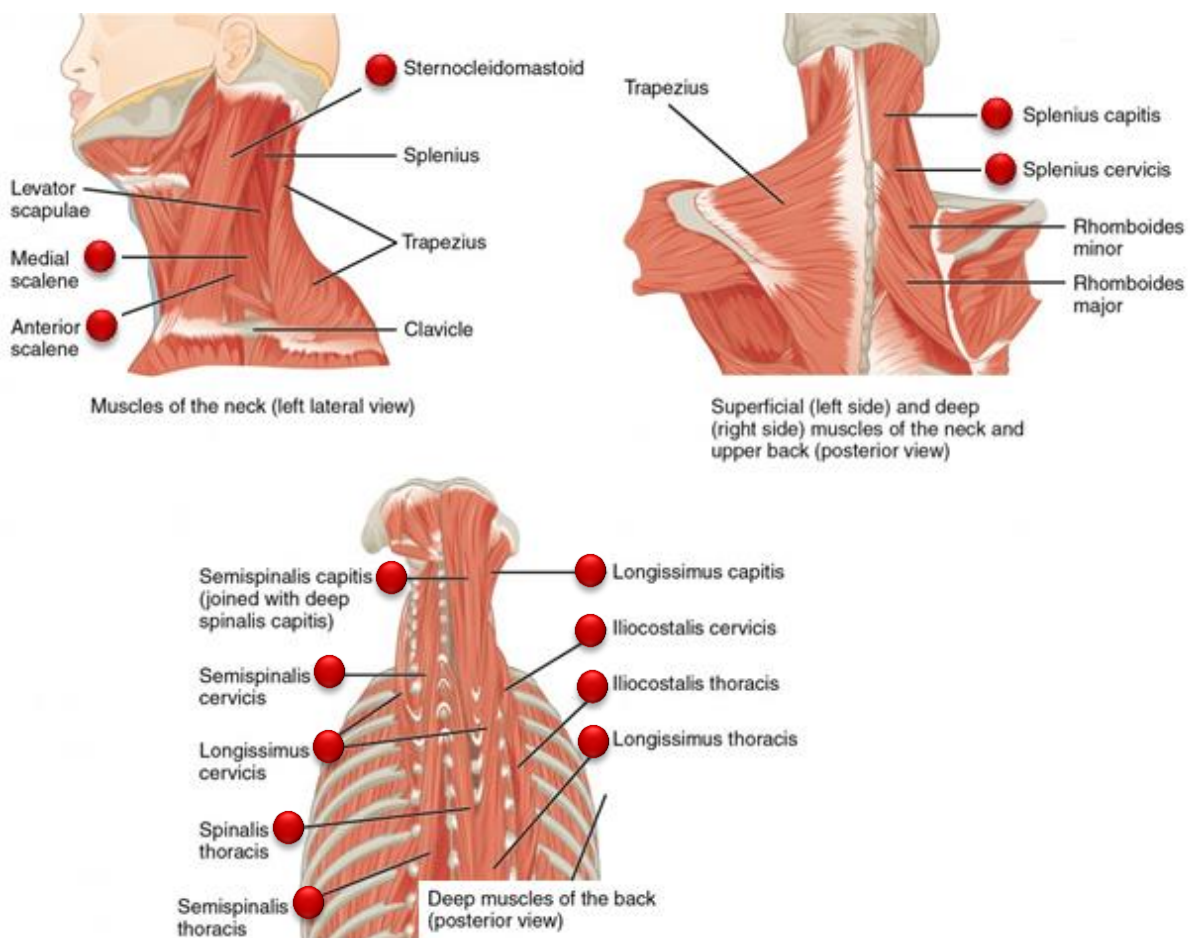


Figure 2.3 Muscles of the upper-quarter – spinal rotators (Martini, 2007:1013)



The most prominent deep back muscle is the erector spinae which includes the iliocostalis (laterally placed) group, the longissimus (intermediately placed) group, and the spinalis (medially placed) group (Milenković *et al.*, 2012). These muscles function sufficiently similarly to control the extension, lateral flexion, and rotation of the vertebral column (Milenković *et al.*, 2012). The iliocostalis group includes the iliocostalis cervicis, located from the first 6 ribs to the posterior tubercle of the transverse process of C6-C4; the iliocostalis thoracis, crossing from the last 6 ribs to the first 6 ribs; and the iliocostalis lumborum (associated with the lumbar region) (Milenković *et al.*, 2012).

There are three muscles of the longissimus group (Shultz *et al.*, 2010). The longissimus capitis originates from the transverse processes of C3-T3 and inserts into the mastoid process of the temporal bone (Shultz *et al.*, 2010). The longissimus cervicis arises from the transverse processes of T1-T6 and inserts into the transverse processes of C2-C7 (Shultz *et al.*, 2010). The longissimus thoracis originates from the sacrum, spinous processes of the lumbar vertebrae and transverse process of the last thoracic vertebra and inserts into the transverse processes of the lumbar vertebrae, erector spinae aponeurosis, ribs and costal processes of the thoracic vertebrae (Shultz *et al.*, 2010; Milenković *et al.*, 2012). The spinalis group, includes the (i) spinalis capitis that runs from the cervical and upper thoracic vertebrae and inserts into the external occipital protuberance; the (ii) spinalis cervicis that arises from the spinous process of C6-T2 and inserts in the spinous process of C2-C4; and the (iii) spinalis thoracis, originates from the spinous process of T10-L3 and inserts in the spinous process of T2-T8 (Shultz *et al.*, 2010; Milenković *et al.*, 2012). These muscles work together to extend and laterally bend the neck and trunk (Milenković *et al.*, 2012).

Similar to the erector spinae muscles are the semispinalis group that are named for their associated location on the vertebral region (Atalar *et al.*, 2009). The semispinalis muscles include the semispinalis capitis, the semispinalis cervicis, and the semispinalis thoracis (Atalar *et al.*, 2009). The semispinalis capitis and semispinalis cervicis primarily act to extend and contralaterally rotate the head as they arise from the articular processes of vertebrae C4-C7 and transverse processes of T1-T6 respectively (Atalar *et al.*, 2009). They insert into the occipital bone between the nuchal lines and on the spinous processes of vertebrae C2-C5 (Atalar *et al.*, 2009). Superior to the semispinalis capitis, the splenius capitis



originates from the inferior half of the spinous processes of the C7 vertebrae and the inferior four thoracic vertebrae (Atalar *et al.*, 2009; Stirn *et al.*, 2011). It inserts into the mastoid process and occipital bone just inferior to the superior nuchal line (Atalar *et al.*, 2009). The splenius cervicis arises from the spinous processes of vertebrae T3-T6 and inserts on the transverse processes of axis and atlas vertebrae (Atalar *et al.*, 2009). When activated, the splenius capitis and –cervicis unilaterally perform ipsilateral flexion and slight rotation of the head and bilaterally they extend the head (Atalar *et al.*, 2009; Stirn *et al.*, 2011).

The sternocleidomastoid is one of the most superficial cervical muscles and primarily acts to rotate the head to the opposite side (Atalar *et al.*, 2009; Stirn *et al.*, 2011). The sternocleidomastoid originates from the manubrium of the sternum and medial one third of the clavicle (Stirn *et al.*, 2011). It inserts onto the mastoid process and lateral half of the superior nuchal line (Atalar *et al.*, 2009). Unilateral contraction tilts the head slightly upward and rotation to left or right (Stirn *et al.*, 2011). Bilateral contraction draws the head straight forward and down and also aids in breathing when head is fixed (Stirn *et al.*, 2011). Deep to the sternocleidomastoid the anterior, middle and posterior scalenes arises from the transverse processes of C1 – C7 and inserts onto ribs 1 – 2 (Atalar *et al.*, 2009). Unilateral contraction tilts the head towards the same shoulder causing ipsilateral flexion or contralateral rotation (Stirn *et al.*, 2011). Bilateral contraction flexes the neck and aids breathing when the spine is fixed (Atalar *et al.*, 2009; Stirn *et al.*, 2011).

## **2.3 Muscular involvement during phases of freestyle swimming**

Swimmers have several unique challenges that most land-based athletes do not encounter (Virag *et al.*, 2014). When swimming freestyle a kinetic chain is formed and allows the force generated by the upper extremities to be transferred through the torso to the lower extremities (Letzelter & Freitag, 1983; McMullen & Timothy, 2000; Virag *et al.*, 2014). If a link in this chain is weak, a reduction of power transfer can occur, movement patterns can become uncoordinated and the risk of postural deviations increases (Letzelter & Freitag, 1983; McMullen & Timothy, 2000). The traditional freestyle stroke can be categorised into two phases namely, the pull-through phase and the recovery phase and is illustrated in Figure 2.4 (Letzelter & Freitag, 1983).

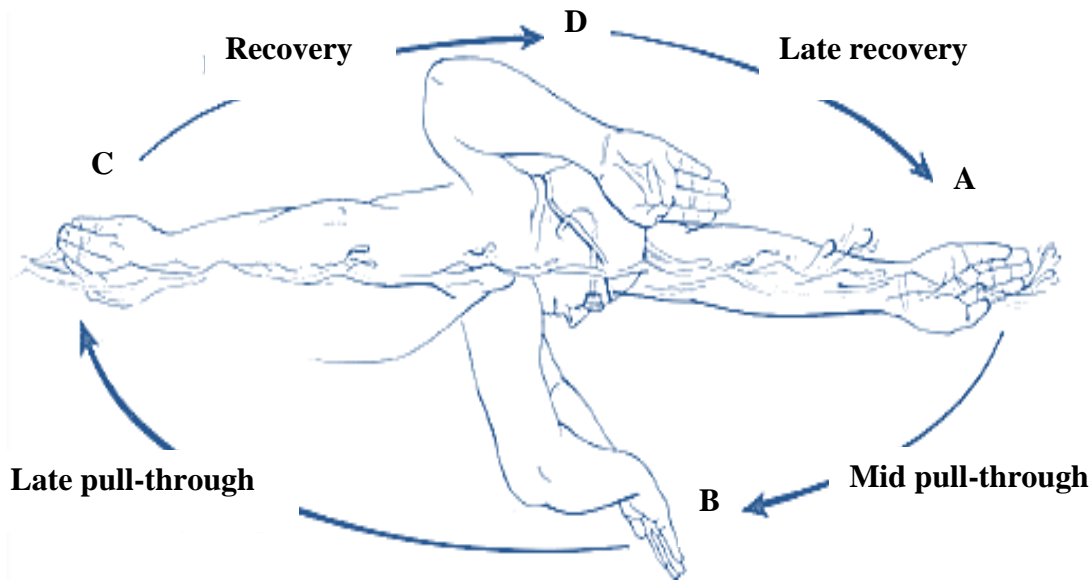


Figure 2.4 The phases of freestyle swimming (Letzelter & Freitag, 1983)

### 2.3.1 The pull-through phase

The pull-through is the underwater portion of the swimming stroke and has been further subdivided into the hand entry, the mid pull-through, and the late pull-through (Letzelter & Freitag, 1983; Laudner *et al.*, 2015).

#### *The hand entry*

The hand entry position is when the hand enters the water and is placed directly in line with the shoulder and lateral to the head (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). The elbow is slightly flexed and pointing upward, so that the fingers are the first to break the water with the palm facing outward (Meliscki *et al.*, 2011; Laudner *et al.*, 2015). This has been referred to as the “high” elbow position (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). Upward rotation of the scapula allows the swimmer to reach an elongated position in the water causing the swimmer to stretch forward (Costa *et al.*, 2017; Paine & Voight, 2013). At the time of hand entry, this places the shoulder in an abducted, flexed, and internally rotated position (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). Phasic muscle activity is predominantly seen in the upper trapezius, rhomboids, supraspinatus, and anterior and middle deltoids (Meliscki *et al.*, 2011; Laudner *et al.*, 2015).



The serratus anterior also shows an increase in activity as it upwardly rotates and protracts the scapula (Meliscki *et al.*, 2011; Laudner *et al.*, 2015). These muscle actions position the glenoid fossa for the humeral head as the arm is flexed and abducted to achieve hand entry (Meliscki *et al.*, 2011; Laudner *et al.*, 2015). Once the hand enters the water, there is a brief period of reaching and gliding, which serves as a transition between recovery and actual pulling (Laudner *et al.*, 2015). At this point, an upward force by the water further flexes the shoulder into a position that causes the subacromial space to decrease (Laudner *et al.*, 2015). The hand and arm then begin a sequential sweeping motion: out, down, in, and up as the hand follows an S-shaped curve during the pulling phase (Meliscki *et al.*, 2011; Laudner *et al.*, 2015). The in-sweep, although briefest in duration, creates the highest muscular activity (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). The predominant muscles that provide this intense pulling activity are the pectoralis major and the latissimus dorsi (Laudner *et al.*, 2015). They powerfully adduct the humerus, causing the hand to sweep under the chest before passing laterally to the pelvis (Meliscki *et al.*, 2011; Laudner *et al.*, 2015).

### ***The mid pull-through***

The pectoralis major fires first and is responsible for the initial powerful shoulder adduction and internal rotation of the humerus causing the body to rotate along its long axis (McMullen & Timothy, 2000; Laudner *et al.*, 2015; Saladin, 2015). The latissimus dorsi works in synergy with the pectoralis major to adduct and extend the arm. When the hand reaches its deepest point in the water, mid pull-through begins (Letzelter & Freitag, 1983; McMullen & Timothy, 2000; Laudner *et al.*, 2015). Here the shoulder is at 90 degrees abduction with neutral rotation and body roll is maximal at 40 to 60 degrees from horizontal (Barbosa *et al.*, 2010; Laudner *et al.*, 2015). As the pectoralis major continues to contract during mid pull-through, the shoulder internally rotates with a flexed elbow (Barbosa *et al.*, 2010; Saladin, 2015). The teres minor simultaneously fires to provide an antagonistic external rotation force to this internal rotation (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Saladin, 2015). This force couple between the teres minor and the pectoralis major serves to balance the humeral head on the glenoid (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015).

Magel & Mc Ardle (1970) stated that the propelling force in swimming depends on muscular strength, effective stroke mechanics and swimming posture. Swimming speed relies on buoyancy, the hydrodynamics of correct stroke technique, and wave-making resistance



(Magel & Mc Ardle, 1970). A diminutive posture (shoulder hyperflexion with abduction and protracting scapula to decrease shoulder width to create a streamline position) causes less resistance and decreases water displacement (Magel & Mc Ardle, 1970). The negative effect of this diminutive posture, if maintained for extended periods of time, may increase the probability of developing upper-quarter postural changes (Magel & Mc Ardle, 1970).

### *The late pull-through*

As the humerus crosses the point where it is perpendicular to the body, the late pull-through phase begins (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). In late pull-through, the latissimus dorsi has the mechanical advantage (Letzelter & Freitag, 1983; McMullen & Timothy, 2000; Saladin, 2015). It begins to fire and, along with the subscapularis, continues the pull by forcefully extending the internally rotated arm (Barbosa *et al.*, 2010). Active pulling stops as the palm approaches the thigh, as opposed to when the hand exits the water (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). This results in a fully adducted and internally rotated shoulder at the end of the pull (Laudner *et al.*, 2015). Activity in the posterior deltoid continues to extend the arm as it nears the thigh; this is followed by activity of the middle and anterior deltoid respectively, as the hand proceeds to exit (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015). The serratus anterior and the other muscles involved in hand entry are also active as the hand exits the water in preparation for recovery (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015).

The serratus anterior and subscapularis are active throughout the entire swimming stroke (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015). By helping to position the scapula, the serratus anterior is able to maintain glenohumeral joint congruency during the entire pull-through phase (Laudner *et al.*, 2015). In a similar manner, it assists in preventing impingement of the coracoid process or acromion on the humerus at hand exit (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015; Saladin, 2015). Finally, by providing a stable scapula, the serratus anterior allows the body to move over the arm as it is pulled through the water by the pectoralis major and latissimus dorsi (Laudner *et al.*, 2015). The serratus anterior and subscapularis are greatly susceptible to fatigue because of their continuous activity during the swimming stroke (Barbosa *et al.*, 2010; Virag *et al.*, 2014; Laudner *et al.*, 2015; Saladin, 2015).



### 2.3.2 The recovery phase

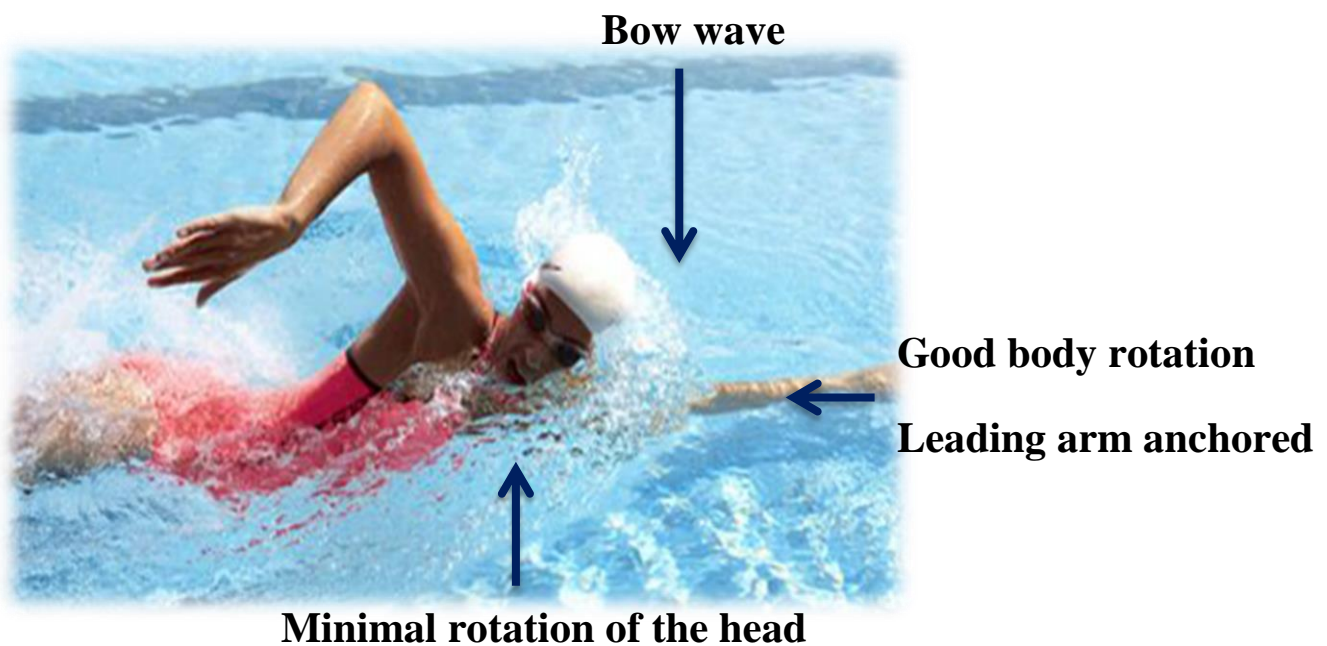
The recovery phase refers to the part of the swimming stroke where the hand is above water (Letzelter & Freitag, 1983; McMullen & Timothy, 2000; Laudner *et al.*, 2015). This phase can be subdivided into three parts: (C) elbow lift, (D) mid recovery, and (A) hand entry (Letzelter & Freitag, 1983). This phase is shorter than the pull-through phase, accounting for 30% to 35% of the freestyle stroke (Laudner *et al.*, 2015). As the elbow lifts out of the water, the arm and hand are internally rotated, thus reducing drag (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). The shoulder then proceeds to follow a sequence of extending, abducting, and internally rotating, as the scapula is retracting to accomplish recovery (Laudner *et al.*, 2015). The muscles involved in this sequence include the middle deltoid, supraspinatus, subscapularis, and rhomboids (Laudner *et al.*, 2015). Another muscle of primary importance from mid-recovery to hand entry is the infraspinatus (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). The infraspinatus serves as a humeral head depressor and provides a stabilizing force for the strong pull of the antagonizing subscapularis (Letzelter & Freitag, 1983; Saladin, 2015). The subscapularis and infraspinatus form another important force couple to control glenohumeral kinematics (Laudner *et al.*, 2015; Saladin, 2015).

During this phase a swimmer rotates her head to breathe (Letzelter & Freitag, 1983; Atalar *et al.*, 2009; Stirn *et al.*, 2011; Laudner *et al.*, 2015). The cervical and thoracic muscles are activated in unison to account for a 160 degree body rotation along its long axis and a slight flexion with lateral rotation of the head (Laudner *et al.*, 2015; Saladin, 2015). The muscles responsible for the breathing action are the erector spinae, semispinalis capitis and –cervics, splenius capitis and –cervics, sternocleidomastoid, and the scalenes (Saladin, 2015). Following these movements, the hand is again in position for entry into the water (Letzelter & Freitag, 1983; Laudner *et al.*, 2015; Saladin, 2015).

The arm movements of freestyle are reciprocal in nature, meaning that while one arm is engaged in recovery the other is in the propulsive phase (Letzelter & Freitag, 1983; Hintzy *et al.*, 2007). No swimmer demonstrates the exact same postural alignment, stroke mechanics and swimming techniques because of individual differences, such as anthropometrics, joint configuration and muscular strength. However, similarities in muscular activity and joint

articulation are observed during the different phases of freestyle swimming (Hintzy *et al.*, 2007; Virag *et al.*, 2014).

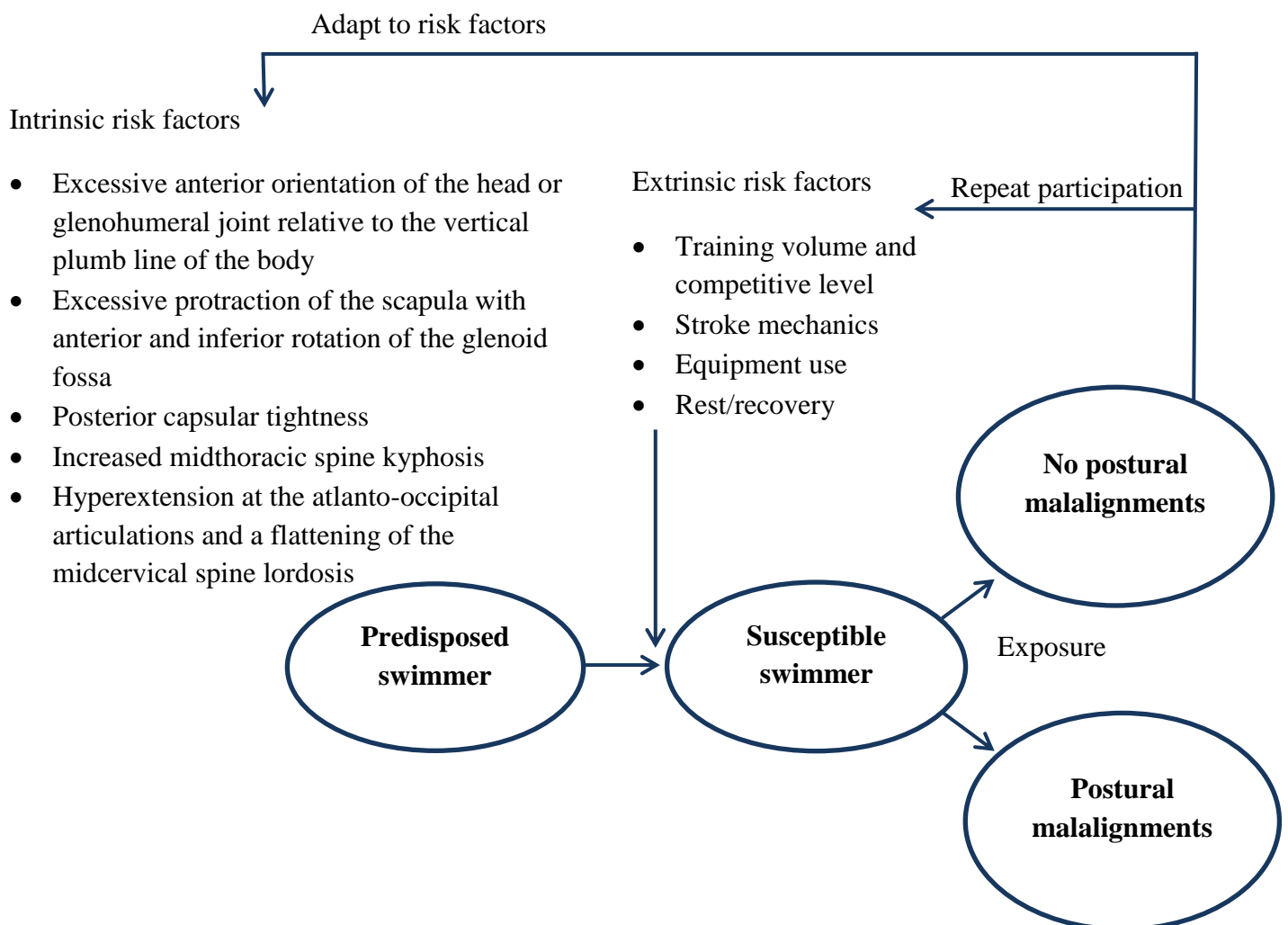
The neck is also subjected to sustained and repetitive movements, which can have implications for postural alignment (Atalar *et al.*, 2009; Stirn *et al.*, 2011). Breathing takes place during the recovery phase of the stroke (Atalar *et al.*, 2009; Stirn *et al.*, 2011). Figure 2.5 illustrates the body rotation when the swimmer is breathing. The face emerges from the water into an air pocket at the bottom of the bow wave, which is created by the head pushing through the water (Letzelter & Freitag, 1983; Atalar *et al.*, 2009). Due to the protection of the bow wave, swimmers only need minimal rotation of the head to obtain a breath (Letzelter & Freitag, 1983; Atalar *et al.*, 2009). Poor body rotation results in over-rotation of the neck in order to breathe (Letzelter & Freitag, 1983; Atalar *et al.*, 2009). If the body is well rotated along its long axis then there is no requirement for the neck to over-rotate (Stirn *et al.*, 2011; Laudner *et al.*, 2015). Contributing to this error can be the practice of breathing unilaterally (Letzelter & Freitag, 1983; Atalar *et al.*, 2009). Breathing only to the favoured side leads to muscular imbalances within the neck, particularly in rotation (Laudner *et al.*, 2015). Such muscular imbalance may be aggravated by forward head carriage when equipment, i.e. a kickboard, is used when training (Hibberd *et al.*, 2012; Laudner *et al.*, 2015).



*Figure 2.5 Body rotation when breathing*

## 2.4 Risk factors predisposing competitive freestyle swimmers to postural malalignments

Literature suggests that the development of postural malalignments in freestyle swimmers is multifactorial, signifying that both extrinsic and intrinsic risk factors can be identified (Meeuwisse *et al.*, 2007; Walker *et al.*, 2012). According to literature a competitive freestyle swimmer presents with a forward head and rounded shoulders with an increased curvature of the thoracic spine (kyphosis) (Lynch *et al.*, 2010; Hibberd *et al.*, 2012; Virag *et al.*, 2014). Figure 2.6 presents the risk factors of postural malalignments, in female competitive swimmers, which has been adapted from Meeuwisse dynamic, recursive model of etiology of sport injury (Meeuwisse *et al.*, 2007).



*Figure 2.6 Risk factors predisposing female competitive swimmers to postural malalignments*



This diagram motivates the research question by describing the probability of postural changes to extrinsic risk factors when repeated participation occurs. It also links postural adaptations to intrinsic risk factors related to the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers.

## 2.4.1 Extrinsic risk factors

This section discusses the probability of postural changes to extrinsic risk factors when repeated participation occurs.

### i. Training volume and competitive level

The swimming season is periodised into a cardiovascular/endurance phase that occurs during training season and a taper phase that occurs during the competitive season (Salo & Riewald, 2008). In preparation to compete at optimal performance the swimmers perform a large volume of distances with high intensity practices in order to gain strength and power during the training season (Salo & Riewald, 2008, Walker *et al.*, 2012). As the competition season approaches, swimmers begin to taper, which allows for muscle recovery and rest, ultimately optimizing physiological and psychological components to maximize performance in competitions (Walker *et al.*, 2012). A pilot study was conducted by Virag *et al.* (2014) proposing that the volume of swim training poses as a risk factor for the development of undesirable postural changes, as it leads to fatigue in scapular stabilizing musculature, development of muscle imbalance, and adaptations of the intrinsic physical characteristics that increase the risk of injury in competitive swimmers.

### ii. Stroke mechanics

Literature shows that due to the large training volume that is completed during the endurance/cardiovascular phases of training, up to 80% of all practice time is spent performing freestyle, regardless of stroke specialty (Magel & Mc Ardle, 1970; Tsai *et al.*, 2003; Wilk *et al.*, 2009; Barbosa *et al.*, 2010). While there are four strokes in the sport of swimming (namely, butterfly, backstroke, breast stroke, and freestyle), freestyle is performed most often by competitive swimmers during training (Wilk *et al.*, 2009; Barbosa *et al.*, 2010). It has been stated that abnormal mechanics during this stroke would theoretically have the greatest impact on the development of postural changes (Wilk *et al.*, 2009; Barbosa *et al.*,



2010). Further, previous research has not yet observed the correlation between stroke specialty and growth rate and posture development of adolescent swimmers (Wilk *et al.*, 2009).

The development of swimming mechanics has concentrated on performance improvements with little focus on mechanical advancements to contend with the vigorous demands placed on swimmers' posture (Magel & Mc Ardle, 1970; Tsai *et al.*, 2003). Swimming with improper freestyle mechanics has been suggested as a dominant risk factor for postural pathology and an increase for injury (Magel & Mc Ardle, 1970; Tsai *et al.*, 2003; Wilk *et al.*, 2009). Theoretical stroke mechanical errors that may be related to postural changes that can be seen in competitive adolescent freestyle swimmers have been identified (Magel & Mc Ardle, 1970; Tsai *et al.*, 2003; Wilk *et al.*, 2009; Barbosa *et al.*, 2010). These errors include improper hand entry angle, hand entry position, pull-through pattern, and elbow position during pull-through, elbow position during recovery, body roll angle, and head carrying angle (Letzelter & Freitag, 1983; Wilk *et al.*, 2009; Barbosa *et al.*, 2010).

The correct and incorrect mechanics, as well as the relationship of the incorrect mechanics to postural changes is presented in Table 2.3. A stroke mechanics assessment is important for all competitive swimmers to help identify contributors to existing and potential postural malalignments (Letzelter & Freitag, 1983; Wilk *et al.*, 2009; Barbosa *et al.*, 2010). While swimming with improper stroke mechanics has been established as a theoretical risk factor for postural changes that may lead to injury, a clear correlation between faulty freestyle stroke technique and postural changes has yet to be identified through mechanical research (Letzelter & Freitag, 1983; Wilk *et al.*, 2009; Barbosa *et al.*, 2010).



*Table 2.3 Summary of mechanical errors during phases of freestyle swimming* (Letzelter & Freitag, 1983; Wilk *et al.*, 2009; Barbosa *et al.*, 2010; Hibberd *et al.*, 2012)

Stroke Phase	Correct freestyle mechanics	Incorrect freestyle mechanics	Relevance to incorrect mechanics and upper-quarter posture changes
<b>Hand Entry</b>	Hand enters water forward and lateral to the head, medial to the shoulder. Little finger or fingers first hand entry.	Hand enters further away from or crosses the midline of the long axis of the body. Thumb first hand entry.	Stresses the biceps attachment to the anterior labrum. Excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa.
<b>Pull-Through</b>	Elbow kept higher than hand and points laterally throughout pull. Swimmer should use a straight back pull-through.	Dropped elbow during pull-through. S-shaped pull-through or excessive horizontal adduction past body midline during pulling.	Increases external rotation of the shoulder, placing muscles of propulsion at mechanical disadvantage. Posterior capsular tightness, often demonstrated by a loss of internal rotation of the glenohumeral joint.
<b>Recovery</b>	Elbow kept higher than the wrist throughout the recovery phase. Body roll of approximately 45° along the longitudinal axis of the body.	Body roll that is greater or less than 45°	Excessive roll can lead to crossover entry position, during the pull phase. A lack of body roll during recovery can increase mechanical stress on the shoulder and lead to improper hand entry position.
<b>All Phases</b>	Head in neutral position. Imagine line through centre of head and extending through spine.	Head carriage is in eyes forward position.	Increase impingement by impending normal scapulothoracic motion. Excessive anterior orientation of the head or glenohumeral joint relative to the vertical plumb line of the body. An increased midthoracic spine kyphosis and hyperextension at the atlanto-occipital articulations and a flattening of the midcervical spine lordosis.



### iii. Equipment use

Various equipment such as hand paddles are often utilized as an adjunct in order to increase propulsive efficiency (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013). Hand paddles are rectangular pieces of plastic that are attached to the hands by rubber tubing and are used to improve the catch of the water and the power of the pull-through stroke (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013). While many coaches believe these are beneficial adjuncts to practice, many studies have identified that the use of hand paddles increases the development of undesirable changes in the shoulder complex and has a direct link to shoulder pain (Hibberd & Myers, 2013). Hand paddles that are larger than the size of the hand normally or do not have holes to allow for drainage of water may increase the stress on the shoulder complex as they place a greater strain on the musculature during the pull-through phase (Hrysomallis & Goodman, 2001; Hibberd *et al.*, 2012; Hibberd & Myers, 2013). In addition, kickboards are often used as recovery or to focus on lower extremity power; however, holding the kickboard overhead places the shoulder in an impingement position, and may increase the stress on shoulder musculature (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013). Kickboard usage has also been linked to an increase curvature in the thoracic spine and a hyperextension at the atlanto-occipital articulations and a flattening of the midcervical spine lordosis which is caused by cervical extension and thoracic compensation (Hrysomallis & Goodman, 2001; Hibberd *et al.*, 2012; Hibberd & Myers, 2013). While some of the evidence on the use of equipment in training is inconclusive, it is important to understand the theoretical risk that exists with the use of training equipment (Hibberd *et al.*, 2012).

### iv. Rest/recovery

Due to the current popular theory of swim training, swimmers train at high volumes with large distances being performed per practice with multiple training sessions a week (Hibberd *et al.*, 2012). This training load does not allow competitive swimmers adequate time to rest and recover between practice sessions (Hibberd *et al.*, 2012). This repetition can cause muscular fatigue, which may result in alterations in physical characteristics, including altered scapular kinematics and undesirable adaptations of the shoulder complex that may increase the risk of upper-quarter postural malalignments (Saladin, 2015; Matthews *et al.*, 2017).



Studies have identified adaptations in scapular kinematics that may promote postural changes or alter muscle functioning following a fatigue protocol (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017). These kinematic adaptations include an increased scapular upward rotation and external rotation, as well as clavicular retraction (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017). Associated with these changes in scapular kinematics were decreases in electromyography activity in the upper trapezius, serratus anterior, anterior and posterior deltoids, and infraspinatus following fatigue, with the greatest decreases in the infraspinatus and deltoids (Saladin, 2015; Matthews *et al.*, 2017). With fatigue, there is an alteration in scapular kinematics and muscle activation that may increase the risk of upper-quarter postural changes and a decrease in optimal performance (Saladin, 2015; Matthews *et al.*, 2017). Adequate rest should be incorporated into the periodisation program to allow for muscles to return to a state of readiness after the onset of fatigue (Hibberd *et al.*, 2012; Matthews *et al.*, 2017).

## 2.4.2 Intrinsic risk factors

This section discusses the postural adaptations to intrinsic risk factors and their relation to the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers.

### i. Excessive anterior orientation of the head or glenohumeral joint relative to the vertical plumb line of the body.

This postural malalignment is commonly known as rounded shoulders and is a result of overactive upper-trapezius, levator scapula and pectoralis muscles as well as the inhibition of serratus anterior, lower and middle trapezius and rhomboid muscles (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017). Overactive splenius capitis, splenius cervicis and the sternocleidomastoid and underactive longus capitis and longus colli are also involved as a primary cause of forward head posture alignment (Hibberd *et al.*, 2012; Walker *et al.*, 2012).

### ii. Excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa.

Optimal function of the upper-quarter of female adolescent competitive freestyle swimmers is reliant on the coordinated movement between the scapula and the humerus



(Paine & Voight, 2013; Laudner *et al.*, 2015). This postural deviation is a result of overactive serratus anterior, shoulder adductor muscles, known as coracobrachialis, pectoralis major, latissimus dorsi and teres major, as well as shoulder internal rotator muscles, known as subscapularis, anterior deltoid, pectoralis major, latissimus dorsi and teres major (Matthews *et al.*, 2017). The under-activity of the mid- and lower trapezius and rhomboid muscles allows the scapula to excessively protract (Hibberd *et al.*, 2012). This also causes a loss of scapular protraction/retraction control either due to capsular tightness or coracoid muscle contracture which may lead to an altered scapulohumeral rhythm and impingement of the supraspinatus tendon, superior joint capsule, subacromial bursa and biceps brachii long head tendon (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017).

The kinematic interaction between the scapula and the humerus was introduced in the 1930s and termed "scapulohumeral rhythm" by Codman (1934). Inman *et al.* (1996) were the first to measure scapulohumeral rhythm (also referred to as glenohumeral rhythm) using radiography. A 2:1 ratio between glenohumeral elevation and scapulothoracic (ST) upward rotation (SUR) was suggested and became the widely accepted normative value (Inman *et al.*, 1996). Imaging modalities such as X-ray and magnetic resonance imaging (Poppen & Walker, 1976), cinematography (Bagg & Forrest, 1988), goniometry (Doody *et al.*, 1970), and more recently 3-dimensional tracking systems (Johnson, 2001; Finley & Lee, 2003; Su *et al.*, 2004) have also been used to gain a better understanding of shoulder kinematics.

**iii. Posterior capsular tightness (loss of internal rotation of the glenohumeral joint, may lead to more superior and anterior translation of the humeral head).**

A loss of humeral internal rotation greater than or equal to 20 degrees compared with the contralateral side is known as glenohumeral internal rotation deficit (GIRD) (Walker *et al.*, 2012). This restriction in range of motion leads to the subacromial space to decrease and has been linked to shoulder impingement (Walker *et al.*, 2012). Solem *et al.* (1993) showed by means of an MRI analysis that the subacromial space decreased with shoulder protraction. In addition, Pink & Tibone (2000) have suggested that a protracted shoulder posture may predispose swimmers to a high risk of shoulder injury.



An analysis was conducted by Pink *et al.* (1991) to compare competitive swimmers with non-swimmers in muscular strength adaptations specific to swimming kinematics. The shoulder internal-rotation to external-rotation strength in competitive swimmers was found to have a ratio of 1.89:1 compared to 1.35:1 in non-swimmers (Pink *et al.*, 1991). This suggested that swimmers have a greater deviation from normative value (i.e. 1:1 ratio) and may be a result of overdeveloped internal rotator and adductor muscles (Pink *et al.*, 1991). The clavicle and scapula is then be repositioned forward over the weaker external rotator and abductor muscles (Pink *et al.*, 1991).

A number of studies have measured shoulder mobility by means of isokinetic testing on the Cybex II dynamometer and concluded that swimmers have an increase of 10 degrees greater external shoulder rotation mobility and 40 degrees lesser internal shoulder rotation mobility compared to the general population (Pink & Tibone, 2000; Virag *et al.*, 2014; Laudner *et al.*, 2015). A decrease in internal shoulder rotation may be related to narrowing of the subacromial space and associated shoulder impingement syndrome (Morrissey *et al.*, 2008; Weon *et al.*, 2010; Virag *et al.*, 2014). These postural abnormalities are often associated with overuse injuries in the shoulder (Johnston, 1937; Doody *et al.*, 1970; Griegel-Morris *et al.*, 1992; Atalar *et al.*, 2009; Thigpen *et al.*, 2010; Paine & Voight, 2013; Laudner *et al.*, 2015).

A decreased subacromial space, scapular elevation, internal rotation and an anterior translation of the GH joint causes the rounded shoulder posture commonly seen in female adolescent swimmers (Hibberd & Myers, 2013; Rushall, 2011). The forward head position with round shoulders changes the normal orientation of the plane of the scapula, which is tilted between 35 degrees to 45 degrees anterior to the frontal plane (Doody *et al.*, 1970; Paine & Voight, 2013; Laudner *et al.*, 2015). This dysfunction, combined with repetitive overhead movements, cause stress to the shoulder's static and dynamic stabilising structures (Laudner *et al.*, 2015) and in turn may lead to soft tissue injuries and instability in the shoulder region which restrict full mobility of the upper extremities (Garcia-Massó & Colado, 2010; Laudner *et al.*, 2015). Poor technique or strain to the agonistic muscles for the purpose of achieving more effective stroke execution in the propulsion phase, can lead to an asymmetric load being placed on the upper body musculature (Meyer *et al.*, 2006). This may



result in postural malalignments and shoulder pain developing over a period of time (Meyer *et al.*, 2006).

**iv. An increased midthoracic spine kyphosis (excessive curvature of the T1 – T12 greater than 45 degrees).**

This deviation in postural alignment is a result of hyperflexion of the thoracic spine caused by overactive rectus abdominis and pectoralis major and minor muscles as well as underactive mid and lower trapezius, longissimus thoracis, iliocostalis thoracis, spinalis thoracis, semispinalis thoracis and rotatores thoracis muscles (Hibberd *et al.*, 2012; Walker *et al.*, 2012). Milenković *et al.* (2012) reported the frequency of postural changes among thirty male and female swimmers (aged 13 - 26 years  $\pm$  6 months) by the use of a Spinal Mouse device. In the case of the male swimmers, scoliotic posture was noted in 33% of the subjects, while in the case of the female swimmers the percentage was somewhat lower namely 27%. Female swimmers demonstrated 47% incidence of two postural changes, namely lordosis and kyphosis, compared with 27% incidence in male swimmers. The presence of a combined kyphotic and scoliotic posture was exhibited by 20% of the female and by 13% of the male swimmers.

**v. Hyperextension at the atlanto-occipital articulations and a flattening of the midcervical spine lordosis.**

This spinal malalignment is caused by cervical extension and thoracic compensation. When performing the freestyle stroke cervical rotation accounts for 55% movement provided by the atlanto-axial joint (C1-C2), 5% by the occiput-atlas joint (C0-C1) and the remaining 40% is spread between C2-C6. A study by Guth (1995) found that there was a greater mean range of cervical rotation in 14-17 year-old swimmers than non-swimmers. In this study, the analysis was made using goniometric measurement of cervical rotation. This result supported the concept that active motion through swimming contributes to a greater degree of flexibility and rotation of the cervical spine and related structures (Guth, 1995). Neck over-rotation loads the cervical spine ligaments and muscles, which encourages asymmetrical development (Guth, 1995; Hibberd *et al.*, 2012). The last two postural malalignments (iv and v) are typically seen as an “S” shape of the spine when observed from the side (Hibberd *et al.*, 2012; Walker *et al.*, 2012).



## 2.5 Postural characteristics of female adolescent competitive freestyle swimmers

Tanchev *et al.* (2000) named three of the main contributors to postural malalignment in female adolescent competitive freestyle swimmers, namely general joint hyper-mobility, slow growth and maturation due to physical, dietary and physiological stress, and constant asymmetric muscular load. Wu & Williams (2001) stated that postural responses depend on the daily demands placed on the individual, such as sport participation. Additionally, the postural responses differ in relation to gender and skeletal maturity (Wu & Williams, 2001). Penha *et al.* (2008) supported this research by stating that certain postural abnormalities during adolescence were indicative of normal postural development. These abnormalities will most likely be corrected during normal growth and development. However, certain abnormalities are caused by excessive sports training or incorrect technique and may result in decreased quality of performance during adolescents and adulthood (Penha *et al.*, 2008).

Research on postural patterns and development in school-age adolescents is very limited, especially when the gender differences in posture are taken into consideration in relation to competitive sports participation such as swimming (Chansirinukor *et al.*, 2001; Grimmer *et al.*, 2002; Penha *et al.*, 2008; Tate *et al.*, 2012). According to Penha *et al.* (2008), further investigation is needed in order to explain the influence of gender differences during the process of development and to understand to what extent these changes can influence the formation of adult postural patterns. Female adolescent competitive freestyle swimmers are at a greater risk of undesirable postural changes than males because of earlier maturation and skeletal structure development (Brink *et al.*, 2012). This, in combination with repetitive exposure to extrinsic risk factors associated with competitive swimming, further increases their risk of attaining postural malalignments in their upper-quarter (Brink *et al.*, 2012).

Adolescence is the time of critical skeletal growth in the vertebral column, making female adolescents particularly vulnerable to undesirable musculoskeletal adaptations when competing in a sport at elite level (Grimmer *et al.*, 2002; Busscher *et al.*, 2011; Brink *et al.*, 2012). This being said, adolescents, 12 to 18 years of age, undergo rapid muscular and skeletal development (Gangnet *et al.*, 2003). It is during this stage of puberty that girls have



an increased risk to postural changes, as their musculoskeletal system adapts to the strenuous swimming training that they are exposed to on a daily basis.

Good swimming posture is a state of equilibrium of body segments, in a position of least effort and maximum support (Busscher *et al.*, 2011; Brink *et al.*, 2012). Many postural deviations originate during the adolescent period (Brink *et al.*, 2012). During the pre-pubertal phase and puberty, female adolescents experience the greatest amount of postural adaptations and adjustments in order for the body to be in balance with the new proportional changes in body segments (Busscher *et al.*, 2011). Some of these postural adaptations are common in adolescents of the same age group and are considered to be a response of the body to the demands of gravity (Busscher *et al.*, 2011). They are usually corrected spontaneously with the development of muscle strength. However, if they persist due to repetitive exposure to extrinsic risk factors related to swimming, they may lead to postural malalignment, causing discomfort and functional impairment (Busscher *et al.*, 2011; Brink *et al.*, 2012).

## 2.6 Summary

Posture is the alignment and maintenance of body segments in certain positions (Young, 2002). There is thought to be an optimal posture for any task (Gracovetsky, 1988) and unique to every individual (Stirn *et al.*, 2011). Considerable deviations from optimal posture are thought to be aesthetically unpleasant and may adversely influence muscle activity thereby predisposing individuals to musculoskeletal or neurological pathological conditions (Hrysomallis & Goodman, 2001). A number of factors influence postural adaptations in female adolescent competitive freestyle swimmers. These factors can be categorised into intrinsic and extrinsic risk factors (Hibberd *et al.*, 2012; Walker *et al.*, 2012). The repetitive nature of swimming and unremitting exposure to these risk factors may predispose female swimmers to develop structural and muscular imbalances, particularly in the upper-quarter (Morrissey *et al.*, 2008; Hibberd *et al.*, 2012). Muscular imbalances lead not only to strength imbalances in the shoulder girdle but also to undesirable postural and joint articulation changes commonly seen in female adolescent competitive swimmers (Virag *et al.*, 2014). These changes predispose the swimmer to injury and inhibit optimal performance (Peterson *et al.*, 1997; Virag *et al.*, 2014).



Adolescence is the time of critical skeletal and muscular growth, making female adolescents particularly vulnerable to undesirable musculoskeletal adaptations when competing in a sport at elite level (Grimmer *et al.*, 2002; Busscher *et al.*, 2011; Brink *et al.*, 2012). It is important to identify postural deviations during the adolescent stage, because their skeletal structure is still susceptible to changes and poor posture is more easily corrected at this stage of development (Brink *et al.*, 2012).



# CHAPTER 3

## METHODOLOGY

---

This chapter includes the following sections that describe the actions taken to investigate the research problem:

- Research approach and design
- Research procedures and strategy
- Ethical approval and considerations
- Setting
- Participant selection and recruitment
- Procedures and instruments
- Statistical analysis

### 3.1 Research Approach and Design

A prospective observational and comparative, cross-sectional study design was used to evaluate the differences in upper-quarter posture between female adolescent competitive freestyle swimmers and female adolescent non-swimmers. Observational studies are those where the researcher is not acting upon the study participant, but instead observing natural relationships between factors and outcomes. Comparative cross-sectional studies aim to find the prevalence of a phenomenon by measuring variables between groups at a specific time. This study followed a quantitative research approach by describing statistics to establish associations between and within variables (Thomas & Nelson, 2001; Brink *et al.*, 2012).

A comparison was made between the shoulder posture alignment, flexibility and muscular strength of female adolescent competitive freestyle swimmers and female adolescent non-swimmers. Various tests were conducted to determine whether significant differences existed in postural alignment, muscular strength and flexibility in female adolescent competitive freestyle swimmers and female adolescent non-swimmers.

### 3.2 Research Procedures and Strategy

The research procedures and strategy followed in this study are graphically represented in chronological order in Figure 3.1. This chapter highlights and discusses the participant selection and measurement procedures utilised in this study.

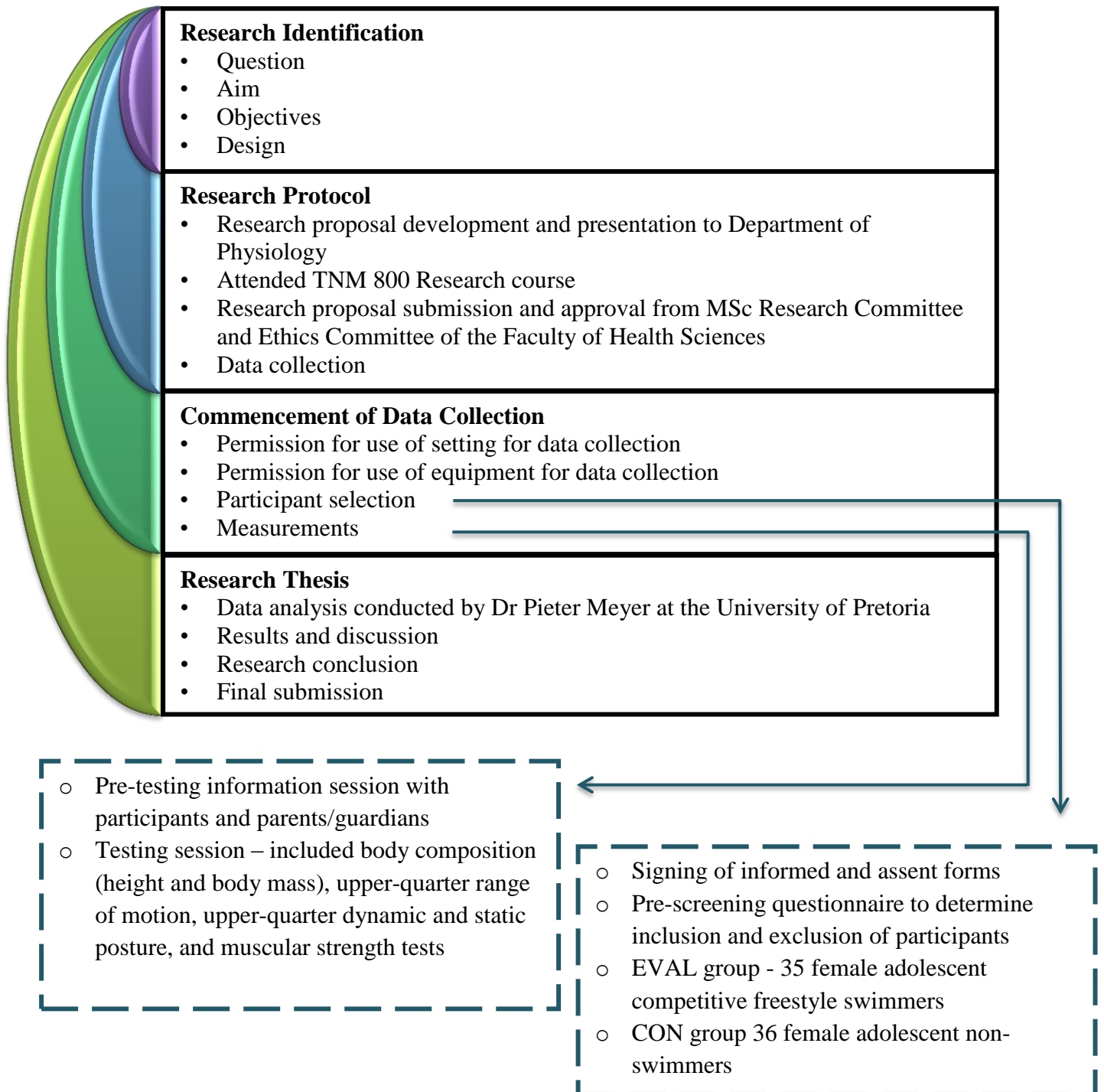


Figure 3.1 Schematic summary of the research procedure and strategies



### 3.3 Ethical Approval and Considerations

The research protocol was submitted for written approval, prior to the commencement of the data collection, to the MSc Research committee and Ethics committee (124/2017) of the Faculty of Health Sciences at the University of Pretoria (ANNEXURE A & ANNEXURE B, respectively). All information and data obtained during the course of this study was treated confidentially. The data was analysed and reported anonymously. Anonymity of the participants was ensured by allocating a number code to each participant. The scores captured on the data sheets were not released or reported to any person, only to the researcher. The participants and their parents only had access to the research data specific to them. The data is currently stored at the Department of Physiology, Division of Biokinetics and Sport Science, Faculty of Health Sciences at the University of Pretoria. The data will be stored for a period of 15 years at the Department of Physiology, University of Pretoria (ANNEXURE H).

Prior to the testing, the participants that met the inclusion criteria for both the EVAL- and CON groups completed and signed a contextual information form, which was used to collect applicable screening information for this study. The EVAL group was required to share information, such as: injury history as well as an in-depth swimming profile of training age, preferred training stroke, preferred competing stroke and distance, ranking, hours of training, age, height and body mass (ANNEXURE E). The CON group was required to share information such as: injury history, previous participation in sport or recreational activity (ANNEXURE F). The Acting Head of the Division of Biokinetics and Sport Science at the University of Pretoria approved an equipment loan, for the use of UP Biokinetics equipment (ANNEXURE D).

Participation in the study was voluntary and was conducted on female adolescents under the age of 18 years. Therefore, those who chose to participate in the testing procedure were asked to complete and sign an assent form (ANNEXURE I) before testing. Additionally, participants' parents/legal guardian completed and signed an informed consent form, giving permission for their child's participation (ANNEXURE J). An information meeting, involving all parties (participants, parents/guardian and coaches), took place in the Diocesan Hall at St Mary's DSG before informed consent was signed.



The researcher conducted the information meeting. A thorough explanation of the protocol, the inclusion and exclusion criteria and all testing procedures was provided. Additionally, a demonstration of each procedure was displayed in order to facilitate learning and to answer any questions from parties involved. There were no private, one-on-one testing sessions. The testing sessions were conducted in a group. Moreover, the testing sessions were conducted prior to the participants' normal swim training with only parents or guardians of the participant as external observers.

### **3.4 Setting**

The physical testing of the EVAL- and CON group was conducted at St Mary's DSG Pretoria. Permission was granted to use St Mary's DSG gymnasium and Diocesan Hall for the testing. Permission was authorised by: The Reverend Canon A.W. Paterson, Head of School- [frpaterson@stmarys.pta.school.za](mailto:frpaterson@stmarys.pta.school.za) (ANNEXURE C).

### **3.5 Participation Selection and Recruitment**

#### **Sample size**

The total sample consisted of 71 female adolescent participants. The EVAL group consisted of 35 female adolescent competitive freestyle swimmers who qualified for SSA Level 3 in any of the freestyle events during the 2017 swimming season. The CON group consisted of 36 female adolescent non-swimmers, recruited from St Mary's DSG Pretoria. Permission was granted by: The Reverend Canon A.W. Paterson, Head of School- [frpaterson@stmarys.pta.school.za](mailto:frpaterson@stmarys.pta.school.za) (ANNEXURE C) to approach and recruit the pupils of St Mary's DSG, for this study.

#### **Evaluation group**

Participants were recruited by means of personal approach and word of mouth from three swimming clubs located in the Tshwane region, namely Diadora Aquatics, TUKS Swimming and Players Academy. These swimming clubs were chosen as they produced a number of qualified Swim South Africa (SSA) Level 3 Regional Age Group female adolescent freestyle swimmers in the past. Pre-screening questionnaires (ANNEXURE E) were distributed to all the female swimmers in the club. After completing the pre-screening



questionnaire a short list for this study was identified. An assent form (ANNEXURE I) and informed consent form (ANNEXURE J) were distributed to the prospective participants to be completed in order to be included in this study. The inclusion and exclusion criteria applied for the EVAL group are listed below.

### **Inclusion Criteria:**

Competitive female adolescent swimmers who:

- Specialised in freestyle.
- Qualified for SSA Level 3 time in one of the freestyle events before the end of the swimming season (ANNEXURE K).
- Were between 13 and 18 years of age.
- Trained a minimum of five (5) swim training sessions per week.
- Did a minimum of two (2) callisthenic exercises or weight training sessions per week.
- Completed the pre-participation screening questionnaire.
- Completed the child consent and informed consent forms.

### **Exclusion Criteria:**

Participants who met any of the following criteria were excluded from this study:

- All participants who did not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the 12 weeks prior to testing.
- Participants who used any source of external posture correctional device.

## **Control group**

Female adolescent non-swimmers were recruited by means of personal approach, word of mouth and notices placed on announcement boards at St Mary's DSG. Information was liaised via a letter regarding the requirements of this study once the identified participant expressed their interest. The prospective participants were required to complete a pre-participation questionnaire (ANNEXURE F) to determine their suitability for the study. The inclusion and exclusion criteria applied for the CON group are listed below.



### **Inclusion Criteria:**

Female adolescent non-swimmers who:

- Did not engage in any form of overhead sporting activity.
- Were between 13 and 18 years of age.
- Did not participate in callisthenic exercises or weight training.
- Completed the pre-participation questionnaire.
- Completed the child consent and informed consent forms.

### **Exclusion Criteria:**

Participants who met any of the following criteria were excluded from this study:

- All participants who did not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the 12 weeks prior to testing.
- Participants who were using any source of external posture correctional device.
- Participants who performed rehabilitation (strengthening and stretching) exercises that targeted the upper quarter of the body.

## **3.6 Procedures and Instruments**

### **Reliability and validity of the testing procedures**

Testing is valuable as it assesses a small number of variables within a short time frame to give the researcher an idea of the participant's ability to engage in physical activity (Hendelman *et al.*, 2000). Test effectiveness is dependent on the validity and reliability of a test. Validity can be divided into construct and criterion validity (Brink, 1993). Construct validity refers to the degree to which an instrument measures the construct it is intended to measure, and criterion validity pertains to evidence of a relationship between the attributes in a measurement tool with its performance on some other variable. Reliability pertains to the ability of an instrument to consistently measure an attribute (Brink, 1993).

All tests selected for this study were conducted by the same tester and have reported good intra-inter tester variability. A familiarisation trial with the participants was conducted before the onset of this study, to ensure that participants accumulated knowledge and experience of the procedures and requirements of the testing protocol. This contributed to limiting the time spent measuring various tests, as the participants knew which procedure to follow and what to expect. Calibration of all equipment was done thirty minutes before the testing session started. Calibrating the equipment prior to testing helped ensure that the data collected was valid and reliable. The validity and reliability scores of each testing procedure are stated with the explanation of the testing procedures. To ensure validity and reliability the exact procedure for each test was used.

### **Range of motion**

Range of motion actively measures the full range of motion about a joint, highlighting the laxity or limitations of the joint (Taylor *et al.*, 2015).

#### **1. Shoulder joint range of motion with scapular motion**

Measurements were performed using a goniometer (Figure 3.2: EZ Read Jamar - 8" 20cm, Model 7540, Cambridge) and scribed in unit of degree ( $^{\circ}$ ). Peolsson *et al.* (2001) reported that the intra-class correlation coefficient values for the shoulder joint with scapular motion showed good reliability, with 0.71, whereas the values for the cervical spine range of motion revealed very good intra-rater reliability of 0.83. The standard error of measurement (SEM) ranged from 4-7 degrees for intra-rater and 6-9 degrees for inter-rater agreement on movements that achieved the criterion reliability (Peolsson *et al.*, 2001). The minimal clinical difference (MCD) ranged from 11-16 degrees for a single evaluator and 14-24 degrees for two evaluators (Peolsson *et al.*, 2001).



***Figure 3.2 Goniometer***

Figures 3.3 – 3.8 illustrate the methodology used for the shoulder joint with scapular motion range of motion measurements conducted. Additionally, Tables 3.1 – 3.6 outlines the muscular involvement and normative ranges for each shoulder and cervical range of motion measurement are stated.

*Table 3.1 Goniometric examination of shoulder flexion range of motion*

Muscles Lengthened	Methodology	Normative Range
<b>Shoulder Flexion</b>		
<ul style="list-style-type: none"> <li>• Latissimus dorsi</li> <li>• Triceps brachii</li> <li>• Pectoralis major</li> <li>• Infraspinatus</li> <li>• Posterior deltoid</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Fulcrum of goniometer is positioned on deltoid tuberosity.</li> <li>• Stationary arm of goniometer is positioned along the thorax, parallel with the plinth.</li> <li>• Moving arm is aligned with the longitudinal axis of the upper arm with the lateral epicondyle of the humerus as the distal reference point.</li> <li>• Participant performs bilateral shoulder flexion in the sagittal plane with elbows remaining extended (Meiring <i>et al.</i>, 1993; Borms &amp; van Roy, 2009).</li> </ul>	180 degrees (Kendall <i>et al.</i> , 1983)



*Figure 3.3 Shoulder flexion range of motion*

Table 3.2 Goniometric examination of shoulder extension range of motion

Muscles Lengthened	Methodology	Normative Range
<b>Shoulder Extension</b>		
<ul style="list-style-type: none"> <li>• Pectoralis major</li> <li>• Anterior deltoid</li> <li>• Biceps brachii</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies prone on plinth.</li> <li>• Arms are placed next to the body, palms facing each other.</li> <li>• Fulcrum of the goniometer is positioned along the thorax, parallel to the plinth.</li> <li>• Moving arm is aligned with the longitudinal axis of the upper arm with the lateral epicondyle of the humerus as the distal reference point.</li> <li>• Participant performs bilateral shoulder extension in the sagittal plane with elbows extended (Meiring <i>et al.</i>, 1993; Borms &amp; van Roy, 2009).</li> </ul>	<p>45 degrees (Kendall <i>et al.</i>, 1983)</p>

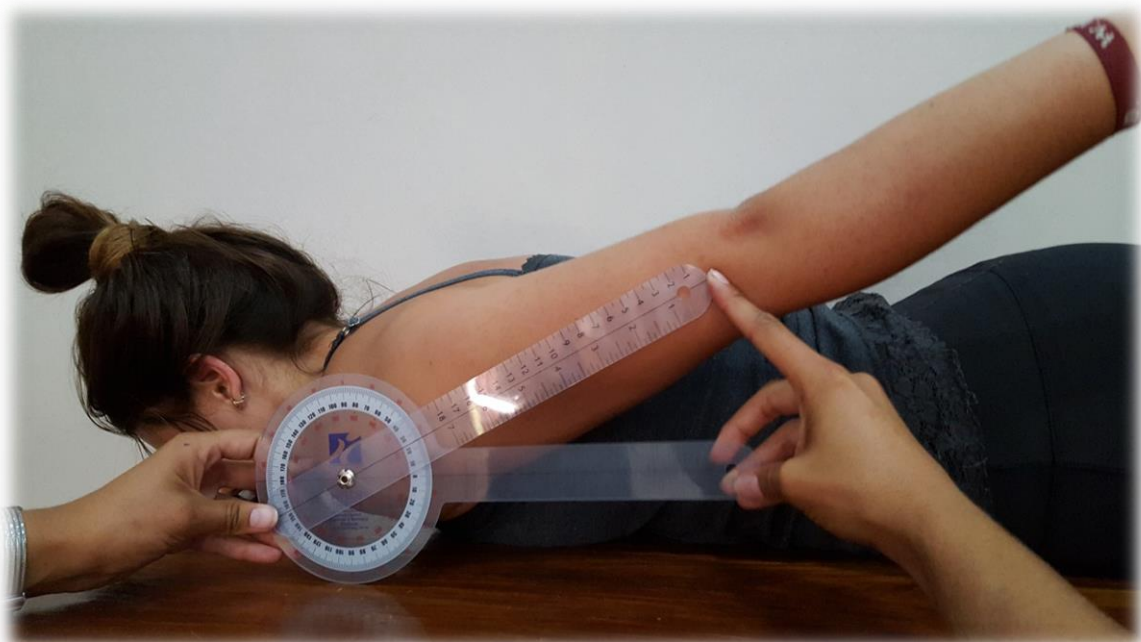


Figure 3.4 Shoulder extension range of motion

Table 3.3 Goniometric examination of shoulder abduction range of motion

Muscles Lengthened	Methodology	Normative range
<b>Shoulder Abduction</b>		
<ul style="list-style-type: none"> <li>• Pectoralis major</li> <li>• Teres major</li> <li>• Teres minor</li> <li>• Coracobrachialis</li> <li>• Subscapularis</li> <li>• Biceps brachii</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed 90 degrees.</li> <li>• Palms are kept in the sagittal plane, thumbs directed forward, elbows extended and wrists in neutral.</li> <li>• Fulcrum of goniometer is placed on the scapula.</li> <li>• Stationary arm is positioned parallel with the spine. Moving arm is positioned in line with the longitudinal axis of the humerus with the lateral epicondyle of the humerus as the distal reference point.</li> <li>• Participant performs bilateral shoulder abduction to prevent compensatory movement with the spine (Meiring <i>et al.</i>, 1993; Borms &amp; van Roy, 2009).</li> </ul>	<p>180 degrees (Borms &amp; van Roy, 2009)</p>



Figure 3.5 Shoulder abduction range of motion

*Table 3.4 Goniometric examination of horizontal shoulder adduction range of motion*

Muscles Lengthened	Methodology	Normative Range
<b>Horizontal Shoulder Adduction</b>		
<ul style="list-style-type: none"> <li>• Deltoids</li> <li>• Supraspinatus</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed at 90 degrees, and back against a wall.</li> <li>• Shoulder is in 90 degrees flexion (sagittal plane) and elbows remain extended with palms facing the medial axis of the body.</li> <li>• Fulcrum of the goniometer is placed superiorly on the acromioclavicular joint. Stationary arm is kept parallel with the wall (laterally). Moving arm is parallel with the longitudinal axis of the humerus with the lateral epicondyle of the humerus as the distal reference point.</li> <li>• Participant performs maximum adduction of the arm in a horizontal plane with both scapulas remaining in contact with the wall (Borms &amp; van Roy, 2009).</li> </ul>	<p>35 degrees (Borms &amp; van Roy, 2009)</p>



*Figure 3.6 Horizontal shoulder adduction range of motion*

Table 3.5 Goniometric examination of shoulder external rotation range of motion

Muscles Lengthened	Methodology	Normative Range
<b>Shoulder External Rotation</b>		
<ul style="list-style-type: none"> <li>• Pectoralis major</li> <li>• Teres major</li> <li>• Subscapularis</li> <li>• Latissimus dorsi</li> <li>• Anterior joint capsule</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulders abducted 90 degrees, elbows flexed at 90 degrees with forearm perpendicular to the plinth, wrist in neutral and hand in prolongation with forearm, thumb directed towards the medial axis of the body.</li> <li>• Fulcrum is placed on the olecranon process of the ulna. Stationary arm is aligned vertically (0 degrees) and remains in this position while measurement is taken. Moving arm is aligned with ulnar styloid process.</li> <li>• Bilateral shoulder externally rotates and ensures that the lower back remains in contact with the plinth (Meiring <i>et al.</i>, 1993).</li> </ul>	<p>104 degrees (Borms &amp; van Roy, 2009)</p>



Figure 3.7 Shoulder external rotation range of motion

Table 3.6 Goniometric examination of shoulder internal rotation range of motion

Muscles Lengthened	Methodology	Normative Range
<b>Shoulder Internal Rotation</b>		
<ul style="list-style-type: none"> <li>• Supraspinatus</li> <li>• Infraspinatus</li> <li>• Teres minor</li> </ul> Posterior joint capsule	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulders abducted 90 degrees, elbows flexed at 90 degrees with forearm perpendicular to the plinth, wrist in neutral and hand in prolongation with forearm, thumb directed towards the medial axis of the body.</li> <li>• Fulcrum is placed on the olecranon process of the ulna.</li> <li>• Stationary arm is aligned vertically (0 degrees) and remains in this position while measurement is taken. Moving arm is aligned with ulnar styloid process.</li> <li>• Bilateral shoulder internally rotates and ensures that the posterior aspect of the shoulder remains in contact with the plinth (Meiring <i>et al.</i>, 1993).</li> </ul>	69 degrees (Borms & van Roy, 2009)



Figure 3.8 Shoulder internal rotation range of motion

## 2. Cervical spine range of motion

The cervical spine range of motion measurements were measured with a tape measure (CESCORF Sports Equipment Ltd., Porto Alegre, Brazil) and scribed in units of millimetre (mm). Fletcher & Bandy (2008) reported that the intra-rater reliability for cervical range of motion using a tape measure presented good values, with 0.75, and intra-class correlation coefficient values of 0.79. The standard errors of measurement ranged from 0.04 – 0.12mm for tape measure intra-rater reliability (Fletcher & Bandy, 2008). Cervical spine range of motion muscular involvement, methodology and normative ranges are outlined in Tables 3.7 – 3.10 and illustrated by Figures 3.9 – 3.12.

*Table 3.7 Tape measure examination of cervical forward flexion range of motion*

Muscles Lengthened	Methodology	Normative Range
<b>Cervical Forward Flexion</b>		
<ul style="list-style-type: none"> <li>• Rectus capitis posterior major and minor</li> <li>• Obliquus capitis superior</li> <li>• Splenius capitis</li> <li>• Splenius cervicis</li> <li>• Longissimus capitis</li> <li>• Semispinalis capitis</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits erect with knees in 90 degrees and arms placed on legs</li> <li>• Participant flexes the neck by moving the chin towards chest</li> <li>• Ensure that jaw does not move to open mouth</li> <li>• Place measuring tape on most inferior part of mental protuberance and tip of sternal notch</li> <li>• The measurement is taken as the distance (mm) between the tip of the mental protuberance to tip of sternal notch (Shultz <i>et al.</i>, 2010).</li> </ul>	<p>Most inferior part of mental protuberance touching sternal notch (Shultz <i>et al.</i>, 2010)</p>



*Figure 3.9 Cervical forward flexion range of motion*

Table 3.8 Tape measure examination of cervical extension range of motion

Muscles Lengthened	Methodology	Normative Range
<b>Cervical Extension</b>		
<ul style="list-style-type: none"> <li>• Sternocleidomastoid</li> <li>• Longus colli</li> <li>• Longus capitis</li> <li>• Rectus capitis anterior</li> <li>• Scalenes anterior, medius and posterior</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits erect with knees in 90 degrees and arms placed on legs</li> <li>• Participant extends neck looking at the ceiling</li> <li>• Ensure that jaw does not move to open mouth</li> <li>• Place measuring tape on most inferior part of mental protuberance and tip of sternal notch</li> <li>• The measurement was taken as the distance (mm) between the tip of the mental protuberance to tip of sternal notch (Shultz <i>et al.</i>, 2010).</li> </ul>	<p>Eyes pointing straight to the ceiling (Shultz <i>et al.</i>, 2010)</p>



Figure 3.10 Cervical extension range of motion

*Table 3.9 Tape measure examination of cervical lateral flexion range of motion*

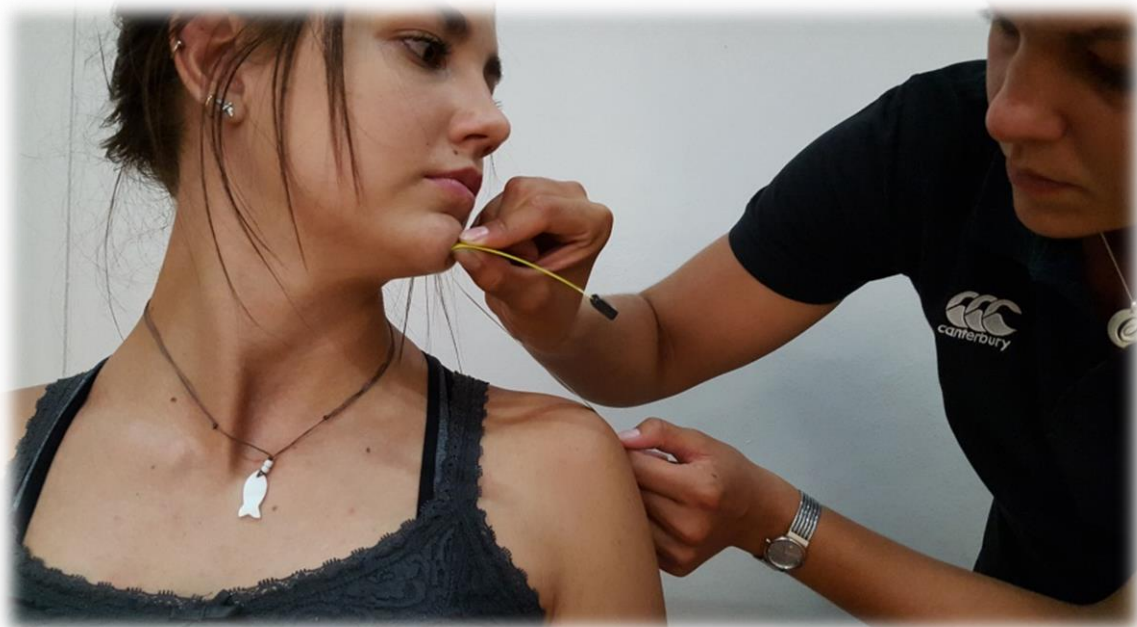
Muscles Lengthened	Methodology	Normative Range
<b>Cervical Lateral Flexion</b>		
<ul style="list-style-type: none"> <li>• Sternocleidomastoid</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits erect with knees in 90 degrees and arms placed on legs</li> <li>• Participant laterally flexes the neck with a direct movement of ear to the shoulder</li> <li>• Ensure that head does not rotate and shoulder is not elevated</li> <li>• Measure the distance (mm) by placing the measuring tape on mastoid process and the acromion process (Shultz <i>et al.</i>, 2010).</li> </ul>	<p>Head tilts bilaterally at 45 degrees (Shultz <i>et al.</i>, 2010).</p>



*Figure 3.11 Cervical lateral flexion range of motion*

*Table 3.10 Tape measure examination of cervical lateral rotation range of motion*

Muscles Lengthened	Methodology	Normative Range
<b>Cervical Lateral Rotation</b>		
<ul style="list-style-type: none"> <li>• Sternocleidomastoid</li> <li>• Longus capitis</li> <li>• Rectus capitis lateralis</li> <li>• Scalenus anterior</li> <li>• Scalenus medius</li> <li>• Scalenus posterior</li> <li>• Rectus capitis posterior major</li> <li>• Obliquus capitis inferior and superior</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits erect with knees in 90 degrees and arms placed on legs</li> <li>• Participant laterally rotates the neck with a direct movement of chin to the shoulder</li> <li>• Ensure that the lower jaw remains closed and no flexion, extension or lateral flexion of the head contributes to the movement</li> <li>• Measure the distance (mm) between the tip of the mental protuberance and the tip of acromion process (Shultz <i>et al.</i>, 2010).</li> </ul>	<p>Head tilts bilaterally at 45 degrees (Shultz <i>et al.</i>, 2010).</p>



*Figure 3.12 Cervical lateral rotation range of motion*



## Static posture

Static posture measurements display the angular relationship between body parts that can aid in identifying postural deviations and impairments (Thigpen *et al.*, 2010).

### **1. Photographic upper-quarter posture analysis**

Spinal sagittal posture was assessed by means of the Photographic Posture Analysis Method (PPAM) described by Straker *et al.* (2009) and Brink *et al.* (2009). The validity and reliability of the PPAM were tested by Van Niekerk *et al.* (2008) and illustrated good results. Van Niekerk *et al.* (2008) tested a total of 17 subjects (14 females and 3 males) aged 15 to 17 years for the reliability study. The intra-class correlation coefficient values for the shoulder angle and the cervical angle reported good reliability, with 0.78 and 0.72 respectively, whereas the values for the sagittal head angle revealed very good intra-rater reliability of 0.83.

This method measured the seated posture of the female adolescent competitive freestyle swimmers and non-swimmers by placing visual markers on bony landmarks (Brink *et al.*, 2009; Straker *et al.*, 2009). The angles displayed were analysed by means of Dartfish video analyser (Dartfish.exe, 6.0.13480, Fribourg, Switzerland). The following postural angles in the sagittal plane were measured on the right side of the body, as illustrated in Figure 3.13:

- Head tilt – the angle (degrees) between the line drawn from the canthus to the midpoint of the tragus and the horizontal line through the tragus (Brink *et al.*, 2009; Straker *et al.*, 2009).
- Cervical angle – the angle (degrees) between the line drawn from the midpoint of the tragus to the C7 spinous process and the horizontal line through the C7 spinous process (Brink *et al.*, 2009; Straker *et al.*, 2009).
- Shoulder protraction and retraction angle – the angle (degrees) between the line drawn from the midpoint of the humeral head to the C7 spinous process and the horizontal line through the midpoint of the humeral head (Straker *et al.*, 2009).
- Thoracic angle – the angle (degrees) between the line drawn from the C7 spinous process to the midpoint of the superior border of the manubrium and the line drawn from the T8 spinous process to the midpoint of the superior boarder of the manubrium (Brink *et al.*, 2009; Straker *et al.*, 2009).



**Figure 3.13 (A) Head tilt (black line) and cervical angle (yellow line); (B) Shoulder protraction/retraction (black line) and thoracic angle (yellow line)**

Prior to the data collection the trained researcher palpated for the bony landmarks and placed markers (9 mm circle, harlequin green) on the right side of the participant's body (Brink *et al.*, 2009; Straker *et al.*, 2009). The following bony landmarks were identified: the canthus, the midpoint of the tragus, the spinous process of C7 and T8, the superior border of the manubrium and the midpoint of the humeral head (Brink *et al.*, 2009; Straker *et al.*, 2009).

The participants were requested to sit on an adjustable chair, maintaining the following position for the duration of the test: the participant's hips and knees were measured with a goniometer to 90 degrees flexion, feet positioned shoulder width apart with arms relaxed and palms placed parallel to and on top of their quadriceps. The participants maintained a head position by viewing a designated point ahead at eye level (Brink *et al.*, 2009; Straker *et al.*, 2009). Two lateral photographs (image resolution 2594 × 1944 pixels) were taken of self-orientated erect seated posture, looking at the designated point. To minimise parallax error, the camera (Nikon, AF-S DX VR 55-200/4-5.6G IF-ED, 3610489 Digital Zoom, Europe), was positioned on a tripod 80 cm from the floor and 250 cm from the chair, with the participant's right side aligned to face perpendicular to the camera (Brink *et al.*, 2009; Straker *et al.*, 2009).

## Dynamic posture

Dynamic posture is the alignment of joints and movement patterns of the body when performing an activity.

### 1. Upper-quarter Y balance test

Assessment of dynamic upper-quarter performance at the limit of stability was measured through the upper-quarter Y balance test (YBT-UQ), described by Butler *et al.* (2014) and Gorman *et al.* (2012). The YBT-UQ reliability was tested by Gorman *et al.* (2012) and demonstrated an intra-class correlation coefficient range of 0.80 to 0.99 for test-retest reliability and 1.00 for inter-rater reliability. The results of the study suggest that the YBT-UQ protocol is a reliable test across raters and across days, measuring upper extremity reach distance while in a closed-chain position (McMullen & Timothy, 2000; Gorman *et al.*, 2012; Butler *et al.*, 2014).

The YBT-UQ can easily be assembled and conducted in a field setting with minimal equipment. The equipment required for the YBT-UQ are three flexible tape measures (Figure 3.14: CESCORF Sports Equipment Ltd., Porto Alegre, Brazil), three rectangular wooden boxes (20cm $l$  x 10cm $w$  x 3cm $h$ ) and a rectangular wooden box (30cm $l$  x 10cm $w$  x 3cm $h$ ) (Gorman *et al.*, 2012; Westerick *et al.*, 2012; Taylor *et al.*, 2015). The wooden boxes used in this study were manufactured by Builders Warehouse, according to the specifications stated.



*Figure 3.14 Steel tape measure*

The YBT-UQ examined the unilateral performance of the upper quarter at the end range of the participant's ability to maintain stability (Gorman *et al.*, 2012; Taylor *et al.*, 2015). The right and left upper extremity was measured in a medial, inferolateral, and superolateral direction. The maximum score of two trials for each direction was normalized to upper extremity length (Gorman *et al.*, 2012). The average of the greatest normalised reach score in each reach direction was used to develop a composite score (Gorman *et al.*, 2012; Westerick *et al.*, 2012; Butler *et al.*, 2014; Taylor *et al.*, 2015).

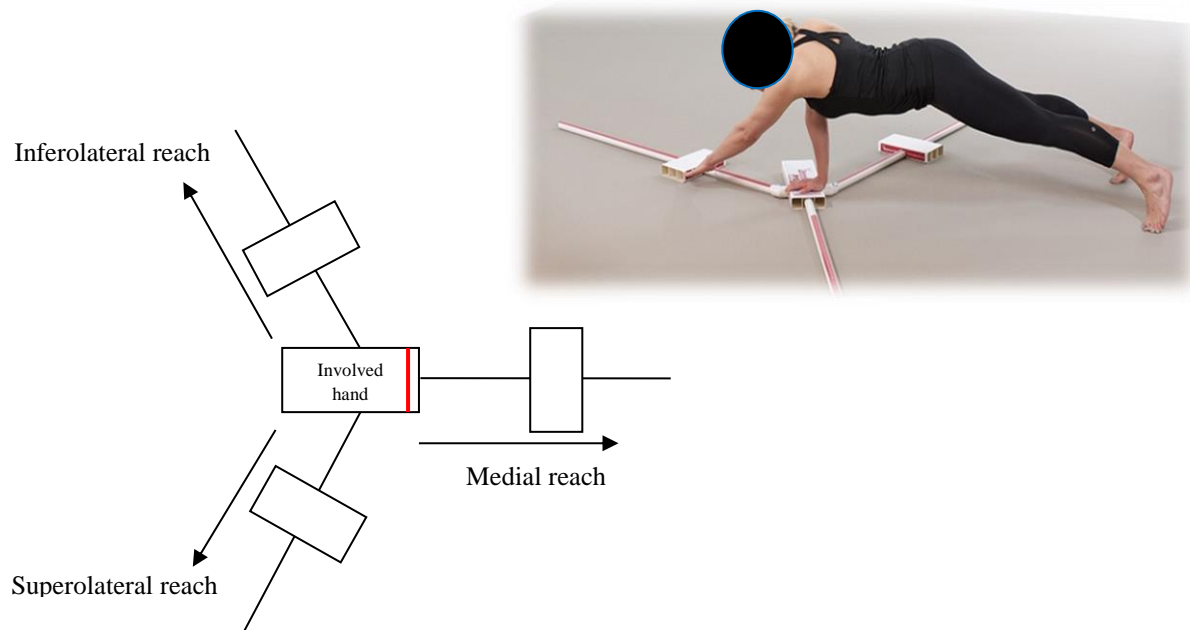
$$\frac{\text{average distance in three directions}}{\text{extremity length (EL)}} \times 100$$

Upper-quarter extremity length (EL) of each participant was measured by means of a tape measure (CESCORF Sports Equipment Ltd., Porto Alegre, Brazil). The participant was positioned in an erect standing posture, with feet together and shoulders abducted to 90 degrees, the elbows extended, and wrists and hands in neutral. EL is the distance in centimetres (cm) from the C7 spinous process to the tip of the right digitus medius (middle finger) (Gorman *et al.*, 2012; Westerick *et al.*, 2012). The participants were instructed to assume the starting position, defined as the feet being placed shoulder width apart in a push up position with the involved (stance) hand on the stance platform and the digitus primus (thumb) adducted and aligned behind the red line as indicated in Figure 3.15 (Gorman *et al.*, 2012; Westerick *et al.*, 2012). The uninvolved (reach) hand was placed on top of the reach box, shoulder width apart from the stance hand (Gorman *et al.*, 2012; Westerick *et al.*, 2012; Taylor *et al.*, 2015). The test entailed two practice trials and three performance trials, attempting to reach further in all three directions, with 1-minute rest between trials.



*Figure 3.15 Upper-quarter extremity length (EL)*

A standardized order was conducted, completing three performance trials on the right side followed by three performance trials on the left side: (i) medial, (ii) inferolateral, and (iii) superolateral, depicted in Figure 3.16, with the uninvolvement hand pushing the box in a controlled manner and maintaining contact with the side of the box in the area of the red tape before returning to the starting position (Gorman *et al.*, 2012; Taylor *et al.*, 2015).



**Figure 3.16** Illustration of different reach directions of the upper-quarter Y balance test (Gorman *et al.*, 2012; Taylor *et al.*, 2015)

The following criteria had to be met for each trial to be completed successfully (Gorman *et al.*, 2012; Butler *et al.*, 2014; Taylor *et al.*, 2015):

1. At all times three points of contact should be maintained between the involved hand and stance platform and between the floor and feet.
2. No momentum may be used to move the reach box (box should be moved in a controlled manner and remains in contact with uninvolvement hand).
3. The top of the reach box or any other testing equipment may not be used to stabilise the body.
4. The uninvolvement hand may not come into contact with the ground during the trial.
5. The participant should return the uninvolvement hand to the starting position in a controlled manner at the end of the attempt.



An unsuccessful trial was discarded and after sufficient rest the participant was requested to have another attempt until three completed trials in each direction were obtained (Gorman *et al.*, 2012; Butler *et al.*, 2014). Each reach distance was measured to the nearest 0.5 cm increment and the maximum score for each reach direction was used for calculation to present the end range of the participant's performance (Butler *et al.*, 2014). To compare the reach distance between participants, the maximum score was normalized to the participant's extremity length (calculated as percentage of EL) (Butler *et al.*, 2014). The normalized values for the right and left sides represent an average for each direction (Gorman *et al.*, 2012; Butler *et al.*, 2014; Taylor *et al.*, 2015). The mean values for each reach direction were compared as well as the average of the normalized values across all directions between participants (Gorman *et al.*, 2012). The absolute value of the differences between the maximum reach on the right and left side for each participant was calculated for each direction (Gorman *et al.*, 2012; Butler *et al.*, 2014). The mean absolute value for each direction was compared between participants and the absolute value differences for all three directions were calculated together and compared between participants (Gorman *et al.*, 2012; Butler *et al.*, 2014; Taylor *et al.*, 2015).

## Muscular strength

Muscular strength is the amount of force a muscle can produce with a single maximal effort and is measured during muscular contraction (Merlini *et al.*, 2002; Kelln *et al.*, 2008).

### **1. Muscular strength examination**

Muscular strength is a critical component of functional movement (Kolber & Cleland, 2013). These tests required the use of a manual muscular strength tester - MicroFET (MicroFET3 handheld dynamometer by Hoggan Health Industries, United States of America) and are most appropriate for field testing to evaluate muscular strength (Merlini *et al.*, 2002; Kelln *et al.*, 2008). The MicroFET dynamometer is a digital handheld muscular strength device which fits in the palm of the tester's hand and displays data instantly and accurately (Figure 3.17) (Kelln *et al.*, 2008). The MicroFET software automatically performs calculations and validity drafts. The MicroFET dynamometer was calibrated 30 minutes prior to the testing (Merlini *et al.*, 2002; Kelln *et al.*, 2008). The measurement results were

presented in units of kilogram-force (kgF) (Merlini *et al.*, 2002; Kelln *et al.*, 2008; Kolber & Cleland, 2013).



**Figure 3.17** *MicroFET device*

Manual resistance was applied in a controlled manner to the distal segment of the actively contracting muscle group (Merlini *et al.*, 2002; Kolber & Cleland, 2013). During the motion the participant gradually increased the amount of resistance against the manual resistance applied by the tester. The applied force continued until the participant reached their maximal level of resistance. At this point, the motion ceased (Merlini *et al.*, 2002). Two-joint muscles were tested in mid-range where over- and under-active ratio was most favourable (Merlini *et al.*, 2002). The specific motions at the GH joint that were tested for strength were: shoulder (i) flexion and (ii) extension, shoulder (iii) internal and (iv) external rotation, and shoulder (v) abduction and (vi) adduction. Scapular motion was tested through scapular (vii) elevation, (viii) depression, (ix) retraction, and (x) protraction (Kolber & Cleland, 2013). The test entailed two performance trials with no practice trial, attempting to apply more force in both trials, with 1 minute rest between trials. A standardized order was conducted, completing two performance trials on the right side followed by two performance trials on the left side, of which the best score was recorded.

Shoulder and scapular muscular involvement and the methodology used are outlined in Table 3.11 - Table 3.20 and accompanied by Figures 3.18 - Figure 3.27.

*Table 3.11 MicroFET examination of shoulder flexion muscular strength*

Muscular involvement	Methodology
<b>Shoulder Flexion</b>	
<ul style="list-style-type: none"> <li>• Biceps brachii (long head)</li> <li>• Pectoralis major (clavicular part)</li> <li>• Coracobrachialis</li> <li>• Serratus anterior</li> <li>• Anterior deltoid</li> <li>• Subscapularis</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulder positioned at 90 degrees flexion, arm vertically aligned.</li> <li>• MicroFET dynamometer is placed proximal to the elbow on the anterior surface of the upper arm.</li> <li>• Tester stabilises the shoulder with non-dominant hand.</li> <li>• Participant performs shoulder flexion, in the sagittal plane, to maximum effort with elbows remaining extended.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013; Kelln <i>et al.</i>, 2008).</li> </ul>



*Figure 3.18 Shoulder flexion muscular strength*

*Table 3.12 MicroFET examination of shoulder extension muscular strength*

Muscular involvement	Methodology
<b>Shoulder Extension</b>	
<ul style="list-style-type: none"> <li>• Pectoralis major (sternocostal part)</li> <li>• Latissimus dorsi</li> <li>• Posterior deltoid</li> <li>• Teres major</li> <li>• Triceps brachii</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulder positioned at 90 degrees flexion and elbow flexed at 90 degrees.</li> <li>• MicroFET dynamometer is placed proximal to the elbow on the posterior surface of the upper arm.</li> <li>• Tester stabilises the shoulder with non-dominant hand.</li> <li>• Participant performs shoulder extension, in the sagittal plane, to maximum effort with elbows remaining flexed.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013; Kelln <i>et al.</i>, 2008).</li> </ul>



*Figure 3.19 Shoulder extension muscular strength*

*Table 3.13 MicroFET examination of shoulder internal rotation muscular strength*

Muscular involvement	Methodology
<b>Shoulder Internal Rotation</b>	
<ul style="list-style-type: none"> <li>• Pectoralis major</li> <li>• Latissimus dorsi</li> <li>• Anterior deltoid</li> <li>• Teres major</li> <li>• Coracobrachialis</li> <li>• Subscapularis</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulders abducted 45 degrees, elbows flexed at 90 degrees with forearm perpendicular to the plinth, wrist in neutral and hand in prolongation with forearm, thumb directed 45 degrees towards the medial axis of the body.</li> <li>• MicroFET dynamometer is placed proximal to the ulnar styloid process, on the posterior surface of the arm.</li> <li>• Tester stabilises the elbow with non-dominant hand.</li> <li>• Participant performs shoulder internal rotation to maximum effort with elbows remaining flexed.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013).</li> </ul>



*Figure 3.20 Shoulder internal rotation muscular strength*

*Table 3.14 MicroFET examination of shoulder external rotation muscular strength*

Muscular involvement	Methodology
<b>Shoulder External Rotation</b>	
<ul style="list-style-type: none"> <li>• Posterior deltoid</li> <li>• Infraspinatus</li> <li>• Teres minor</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulders abducted 45 degrees, elbows flexed at 90 degrees with forearm perpendicular to the plinth, wrist in neutral and hand in prolongation with forearm, thumb directed 45 degrees towards the medial axis of the body.</li> <li>• MicroFET dynamometer is placed proximal to the ulnar styloid process, on the anterior surface of the arm.</li> <li>• Tester stabilises the elbow with non-dominant hand.</li> <li>• Participant performs shoulder external rotation to maximum effort with elbows remaining flexed.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013).</li> </ul>



*Figure 3.21 Shoulder external rotation muscular strength*

*Table 3.15 MicroFET examination of shoulder abduction muscular strength*

Muscular involvement	Methodology
<b>Shoulder Abduction</b>	
<ul style="list-style-type: none"> <li>• Teres major</li> <li>• Teres minor</li> <li>• Coracobrachialis</li> <li>• Subscapularis</li> <li>• Biceps brachii</li> <li>• Lateral deltoid</li> <li>• Supraspinatus</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulder positioned at 45 degrees flexion, arm in horizontal plane.</li> <li>• MicroFET dynamometer is placed proximal to the elbow on the anterior surface of the upper arm.</li> <li>• Participant performs shoulder flexion, in the horizontal plane, to maximum effort with elbows remaining extended (Meiring <i>et al.</i>, 1993; Borms &amp; van Roy, 2009).</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013; Kelln <i>et al.</i>, 2008).</li> </ul>



*Figure 3.22 Shoulder abduction muscular strength*

*Table 3.16 MicroFET examination of shoulder adduction muscular strength*

Muscular involvement	Methodology
<b>Shoulder Adduction</b>	
<ul style="list-style-type: none"> <li>• Pectoralis major</li> <li>• Latissimus dorsi</li> <li>• Deltoid</li> <li>• Supraspinatus</li> </ul>	<ul style="list-style-type: none"> <li>• Participant lies supine, knees flexed to 90 degrees, feet and lower back flat on the plinth.</li> <li>• Shoulder positioned at 90 degrees flexion and elbow flexed at 90 degrees.</li> <li>• MicroFET dynamometer is placed proximal to the radial styloid process, on the medial surface of the arm.</li> <li>• Tester stabilises the shoulder with non-dominant hand.</li> <li>• Participant performs shoulder adduction, in the horizontal plane, to maximum effort with elbows remaining flexed.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013; Kelln <i>et al.</i>, 2008).</li> </ul>



*Figure 3.23 Shoulder adduction muscular strength*

*Table 3.17 MicroFET examination of scapular elevation muscular strength*

Muscular involvement	Methodology
<b>Scapular Elevation</b>	
<ul style="list-style-type: none"> <li>• Levator scapulae</li> <li>• Trapezius superior fibres</li> <li>• Rhomboid major</li> <li>• Rhomboid minor</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed 90 degrees.</li> <li>• Shoulders remain in neutral, elbows flexed and relaxed next to the body.</li> <li>• MicroFET dynamometer is placed proximal to the glenohumeral joint.</li> <li>• Participant performs bilateral scapular elevation, to maximum effort with elbows remaining flexed.</li> <li>• Tester stabilises the elbow in order for the participant not to press against her body when performing test.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013).</li> </ul>



*Figure 3.24 Scapular elevation muscular strength*

*Table 3.18 MicroFET examination of scapular depression muscular strength*

Muscular involvement	Methodology
<b>Scapular Depression</b>	
<ul style="list-style-type: none"> <li>• Pectoralis minor</li> <li>• Trapezius (inferior fibres)</li> <li>• Subclavius</li> <li>• Latissimus dorsi</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed 90 degrees.</li> <li>• Shoulders remain in neutral, elbows flexed and relaxed and placed behind the body.</li> <li>• MicroFET dynamometer is placed proximal to the olecranon process.</li> <li>• Participant performs bilateral scapular depression, to maximum effort with elbow remaining flexed behind her back.</li> <li>• Tester stabilises the shoulder and ensures that her elbow does not press against her body when performing test.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Kolber &amp; Cleland, 2013).</li> </ul>



*Figure 3.25 Scapular depression muscular strength*

Table 3.19 MicroFET examination of scapular retraction muscular strength

Muscular involvement	Methodology
<b>Scapular Retraction</b>	
<ul style="list-style-type: none"> <li>• Rhomboid major</li> <li>• Rhomboid minor</li> <li>• Trapezius</li> <li>• Levator scapulae</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed 90 degrees.</li> <li>• Shoulders remain in neutral, elbows flexed and relaxed next to the body.</li> <li>• MicroFET dynamometer is placed proximal to the glenohumeral joint, on the posterior surface of the shoulder.</li> <li>• Participant performs bilateral scapular retraction, to maximum effort with elbows remaining flexed and relaxed.</li> <li>• Tester stabilises the shoulder and ensures that the elbow does not press against her body when performing test.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Merlini <i>et al.</i>, 2002; Kolber &amp; Cleland, 2013).</li> </ul>



Figure 3.26 Scapular retraction muscular strength

Table 3.20 MicroFET examination of scapular protraction muscular strength

Muscular involvement	Methodology
<b>Scapular Protraction</b>	
<ul style="list-style-type: none"> <li>• Serratus anterior</li> <li>• Pectoralis minor</li> </ul>	<ul style="list-style-type: none"> <li>• Participant sits, feet on the floor, hips and knees flexed 90 degrees.</li> <li>• Shoulders remain in neutral, elbows flexed and relaxed next to the body.</li> <li>• MicroFET dynamometer is placed on the glenohumeral joint, on the anterior surface of the shoulder.</li> <li>• Participant performs bilateral scapular protraction, to maximum effort with elbows remaining flexed and relaxed.</li> <li>• Tester stabilises the elbow in order for the participant not to press against her body when performing test.</li> <li>• Participant exerts maximal effort for 3 seconds, applying force against the MicroFET dynamometer (Merlini <i>et al.</i>, 2002; Kolber &amp; Cleland, 2013).</li> </ul>



Figure 3.27 Scapular protraction muscular strength



### 3.7 Statistical Analysis

The data collected was analysed and interpreted with the assistance of a statistician, Dr P. Meyer, Department of Immunology, Faculty of Health Sciences (ANNEXURE G). Data was analysed by using the STATA 13 software application. Quantitative data of the different variables are collected and subjected to descriptive and inferential statistics. Graphical representation of data was deemed informative and was included.

Descriptive statistics were reported as medians with inter-quartile ranges. Bivariate hypothesis testing between the EVAL and CON groups were calculated after categorisation of data as either parametric or non-parametric as determined by the skewness and kurtosis test for normality (D'Agostino & Belanger, 1990). The One-way ANOVA was performed using the Kruskal-Wallis test for non-parametric data for more than 2 groups or the Mann-Whitney test when 2 groups were compared. The Wilcoxon signed rank test was used to gauge differences within groups. Statistical significance was determined by P-value equal to or less than 0.05.



## CHAPTER 4

# RESULTS AND DISCUSSION

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To summarise the results, the aim of this study was to determine whether significant ( $p \leq 0.05$ ) differences existed in the upper-quarter postural measurement characteristics between female adolescent competitive freestyle swimmers and female adolescent non-swimmers.

The objectives of the study were to:

3. assess the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers and of female adolescent non-swimmers by measuring the cervical and shoulder range of motion measurements, static upper-quarter posture through photographic analysis, dynamic upper-quarter performance by means of the Y-balance test, and muscular strength of the shoulder and scapula by means of a MicroFET device; and
4. compare the upper-quarter postural measurement characteristics of female adolescent competitive freestyle swimmers to female adolescent non-swimmers by assessing the cervical and shoulder range of motion measurements, static upper-quarter posture through photographic analysis and dynamic upper-quarter performance by means of the Y-balance test, and muscular strength of the shoulder and scapula by means of a MicroFET device.

The results of the study are presented in tabular form (Tables 4.1 to 4.7). All results presenting significant difference are reported at the 95% level of confidence, unless otherwise specified, and are subsequently discussed within the context of the applicable literature.



## 4.1 Demographics

The initial study population that completed the pre-screening questionnaire (ANNEXURE K; ANNEXURE L), consisted of 116 (52 EVAL group; 64 CON group) female adolescent participants, aged 13-18 years. Of the 116 participants, 73 (37 EVAL group; 36 CON group) complied with the inclusion criteria, as stated in chapter 3. Furthermore, two of the 37 EVAL group participants withdrew from the study due to a sub-acute shoulder injury obtained during their normal training practice and their results were excluded from this study. The results of the final sample of 71 participants were used for statistical analysis. The EVAL group consisted of 35 female adolescent competitive freestyle swimmers (mean age =  $15 \pm 3$  yrs; mean height =  $166.5 \pm 9.9$  cm; mean body mass =  $65.5 \pm 7.7$  kg; mean BMI =  $23.6 \text{ kg/m}^2$ ) with a  $7.1 \pm 3$  years of swimming experience, engaging in  $5.5 \pm 1$  swimming training sessions per week and  $3.2 \pm 1$  callisthenic training sessions per week. The CON group consisted of 36 female adolescent non-swimmers (mean age =  $15 \pm 3$  years; mean height =  $164.2 \pm 6.7$  cm; mean body mass =  $62.1 \pm 9.1$  kg; mean BMI =  $23.0 \text{ kg/m}^2$ ). The EVAL and CON group were shown to be similar in age, height, mass and BMI. The similarities between the groups allowed for more reliable comparisons.

Table 4.1 represents the descriptive statistics, p50 (mean)  $\pm$  iqr (interquartile range), of the anthropometric measures of both the CON group (n = 35) and the EVAL group (n = 36).

*Table 4.1 Participant demographics*

<b>Demographics</b>	<b>CON group (n = 35) p50 <math>\pm</math> iqr</b>	<b>EVAL group (n = 36) p50 <math>\pm</math> iqr</b>
Age (yrs)	15 $\pm$ 3	15 $\pm$ 3
Height (cm)	164.2 $\pm$ 6.7	166.5 $\pm$ 9.9
Body mass (kg)	62.1 $\pm$ 9.1	65.5 $\pm$ 7.7
BMI ( $\text{kg/m}^2$ )	23.0	23.6

Data is presented as p50 (mean)  $\pm$  iqr (interquartile range); BMI = Body Mass Index; CON = Control group; EVAL = Evaluation group; yrs = years; cm = centimetres; kg = kilograms;  $\text{kg/m}^2$  = kilogram force per square meter



Studies investigating the physical characteristics of female adolescent competitive swimmers reported similar anthropometric measurements in height (average =  $167\pm 6.2$  cm), body mass (average =  $64\pm 4.7$  kg) and BMI (average =  $22\pm 2.3$  kg/m<sup>2</sup>) as those found in this study (Riemann *et al.*, 2011; Hibberd *et al.*, 2012; Tate *et al.*, 2012; Walker *et al.*, 2012).

To perform any movement while swimming, adequate arthrokinematics in a number of joints, proper muscular control and muscle length changes, are required (Matthews *et al.*, 2017). These factors, in combination with muscular strength, play a significant role in determining individual differences in flexibility and mobility, predisposition to postural deviations, and the distinction between normal and pathological movement (Lynch *et al.*, 2010; Matthews *et al.*, 2017).

To address the study objectives comprehensively, the descriptive and comparative statistics are reported and discussed under the following themes, 1) Shoulder and Cervical Range of Motion, 2) Static and Dynamic Upper-Quarter Posture and 3) Shoulder and Scapular Muscle Strength.

## 4.2 Shoulder and Cervical Range of Motion

When considering the freestyle stroke phases, the shoulder moves through a number of ranges. Laudner *et al.* (2015) and Letzelter & Freitag (1983) described the freestyle stroke in four different phases. During the hand entry phase the shoulder performs abduction, flexion, and internal rotation. The arm continues to the mid pull-through phase and performs shoulder adduction, internal rotation, and extension. Thereafter, the shoulder performs full extension, internal rotation and adduction during the late pull-through phase. Lastly, the recovery phase is initiated when the hand is above the water and the shoulder proceeds to follow a sequence of extending, abducting, horizontally adducting, and internally rotating as the scapula is retracting to accomplish recovery (Letzelter & Freitag, 1983; Laudner *et al.*, 2015). During the recovery phase, a swimmer also has to rotate their head to breathe (Letzelter & Freitag, 1983; Atalar *et al.*, 2009; Stirn *et al.*, 2011; Laudner *et al.*, 2015). The cervical and thoracic muscles are activated in unison to account for a 160-degree body rotation along its long axis and a slight flexion with external rotation of the head (Laudner *et al.*, 2015; Saladin, 2015). To help identify the differences in shoulder and cervical range of motion between female adolescent competitive freestyle swimmers and non-swimmers, the



present study measured general shoulder and cervical movements, characteristic of the freestyle swimming stroke.

Table 4.2 presents the descriptive statistics, p50 (mean) ± iqr (interquartile range), of the shoulder and cervical range of motion measurements of both the CON group and the EVAL group.

*Table 4.2 Descriptive statistics of the shoulder and cervical range of motion*

Variables	CON group (n = 35)		EVAL group (n = 36)	
	Left p50 ± iqr	Right p50 ± iqr	Left p50 ± iqr	Right p50 ± iqr
Shoulder abduction (deg)	148±5.5	148±5	180±4	182±5
Horizontal shoulder adduction (deg)	36±4.5	36±4	25±5	25±5
Shoulder flexion (deg)	182±5.5	182±5	157±4	157±5
Shoulder extension (deg)	46±6	46.5±6.5	36±4	37±4
Shoulder external rotation (deg)	96±5	97±5	109±4	109±5
Shoulder internal rotation (deg)	69±3.5	70±4	60±8	61±8
Cervical forward flexion (mm)	11.5±13.5		13±16	
Cervical extension (mm)	198±16		215±21	
Cervical lateral flexion (mm)	96±5	98±8.5	109±4	98±12
Cervical lateral rotation (mm)	154.5±6.5	97±5	146±7	109±5

Data is presented as p50 (mean) ± iqr (interquartile range); ROM = Range of motion; CON = Control group; EVAL = Evaluation group; deg = degrees; mm = millimetres

Many studies have examined the shoulder and cervical characteristics of athletes to determine undesirable upper-quarter posture (Pink & Tibone, 2000; Weldon & Richardson, 2001; Ruivo *et al.*, 2014); however, only a few have investigated the shoulder and cervical characteristics of an adolescent population group. Studies investigating the shoulder and cervical characteristics of adolescents have presented descriptive findings similar to those of the present study (Riemann *et al.*, 2011; Hibberd *et al.*, 2012; Walker *et al.*, 2012). Walker *et al.* (2012) investigated the shoulder range of motion of adolescent athletes performing overhead sports (namely tennis, swimming, baseball, softball and volleyball) to determine forward head with rounded shoulder posture. The study reported mean results - for horizontal



shoulder adduction ( $23.4 \pm 7$  deg), shoulder internal rotation ( $59 \pm 3$  deg), shoulder external rotation ( $106 \pm 7.2$  deg), shoulder flexion ( $159 \pm 3.2$  deg) and shoulder extension ( $38 \pm 3$  deg) - similar to those achieved by the EVAL group of this study (Walker *et al.*, 2012). Similarly, the mean results for shoulder external rotation ( $88.4 \pm 7.3$  deg) and shoulder internal rotation ( $44.7 \pm 7.6$  deg) reported by Riemann *et al.* (2011) for female competitive swimmers (mean age =  $15.8 \pm 0.8$  yrs) were similar to those of the EVAL group. Riemann *et al.* (2011) investigated the glenohumeral joint range of motion of competitive swimmers to determine significant differences by sex, age group, and shoulder dominance.

Hibberd *et al.* (2012) assessed the upper-quarter structures of adolescent swimmers and non-overhead adolescent athletes, to determine the effect of swim training over a 6-week intervention period. Hibberd *et al.* (2012) reported findings for - shoulder abduction (Swimmers =  $181 \pm 7.2$  deg; Non-overhead athletes =  $161 \pm 4.4$ ), horizontal shoulder adduction (Swimmers =  $18.9 \pm 4.7$  deg; Non-overhead athletes =  $24.3 \pm 4.4$ ) shoulder internal rotation (Swimmers =  $59.5 \pm 9.2$  deg; Non-overhead athletes =  $70 \pm 4.2$  deg) and shoulder external rotation (Swimmers =  $108.06 \pm 12.3$  deg.; Non-overhead athletes =  $103.5 \pm 7.3$  deg,) - similar to those presented by both groups of this study.

When performing the freestyle stroke, cervical rotation accounts for 55% of movement provided by the atlanto-axial joint (C1-C2), 5% by the occiput-atlas joint (C0-C1) and the remaining 40% is spread between C2-C6 (Hibberd *et al.*, 2012; Tate *et al.*, 2012). A study by Guth (1995) compared the range of active physiological cervical rotation between 14-17 year old swimmers and non-swimmers. The study investigated the muscular involvement and cervical rotation range of motion when performing the freestyle stroke (Guth, 1995). The demographics of the sample group are closely related to the EVAL group, reporting a mean value of height =  $168 \pm 3$  cm and body mass =  $67 \pm 2$  kg. Furthermore, Guth (1995) reported that the swimmers demonstrated a greater mean cervical rotation when compared to non-swimmers ( $168 \pm 7$  mm &  $147 \pm 1$  mm, respectively). These findings are similar to the results of the EVAL and CON groups reported by this study. Commonly seen in freestyle swimming is the over-rotation of the neck when breathing (Lynch *et al.*, 2010; Hibberd *et al.*, 2012). This loads the cervical spine ligaments and muscles, which encourages asymmetrical development of the cervical spine (Guth, 1995; Hibberd *et al.*, 2012).



The comparative statistics of the cervical and shoulder range of motion measurements between female adolescent competitive freestyle swimmers and female adolescent non-swimmers are represented in Table 4.3.

*Table 4.3 Differences in the cervical and shoulder range of motion measures between groups*

Variables	Comparative Statistics		Significant difference		Comparisons
	Left (z score)	Right (z score)	Left (p≤0.05)	Right (p≤0.05)	
Shoulder abduction (deg)	7.25	7.25	0.00**	0.00**	CON < EVAL
Horizontal shoulder adduction (deg)	6.79	6.87	0.00**	0.00**	CON > EVAL
Shoulder flexion (deg)	7.24	7.23	0.00**	0.00**	CON > EVAL
Shoulder extension (deg)	6.04	6.97	0.00**	0.00**	CON > EVAL
Shoulder external rotation (deg)	6.97	7.04	0.00**	0.00**	CON < EVAL
Shoulder internal rotation (deg)	6.68	6.69	0.00**	0.00**	CON > EVAL
Cervical forward flexion (deg)	2.11		0.04*		CON > EVAL
Cervical extension (deg)	4.48		0.00**		CON < EVAL
Cervical lateral flexion (deg)	0.74	0.65	0.46	0.52	CON < EVAL
Cervical lateral rotation (deg)	5.29	5.93	0.00**	0.00**	CON < EVAL

Data is presented as comparative statistics between CON and EVAL groups (z-score) and p≤0.05; ROM = Range of motion; CON = Control group; EVAL = Evaluation group; deg = degrees

\* p≤0.05; \*\* p≤0.01

Significant differences (p=0.00) between the EVAL and CON group for all the measured range of motion variables, except for cervical lateral flexion, were noted. The EVAL group achieved lower mean scores for horizontal shoulder adduction (right & left = 11 deg), shoulder flexion (right & left = 25 deg), shoulder extension (right = 9.5 deg & left = 10 deg), shoulder internal rotation (right & left = 9 deg) and cervical forward flexion (1.5 deg), when compared to the mean scores of the CON group.



Interestingly, when comparing the results found by both groups to the published normative values, the EVAL group had mean scores below the normative values for horizontal shoulder adduction (right & left = 10 deg), shoulder flexion (right & left = 23 deg), shoulder extension (right = 8 deg & left = 9 deg) and shoulder internal rotation (right = 8 deg & left = 9 deg). The published normative values for a general adolescent female population are as follows: horizontal shoulder adduction = 35 deg; shoulder flexion = 180 deg; shoulder extension = 45 deg; and shoulder internal rotation = 69 deg (Kendall *et al.*, 1983; Beach *et al.*, 1992; Borms & van Roy, 2009).

Athletes competing in overhead sports have often been reported to demonstrate a minimum of 15 degrees increase in shoulder external rotation and shoulder abduction range of motion (Richardson *et al.*, 1980; Greipp, 1985; McMaster, 1999; Johnson, 1987; Chansirinukor *et al.*, 2001) when compared to published standards (Kendall *et al.*, 1993; Borms & van Roy, 2009). Similar to the reported literature, the mean score achieved by the EVAL group for shoulder external rotation was 5 degrees above the normative range of 104 degrees (Kendall *et al.*, 1983; Borms & van Roy, 2009). Literature reported that athletes in the high external rotation range of motion category (i.e. greater than 100 degrees) are 8.1 times more likely to develop an increased anterior capsule laxity that causes a rounded shoulder posture (Hung *et al.*, 2010; Hibberd *et al.*, 2012). The mean score for shoulder abduction of the EVAL group, however, was within the normative range of 180 degrees. When considering the CON group's shoulder abduction and shoulder external rotation mean scores, both mean scores were below the normative ranges (i.e. 180 deg & 104 deg, respectively) (Kendall *et al.*, 1983; Borms & van Roy, 2009).

A number of studies have measured shoulder mobility by means of isokinetic testing on the Cybex II dynamometer and reported that swimmers may present with a 10 degree greater external shoulder rotation mobility and 40 degrees lesser internal shoulder rotation mobility compared to the general population (Pink & Tibone, 2000; Virag *et al.*, 2014; Laudner *et al.*, 2015). Laudner *et al.* (2015) stated that the shoulder mobility differences between swimmers and the general population might be due to the repetitive nature of the freestyle stroke causing the shoulder complex to be more lax. The EVAL group's mean value for shoulder internal rotation was 9 degrees lower than the CON group and 9 degrees below the normative value. Interestingly, Borsa *et al.* (2008) reported that athletes participating in



overhead activities with posterior shoulder immobility (shoulder internal rotation  $\leq 69$  deg), may present with horizontal shoulder adduction below the normal ranges. This is in accordance with the findings of this study. The EVAL group scored a mean horizontal shoulder adduction value of 9 degrees lower than CON group and 10 degrees below the normative value.

A decrease in internal shoulder rotation may be related to the narrowing of the subacromial space and has been linked to shoulder impingement (Morrissey *et al.*, 2008; Weon *et al.*, 2010; Walker *et al.*, 2012; Virag *et al.*, 2014). Hibberd *et al.* (2012) reported that subacromial space distance, forward head posture, forward shoulder posture, and pectoralis major/minor length are characteristics that have been theorized to change due to anterior shoulder musculature tightness and posterior shoulder muscle weakness. While examining the effects of a 6-week training period on upper-quarter characteristics of swimmers, Hibberd *et al.* (2012) noted that competitive swimmers presented with a 4.1% increased postural tightness and 3.7% lesser internal shoulder rotation when compared with the general population. Hung *et al.* (2010) reported that stiffness of the posterior shoulder musculature (namely, teres minor, infraspinatus, and posterior deltoid) played a significant role in restricting internal shoulder rotation in swimmers. Additionally, studies conducted by Greenfield *et al.* (1985), Beach *et al.* (1992), and Walker *et al.* (2012) all stated that limited shoulder internal rotation may be a result of reactive fibrosis of shoulder capsular tissue because of repetitive microtrauma and the overactive infraspinatus and teres minor muscles causing a glenohumeral internal rotation deficit (GIRD).

Hibberd *et al.* (2012) reported that the muscular over- and underactivity that occur with swimming may be due to the repetitive nature of the freestyle stroke and can be observed when assessing shoulder and cervical range of motion. A study conducted by Walker *et al.* (2012), supported the notion that the overactive upper-trapezius, levator scapula and pectoralis muscles as well as the inhibition of serratus anterior, lower and middle trapezius and rhomboid muscles causes excessive anterior orientation of the glenohumeral joint relative to the vertical plumb line of the body (Walker *et al.*, 2012). Additionally, Walker *et al.* (2012) and Virag *et al.* (2014) reported that the posterior capsular tightness - loss of shoulder internal rotation - leads to more superior and anterior translation of the



humeral head, contributing towards the forward shoulder posture noticed in freestyle swimmers.

Harryman *et al.* (1990) and Laudner *et al.* (2015) reported that when performing the freestyle stroke, shoulder flexion was associated with the hand entry and early pull-through phases. Shoulder extension was associated with the mid- and late pull-through as well as the recovery phases (Harryman *et al.*, 1990; Laudner *et al.*, 2015). The CON group scored significantly greater ( $p=0.00$ ) mean values for shoulder flexion and extension measures, when compared to the EVAL group. Additionally, the mean shoulder flexion and –extension values reported for the EVAL group were below the normative values (180 deg & 45 deg, respectively). Studies have reported that a deficit of shoulder flexion and extension below the suggested normative value may contribute to upper-quarter postural changes and shoulder injury (Harryman *et al.*, 1990; Borsa *et al.*, 2008; Virag *et al.*, 2014; Laudner *et al.*, 2015).

Therefore, when considering the lesser shoulder internal rotation, - horizontal adduction, -flexion, and -extension measures demonstrated by the female adolescent freestyle swimmers - compared with the non-swimmers and normative values, it is likely that the female adolescent freestyle swimmers have increased tightness in their posterior shoulder capsules and a greater probability of attaining a forward shoulder posture. Posterior capsule tightness and excessive anterior orientation of the glenohumeral joint are intrinsic risk factors that predispose swimmers to injury (Meeuwisse *et al.*, 2007).

When referring to the cervical range of motion measures attained, the EVAL group achieved lesser cervical forward flexion of  $13\pm 16$  mm and a greater cervical extension of  $21.5\pm 21$  mm in comparison to the CON group. Literature suggests that high training volumes, stroke mechanics, equipment use and recovery may predispose swimmers to the development of hyperextension at the atlanto-occipital articulation and a flattening of the midcervical spine lordosis (Meeuwisse *et al.*, 2007; Walker *et al.*, 2012). This may possibly explain the lesser cervical forward flexion and a greater cervical extension in the EVAL group.

Interestingly, the EVAL group showed a greater mean range of motion for cervical lateral flexion ( $11\pm 8$  mm) and cervical lateral rotation ( $37\pm 2$  mm) to the left when compared with the right. The CON group, however, were less one-side dominant and demonstrated a greater cervical lateral flexion range of motion ( $2\pm 3.5$  mm) to the right and greater cervical lateral



rotation range of motion ( $57\pm 1.5$  mm) to the left. Since this study did not record the swimmers preferred breathing side, it may be assumed that the greater one-sided rotation and lateral flexion ranges demonstrated by the EVAL group were because of the unilateral cervical rotation performed to breathe during the recovery phase of the freestyle stroke. Guth (1995) reported that the swimmers demonstrated a 12.5% greater mean cervical rotation when compared with non-swimmers. The findings reported by Guth (1995) are similar to the measures attained by the EVAL and CON groups, respectively. These results concluded that the swimmers demonstrated a significantly greater range of cervical rotation ( $p=0.002$ ) and lateral flexion ( $p=0.0002$ ) to their preferred breathing side, and a significantly lesser mean cervical rotation range of motion to their non-preferred breathing side when compared with non-swimmers (Guth, 1995).

Consequently, when considering the greater cervical extension, -rotation and -lateral flexion ranges and the lesser cervical forward flexion attained by the EVAL group when compared to the CON group, the female adolescent freestyle swimmers seem to have a greater predisposition for a forward head posture. The results also highlight that the swimmers may be presenting with another intrinsic risk factor of hyperextension at the atlanto-occipital articulations, predisposing them to injury (Meeuwisse *et al.*, 2007).

### 4.3 Static and Dynamic Upper-Quarter Posture

Postural control can be defined dynamically as the ability to perform a task while maintaining a stable position, and statically as the ability to maintain a base of support with minimal movement (Butler *et al.*, 2014; Chimera *et al.*, 2015). The Y-balance test of the upper-quarter requires the swimmer to balance on one hand whilst simultaneously reaching as far as possible with the other hand in three separate directions: medial, inferolateral, and superolateral reach (Butler *et al.*, 2014; Chimera *et al.*, 2015).

Static upper-quarter posture can be assessed using a number of different methods (Yip *et al.*, 2008; Brink *et al.*, 2009; Straker *et al.*, 2009; Diab & Moustafa, 2012). Photographic analysis is considered the most reliable and most frequently used in studies to detect intrinsic risk factors (Brink *et al.*, 2009; Straker *et al.*, 2009; Silva *et al.*, 2010; Diab & Moustafa, 2012). The Y-balance test was used to help identify the differences in dynamic upper-quarter



stability between female adolescent competitive freestyle swimmers and non-swimmers. Additionally, to identify the differences in static upper-quarter postural characteristics between both groups, the present study used photographic analysis for these measures.

Table 4.4 depicts the descriptive statistics in p50 and iqr values for left and right dynamic upper-quarter performance by means of the Y-balance test and static upper-quarter posture through photographic analysis of the female adolescent freestyle swimmers and non-swimmers.

*Table 4.4 Descriptive statistics for Y-Balance test and for static upper-quarter posture*

Variables	CON group (n = 35)		EVAL group (n = 36)	
	Left p50 ± iqr	Right p50 ± iqr	Left p50 ± iqr	Right p50 ± iqr
YBT-UQ Absolute value (cm)	54.4±7.9	55.2±7.8	64.8±4.6	64.7±2.4
Head tilt angle (deg)	19.1±10.9		10.4±6.4	
Cervical angle (deg)	46.8±13.5		33.5±18	
Shoulder protraction and retraction angle (deg)	59±9.6		35±13.9	
Thoracic angle (deg)	58.8±9.1		66.2±13.1	

Data is presented as p50 (mean) ± iqr (interquartile range); YBT-UQ = Y-balance test of the upper-quarter; CON = Control group; EVAL = Evaluation group

A study by Butler *et al.* (2014) investigated the sex differences in dynamic closed kinetic chain upper-quarter function in collegiate swimmers. Butler *et al.* (2014) stated that the upper-quarter Y-balance test was developed to provide a fundamental assessment of dynamic upper-quarter (shoulder) ability at the limit of core stability. Butler *et al.* (2014) used the same protocol as described in chapter 3 and tested 54 competitive female (mean age = 19.1±0.7 yrs) swimmers. Even though Butler *et al.* (2014) tested a subject group slightly older than the current study it is worth mentioning that the height (166±0.5 mm & 166.5±9.9 mm, respectively), body mass (64.8±5.3 kg & 65.5±7.7 kg, respectively), and limb length (84±5.3 mm & 83.3±4.3 mm, respectively) showed similar values between the aforementioned study population and the participant demographics stated in Table 4.1. Furthermore, Butler *et al.* (2014) reported that the female swimmers had a mean medial absolute value of right = 67.2±8.4 cm and left = 65.4±2.5 cm which corresponds with the



mean absolute value of the EVAL group of this study. Literature on dynamic upper-quarter posture measures such as the Y-balance test is limited (Butler *et al.*, 2014). To the researcher's knowledge, no other authors have examined female adolescent freestyle swimmers. Therefore, this study cannot directly compare the descriptive results with other studies of upper-quarter functional tests.

The present study analysed the static upper-quarter posture to evaluate upper-quarter postural characteristics through four angles of measurement, namely the head tilt angle, the cervical angle, the shoulder protraction and retraction angle, and the thoracic angle. These angles of analyses are reliable and commonly cited in the literature to assess upper-quarter postural characteristics, enabling the comparison of results (Ruivo *et al.*, 2014). Meeuwisse *et al.* (2007), Brink *et al.* (2009), Straker *et al.* (2009), and Virag *et al.* (2014) propose that upper-quarter postural evaluation may predict possible intrinsic risk factors for the development of poor posture. The development of upper-quarter postural malalignments may cause forward head with rounded shoulders and midthoracic spine kyphosis, which are observed in competitive swimmers.

To the researcher's knowledge, minimal research has assessed upper-quarter postural characteristics using photographic analysis on female adolescent freestyle swimmers specifically. Studies conducted on swimmers and adolescents, however, have reported similar mean values for the postural angles measured in this study. A study conducted by Jones (2013) examined the effect of a stretching programme on the static cervical- and shoulder protraction-retraction angle in competitive female swimmers (age =  $19 \pm 1.2$ ; mass =  $72.1 \pm 7.0$ ; height =  $178.7 \pm 7.7$ ). Prior to the intervention, the head tilt angle ( $12 \pm 4.1$  deg); cervical angle ( $39 \pm 1.1$  deg) and shoulder protraction-retraction angle ( $35.6 \pm 8.9$  deg) reported by Jones (2013) were relatively similar to the mean values attained by the EVAL group of this study.

Similarly, a study by Van Niekerk *et al.* (2008) who investigated the upper-body sitting posture of high school students, through photographic measurement, reported cervical angle ( $35 \pm 1.5$  deg) and thoracic angle ( $62.8 \pm 5.4$  deg) mean scores - for the students participating in overhead-sports - similar to the mean values attained by the EVAL group. A study conducted by Ruivo *et al.* (2014), assessing 275 adolescents (age =  $15 \pm 2$  yrs; mass =  $68 \pm 5.1$  kg; height =  $171 \pm 5$  cm), reported a mean head tilt angle ( $17.2 \pm 3$  deg) that was closer to the mean head-



tilt value attained by the CON group of this study. The mean head-tilt angle of the EVAL group was smaller. Interestingly, however, the mean thoracic angle ( $68 \pm 2.4$  deg) reported by Ruivo *et al.* (2014) was closer to the mean thoracic angle attained by the EVAL group. The mean thoracic angle of the CON group was smaller. The literature states that a smaller head tilt angle and a greater thoracic angle increase the probability of developing upper-quarter malalignments, shoulder immobility and pain (Van Niekerk *et al.*, 2008; Brink *et al.*, 2009; Ruivo *et al.*, 2014). This may be of concern for the EVAL group as they present with these postural characteristics.

The comparative statistics of the Y-Balance test absolute score and the static upper-quarter postural measurements between female adolescent competitive freestyle swimmers and female adolescent non-swimmers are represented in Table 4.5.

*Table 4.5 Differences in the Y-Balance test score and the static upper-quarter posture measures between groups*

Variables	Comparative statistics		Significant Difference		Comparisons
	Left (z score)	Right (z score)	Left ( $p \leq 0.05$ )	Right ( $p \leq 0.05$ )	
YBT-UQ Absolute value (cm)	6.63	6.71	0.00**	0.00**	CON < EVAL
Head tilt angle (deg)	5.56		0.00**		CON < EVAL
Cervical angle (deg)	4.74		0.00**		CON > EVAL
Shoulder protraction and retraction angle (deg)	6.03		0.00**		CON > EVAL
Thoracic angle (deg)	3.93		0.00**		CON < EVAL

Data is presented as comparative statistics between CON and EVAL groups (z-score) and  $p \leq 0.05$ ; YBT-UQ = Y-balance test of the upper-quarter; CON = Control group; EVAL = Evaluation group; cm = centimetres; deg = degrees

\*  $p \leq 0.05$ ; \*\*  $p \leq 0.01$

There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group achieving a greater mean absolute value for the Y-balance test than the CON group (right = 9.5 cm & left = 10.4 cm difference). Salo & Riewald (2008), Westrick *et*



*al.* (2012) and Butler *et al.* (2014) reported that a mean absolute reach value of  $\leq 47$ cm is associated with having a poor upper-quarter performance. Even though the reported normative value ( $\leq 47$ cm) for upper-quarter performance is not for female adolescent freestyle swimmers specifically, it may be worth mentioning that the mean absolute value that the EVAL and CON groups attained were above the reported mean absolute reach value (right = 17.7 cm & left = 17.8 cm; right = 8.2 cm & left = 7.4 cm above, respectively). This finding revealed that both groups had good upper-quarter dynamic stability. Studies have suggested that performances on core stability tests (push-ups and lateral trunk endurance tests) are highly correlated with performance on the Y-balance test (Gorman *et al.*, 2012; Taylor *et al.*, 2015). Taylor *et al.* (2015) explained that upper-quarter strength and muscular stabilising endurance has a direct link with maintaining unilateral performance as seen in swimming. This may provide a rationale for the mean absolute value differences in performance between the EVAL and CON groups. However, since the EVAL group achieved a significantly greater mean absolute reach value than the CON group, it may be concluded that the female adolescent freestyle swimmers had a better unilateral performance of the upper-quarter whilst maintaining stability (Gorman *et al.*, 2012; Taylor *et al.*, 2015).

Forward head posture is the protrusion of the head in the sagittal plane so that the head is placed anterior to the trunk (Lynch *et al.*, 2010; Batalha *et al.*, 2012; Virag *et al.*, 2014). It occurs because of the anterior translation of the head, lower cervical flexion or both, and is claimed to be associated with an increase in upper cervical extension (Batalha *et al.*, 2012; Virag *et al.*, 2014). It is associated with the shortening of the upper trapezius, the posterior cervical extensor muscles, the sternocleidomastoid and the levator scapulae (Virag *et al.*, 2014). Forward head posture is assessed through measuring the head-tilt angle and in turn measures the alignment of the upper cervical spine (Brink *et al.*, 2009; Straker *et al.*, 2009).

There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group having a smaller head-tilt angle than the CON group (8.7 deg difference). Chansirinukor *et al.* (2001) reported that the normal posture head-tilt angle should be 16.3 degrees. However, Ruivo *et al.* (2014) – when assessing cervical and shoulder posture of adolescents between 15 and 17 years old (height =  $169 \pm 5$  cm; body mass =  $67 \pm 1$  kg) – reported that a head-tilt angle of  $\leq 15$  degrees from the horizontal line is associated with



undesirable upper-quarter postural characteristics and neck pain. The mean head-tilt angle of the EVAL group is below the reported normative value (4.6 deg below). This result is similar to the findings in the literature (De Wall *et al.*, 1996; Chansirinukor *et al.*, 2001; Ruivo *et al.*, 2014).

De Wall *et al.* (1996) investigated the head-tilt angle of 32 competitive swimmers (23 female, mean age = 14 – 18 yrs; mean height = 164±7 cm; mean body mass = 62±6 kg) and reported that the competitive swimmers had a significantly ( $p=0.003$ ) lesser mean head-tilt angle (10.9 deg difference) when compared to the normative value of 15.7 degrees. Chansirinukor *et al.* (2001) assessed the effect of external loads (i.e. swimming with a kicking board) on the upper-quarter posture in active students (25 females, mean age = 13 – 16 yrs; mean height = 158±6 cm; mean body mass = 58±7 kg). Chansirinukor *et al.* (2001) reported that the active students had significantly lower head-tilt angles ( $p=0.0004$ ) when compared to the normative value (16.3 deg). Furthermore, Chansirinukor *et al.* (2001) stated that continued exposure to external loads may increase the risk of forward head tilt by 76%.

When comparing the mean head-tilt angles attained by the CON and EVAL group to each other and to the normative values, it is suggestive that the EVAL group are subject to a forward head posture. Similar to the reported cervical range of motion findings, the EVAL group may be presenting with the intrinsic risk factor of hyperextension at the atlanto-occipital articulation (Meeuwisse *et al.*, 2007).

The cervical angle is the angle formed at the intersection of the horizontal line through the spinous process of C7 and the line to the tragus of the ear (Brink *et al.*, 2009; Straker *et al.*, 2009).

There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group having a smaller cervical angle than the CON group (13.3 deg lower). Diab & Moustafa (2012) and Ruivo *et al.* (2014) suggested that a smaller cervical angle may be indicative of a forward head posture. Moreover, the literature stated that if the angle is less than 50 degrees, an individual is considered to have a forward head posture (Van Niekerk *et al.*, 2008; Diab & Moustafa, 2012; Ruivo *et al.*, 2014). The selection of 50 degrees as a reference angle was guided by the studies of Yip *et al.* (2008) and Diab & Moustafa (2012).



The CON and EVAL groups' mean cervical angles were below the reported normative value (3.2 deg & 16.5 deg below, respectively). Interestingly, Van Niekerk *et al.* (2008) reported that a cervical angle less than 36 degrees may lead to greater upper-postural deficiencies and pain. Similarly, Brink *et al.* (2009) stated that a cervical angle smaller than 39.2 degrees was considered to contribute towards pain in the upper quarter.

Although the mean cervical angle attained by the CON group was below the reported normative value of 50 degrees, it was above the reported unfavourable range of 39.2 – 36 degrees. The mean cervical angle of the EVAL group, however, was below the unfavourable range of 39.2 – 36 degrees by approximately 5.7 - 3.5 degrees. These findings support the notion that the EVAL group are at a greater risk of a forward head posture as well as experiencing pain in the upper quarter.

Protracted shoulders are a forward displacement of the acromion with reference to the C7 spinous process (Batalha *et al.*, 2012; Virag *et al.*, 2014). Protracted shoulders are frequently associated with a protracted, anteriorly tilted and internally rotated scapula and with a tightness of the pectoralis minor muscle (Batalha *et al.*, 2012; Virag *et al.*, 2014). The shoulder protraction and retraction angle provides a measurement of the shoulder position and is formed at the intersection of the line drawn between the midpoint of the humerus and spinous process of C7 and the horizontal line through the midpoint of the humerus (Brink *et al.*, 2009; Ruivo *et al.*, 2014).

There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group having a smaller protraction and retraction angle than the CON group (24 deg smaller). The literature stated that a rounded shoulder posture in adolescents was associated with a smaller protraction and retraction angle compared with the reported normative value (Van Niekerk *et al.*, 2008; Brink *et al.*, 2009; Ruivo *et al.*, 2014). Van Niekerk *et al.* (2008) reported that a protraction and retraction angle less than 50 degrees is associated with protracted shoulders and shoulder pain.

Correspondingly, Brink *et al.* (2009), and Ruivo *et al.* (2014) reported that adolescents with a head-tilt angle less than 15 degrees paired with a protraction and retraction angle less than 47 degrees were categorised as having a forward head - rounded shoulder



posture. The CON group's mean protraction and retraction angle was above the reported normative value (9 deg above). However, the EVAL group's mean protraction and retraction angle was below the reported normative value (15 deg below). When considering the smaller protraction and retraction angle and the head-tilt angle attained by the EVAL group, the female adolescent freestyle swimmers seem to be more susceptible to attaining the forward head - rounded shoulder posture.

These findings suggest that the female adolescent freestyle swimmers may possibly be presenting with the intrinsic risk factors of excessive anterior orientation of the glenohumeral joint relative to the vertical plumb line of the body, as well as excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa (Meeuwisse *et al.*, 2007). These upper-quarter postural deviations may lead to posterior capsular tightness, predisposing them to injury (Meeuwisse *et al.*, 2007).

The thoracic angle is known as the angle between the line drawn from the C7 spinous process to the midpoint of the superior border of the manubrium and the line drawn from the T8 spinous process to the midpoint of the superior border of the manubrium (Brink *et al.*, 2009; Straker *et al.*, 2009).

There was a significant difference ( $p=0.00$ ) between the EVAL and the CON groups, with the EVAL group having a greater thoracic angle than the CON group (7.4 deg greater). The literature has reported that a midthoracic spine kyphosis in adolescents is associated with an excessive curvature of the T1 – T12 greater than 45 degrees because of hyperflexion of the thoracic spine (Hibberd *et al.*, 2012; Walker *et al.*, 2012). Hyperflexion of the thoracic spine is caused by overactive rectus abdominis and pectoralis major and minor muscles as well as underactive mid and lower trapezius, longissimus thoracis, iliocostalis thoracis, spinalis thoracis, semispinalis thoracis and rotatores thoracis muscles (Hibberd *et al.*, 2012; Walker *et al.*, 2012).

The CON and EVAL groups' mean thoracic angles were both above the reported normative value (13.8 deg & 21.2 deg above, respectively). Interestingly, Szczygiel *et al.* (2015) reported that a thoracic angle greater than 56 degrees may be classified as kyphosis. Although there is a significant difference between the CON and EVAL groups' thoracic



angle, both groups attained mean thoracic angle values above the normative values reported by Hibberd *et al.* (2012), Walker *et al.* (2012) and Szczygiel *et al.* (2015). Wojtys *et al.* (2000) recruited 2270 adolescents (mean age = 13 – 18 yrs) participating in various overhead sports to assess the influence of sport participation on the thoracic and lumbar angles. Wojtys *et al.* (2000) reported a significant correlation between the number of training hours and the degree of thoracic curvature. Of all the sports groups assessed, Wojtys *et al.* (2000) found that the swimmers demonstrated the highest thoracic angle value ( $64.8 \pm 9.1$  degrees) - corresponding closely to the mean thoracic angle value attained by the EVAL group of this study. Interestingly, unlike the findings in this study, the CON group (non-athletic) in the study by Wojtys *et al.* (2000) yielded a mean thoracic angle below the normative value of 56 degrees reported by Szczygiel *et al.* (2015) ( $48.5 \pm 7.2$  degrees).

Additionally, Ruivo *et al.* (2014) found significant correlations between forward head posture and thoracic kyphosis, leading to upper-quarter pain. Ruivo *et al.* (2014) reported that a head-tilt angle of  $\leq 15$  degrees and a thoracic angle of  $\geq 50$  degrees increases the probability of developing upper-quarter malalignments by 83%.

When referring to the EVAL group's mean thoracic angle, the female adolescent freestyle swimmers seem to demonstrate a midthoracic kyphotic posture. This result highlights another intrinsic risk factor mentioned by Meeuwisse *et al.* (2007). Meeuwisse *et al.* (2007) stated that an increased midthoracic spine kyphosis is one of the intrinsic risk factors that may occur from repeated participation in freestyle swimming. It is also important to acknowledge that the CON group's mean thoracic angle was above the normative value. Ruivo *et al.* (2014) and Uritani *et al.* (2014) may explain potential reasons for this finding. These authors stated that the general student population are predisposed to external loads that may contribute to undesirable upper-quarter postural changes (Ruivo *et al.*, 2014; Uritani *et al.*, 2014). The external loads referred to are the sitting posture during laptop or computer use, studying hours, backpack carrying, and slouched posture while walking (Ruivo *et al.*, 2014; Uritani *et al.*, 2014).

Ideal posture is determined by the alignment of significant anatomical landmarks and is associated with proper skeletal alignment that allows muscles, joints, ligaments, nerves and internal organs to function in unison (Kendall *et al.*, 1983; Griegel-Morris *et al.*, 1992). Forward head with rounded shoulder posture is a common deviation from ideal posture and is



distinguished by an increased thoracic kyphosis, decreased cervical lordosis, protracted scapulae and an internally/anteriorly rotated humeral head (Griegel-Morris *et al.*, 1992; Tovin, 2006). These are all postural characteristics that are, thus far, evident in the EVAL group of this study. Forward head with rounded shoulder posture is often accompanied by soft tissue findings that indicate restricted and tight anterior shoulder musculature (Kendall *et al.*, 1983; Tovin, 2006). Furthermore, literature states that lengthened and weakened medial scapular stabilizers may cause forward head with rounded shoulder posture, posterior capsular tightness of the glenohumeral joint and weak anterior cervical flexors (Kendall *et al.*, 1983; McMaster, 1999; Kibler & Mc Mullen, 2003; Tovin, 2006; Hung *et al.*, 2010).

Deviations from the described ‘normal postural alignment’ suggest that abnormal strain on the musculoskeletal system may contribute to upper-quarter musculoskeletal dysfunction (Peterson *et al.*, 1997). These upper-quarter musculoskeletal dysfunctions include abnormal scapulohumeral rhythm, impingement of the rotator cuff tendons, acromioclavicular joint degeneration, bicipital tendinitis and painful trigger point areas (Griegel-Morris *et al.*, 1992; Peterson *et al.*, 1997). Postural deviations from the ideal posture seem to be evident in female adolescent competitive freestyle swimmers. The nature of the freestyle stroke mechanics and the swimmers’ training volume and load may be factors contributing towards these deviations.

Since the results thus far have suggested that the EVAL group deviates more from the ideal normative values (compared with the CON group), the associated musculoskeletal changes, pain and injuries reported in the literature should not be ignored by coaches and sport scientists.

#### **4.4 Shoulder and Scapula Muscle Strength**

Magel & Mc Ardle (1970) stated that the propelling force in swimming depends on muscular strength, effective stroke mechanics and swimming posture. Swimming speed relies on buoyancy, hydrodynamics of correct stroke technique, and antagonistic muscular control (Magel & Mc Ardle, 1970). To help identify the differences in shoulder and scapular strength between female adolescent competitive freestyle swimmers and non-swimmers, the present study assessed the shoulder and scapula muscles involved in the freestyle swimming stroke.



Table 4.6 depicts the descriptive statistics in p50 and iqr values for left and right shoulder and scapular muscular strength by means of a manual muscular strength tester – MicroFET - of the female adolescent freestyle swimmers and non-swimmers.

*Table 4.6 Descriptive statistics of shoulder and scapular muscular strength*

Variables	CON group (n = 35)		EVAL group (n = 36)	
	Left p50 ± iqr	Right p50 ± iqr	Left p50 ± iqr	Right p50 ± iqr
Shoulder flexion (kgf)	99±10.15	99.4±10.15	128.2±2.5	128.6±2.4
Shoulder extension (kgf)	104.9±11.8	106±13.2	101.5±10.1	101.5±10.3
Shoulder external rotation (kgf)	69.3±9.5	70.35±8	106.8±4.8	107±4.7
Shoulder internal rotation (kgf)	95.9±19.9	98.6±20.2	133.2±6.8	133.7±6.6
Shoulder abduction (kgf)	90.8±16.5	93.9±17.4	115.6±7.7	115.6±5.7
Shoulder adduction (kgf)	106.5±8.9	106.7±7.9	129.5±2.9	130±3.2
Scapular elevation (kgf)	162.1±10.8	164.8±9.7	175.8±6.2	176.2±6.4
Scapular depression (kgf)	137.3±12.9	138.2±11.9	152±5.4	152.1±5
Scapular retraction (kgf)	100.5±6.1	101.2±6	76.2±6.4	78±6
Scapular protraction (kgf)	76.3±5.8	77±6.2	101.5±6	101.5±6.2

Data is presented as p50 (mean) ± iqr (interquartile range); CON = Control group; EVAL = Evaluation group; kgf = kilogram force

Muscular strength is measured in kilogram force (kgf) and defined as the amount of force a muscle can produce with a single maximal effort during muscular contraction (Merlini *et al.*, 2002; Kelln *et al.*, 2008). Studies have reported that muscular strength imbalances of the upper-quarter may be a leading cause of shoulder injury – also known as swimmers’ shoulder (Kluemper *et al.*, 2006). Swimmers’ shoulder is a common term used to describe anterior shoulder pain that occurs during or after swim training (Manske *et al.*, 2015). Additionally, studies have reported that swimmers’ shoulder is not only indicative of underlying upper-quarter pain but also upper-quarter postural changes due to intrinsic risk factors (Blanch, 2004; Bedi & Rodeo, 2009; Sein *et al.*, 2010; Manske *et al.*, 2015). The upper-quarter regions that are significantly affected by the freestyle stroke include the shoulder complex, scapular



structures, and vertebral column (Greenfield *et al.*, 1990; Lynch *et al.*, 2010; Matthews *et al.*, 2017).

The mean scores reported in the literature for upper-quarter muscular strength in swimmers and adolescents are similar to the results reported by the EVAL and CON groups of this study. A study conducted by Manske *et al.* (2015) examined the effect of a strengthening programme in 21 competitive female adolescent swimmers (mean age =  $12 \pm 2.2$  yrs; height =  $150.3 \pm 15.1$  cm; body mass =  $44.84 \pm 12.1$  kg). Muscular strength of shoulder flexion, -extension, -abduction, -external rotation, and -internal rotation was measured through a hand-held dynamometer. Prior to intervention the mean measures reported by Manske *et al.* (2015) for shoulder flexion ( $126 \pm 10.9$  kgf), -extension ( $99 \pm 5.9$  kgf), -abduction ( $112 \pm 9.2$  kgf), -external rotation ( $106 \pm 1.7$  kgf), and -internal rotation ( $129 \pm 7.8$  kgf) closely corresponded with the mean values obtained by the EVAL group of this study. Similarly, mean scores reported for the control group (shoulder extension [ $106 \pm 9$  kgf], -abduction [ $74 \pm 2$  kgf], -external rotation [ $62 \pm 6$  kgf], and -internal rotation [ $85 \pm 1.8$  kgf]) were similar to the mean values of the CON group of this study.

Studies have identified adaptations in shoulder and scapular kinematics that may predispose postural changes or altered muscle functioning in freestyle swimmers (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017). Ramsi *et al.* (2004) studied the shoulder muscular strength of high school swimmers (mean age = 16.3 yrs; mean height =  $166.7 \pm 1.7$  cm; mean body mass =  $65.1 \pm 7$  kg) over the course of a competitive season (12 weeks). Shoulder internal and -external strength was measured preseason, midseason, and postseason to detect muscular strength changes. Midseason muscular strength measures closely related to the mean scores for shoulder internal rotation ( $130.8 \pm 2.1$  kgf) and -external rotation ( $109.8 \pm 6$  kgf) of the EVAL group. It is noteworthy to report that the collection of data for this study was conducted during the midseason of the EVAL group's competition season.

The comparative statistics of the shoulder and scapula muscular strength between female adolescent competitive freestyle swimmers and female adolescent non-swimmers are represented in Table 4.7.



*Table 4.7 Differences in the shoulder and scapular muscular strength between groups*

Variables	Comparative statistics		Significant difference		Comparisons
	Left (z score)	Right (z score)	Left (p≤0.05)	Right (p≤0.05)	
Shoulder flexion (kgf)	7.23	7.22	0.00**	0.00**	CON < EVAL
Shoulder extension (kgf)	1.98	2.35	0.05*	0.02*	CON > EVAL
Shoulder external rotation (kgf)	7.12	7.07	0.00**	0.00**	CON < EVAL
Shoulder internal rotation (kgf)	7.25	7.25	0.00**	0.00**	CON < EVAL
Shoulder abduction (kgf)	6.59	7.13	0.00**	0.00**	CON < EVAL
Shoulder adduction (kgf)	7.25	7.25	0.00**	0.00**	CON < EVAL
Scapular elevation (kgf)	6.53	6.57	0.00**	0.00**	CON < EVAL
Scapular depression (kgf)	6.42	6.35	0.00**	0.00**	CON < EVAL
Scapular retraction (kgf)	6.83	6.62	0.00**	0.00**	CON > EVAL
Scapular protraction (kgf)	6.86	6.96	0.00**	0.00**	CON < EVAL

Data is presented as comparative statistics between CON and EVAL groups (z-score) and  $p \leq 0.05$ ; CON = Control group; EVAL = Evaluation group

\*  $p \leq 0.05$ ; \*\*  $p \leq 0.01$

Optimal function of the upper quarter of female adolescent competitive freestyle swimmers is reliant on the coordinated movement between the scapula and the humerus (Paine & Voight, 2013; Laudner *et al.*, 2015).

The EVAL group demonstrated significantly greater mean muscular strength ( $p=0.00$ ) scores for all the variables except for shoulder extension and scapular retraction when compared with the CON group. The comparative statistics highlighted that the female adolescent freestyle swimmers had significantly higher values anterior and middle deltoids, long head of biceps brachii, subscapularis, pectoralis major, latissimus dorsi, teres major and -minor, infraspinatus, supraspinatus, levator scapula, upper and lower trapezius, serratus anterior, and coracobrachialis, when compared with the CON group. Moreover, the female adolescent freestyle swimmers had significantly lower values for posterior deltoids, triceps brachii, rhomboids major and minor, and middle trapezius than the CON group.



When considering the literature on muscular imbalances in swimmers, the differences in muscle strength found in this study were similar. A study on swimmers by Matthews *et al.* (2017) revealed that the swimmers had overactive serratus anterior, coracobrachialis, pectoralis major, latissimus dorsi, teres major, subscapularis, and anterior deltoids. In another study by Hibberd *et al.* (2012) under-activity of the mid- and lower trapezius and rhomboid muscles were noticed in swimmers. Over-activity of serratus anterior, coracobrachialis, pectoralis major, latissimus dorsi and teres major, subscapularis, and anterior deltoids may cause excessive protraction of the scapula, paired with anterior and inferior rotation of the glenoid fossa (Matthews *et al.*, 2017). Furthermore, the under-activity of the mid- and lower trapezius and rhomboid muscles allows the scapula to protract excessively (Hibberd *et al.*, 2012). This may also cause a loss of scapular protraction - retraction control either because of posterior capsular tightness or coracoid muscle contracture (Walker *et al.*, 2012; Virag *et al.*, 2014). Posterior capsular tightness, often demonstrated by a loss of internal rotation of the glenohumeral joint, may lead to a superior and anterior translation of the humeral head (Walker *et al.*, 2012; Virag *et al.*, 2014). Additionally, overactive coracoid musculature and posterior capsular tightness may lead to an altered scapulohumeral rhythm and a decrease in the subacromial space. A decrease in the subacromial space may lead to the impingement of the supraspinatus tendon, superior joint capsule, subacromial bursa and the long head of biceps brachii tendon (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017).

Birrer (1986) and Rupp *et al.* (1995) stated that repetitive exposure to high volumes of training alters the biomechanics of competitive swimmers. The biomechanical changes may cause internal rotator and adductor muscles to become stronger and hypertrophied relative to the antagonist muscles, leading to undesirable upper-quarter posture (Birrer, 1986; Rupp *et al.*, 1995). Shoulder adduction and elbow extension are the primary movements required to produce the force necessary to move the body through the water during freestyle swimming (Ramsi *et al.*, 2004). These movements are predominantly governed by the pectoralis major, teres major, latissimus dorsi, and triceps brachii (Kolber & Cleland, 2013). The contribution from the pectoralis major and latissimus dorsi muscles during freestyle swimming may result in the overstimulation of shoulder internal rotators, namely the subscapularis, pectoralis major, anterior deltoid, latissimus dorsi, and teres major (Kolber & Cleland, 2013).



A diminutive posture used by swimmers (protraction of the scapula and shoulder hyperflexion with abduction) to decrease the resistance and water displacement may also cause muscular imbalances and upper-quarter postural changes. The literature stated that maintaining the diminutive posture for extended periods increases the probability of developing upper-quarter postural changes and kinematic adaptations (Magel & Mc Ardle, 1970; Young, 2002). Kinematic adaptations include an increased scapular upward rotation, external rotation, and protraction that are commonly found in adolescent swimmers (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017).

Considering the differences noticed in muscle strength between the EVAL and CON group and the conclusions made in the literature, it appears that the female adolescent freestyle swimmers are at an increased risk of upper-quarter postural changes. The overactive and underactive muscles found in the EVAL group support the notion that muscular strength imbalances may cause excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa. Excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa, posterior capsular tightness and excessive anterior orientation of the glenohumeral joint are all intrinsic risk factors mentioned by Hibberd *et al.* (2012), Saladin (2015) and Matthews *et al.* (2017).

The results attained for the muscle strength measures and the differences noted between the two groups correspond with the findings reported for the cervical and shoulder range of motion measures, and for the postural measures. The results of this study therefore highlight that the EVAL group (female adolescent competitive freestyle swimmers) are potentially at a greater risk of attaining the forward head, rounded shoulder posture than the CON group (female adolescent non-swimmers). The results also show that the EVAL group seem to be more predisposed to attaining pain and injuries associated with the forward head, rounded shoulder posture. Practically, sport scientists and coaches alike should consider these implications.

Taking into consideration the results of this study and the supporting literature reported and discussed in this chapter, the potential reasons for these findings and subsequent recommendations are discussed in Chapter 5. The limitations and strengths of this study are also highlighted.



## CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

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### **5.1 Conclusions**

The aim of this study was to prospectively identify the incidence of upper-quarter postural differences in competitive female adolescent freestyle swimmers, by comparing their upper-quarter postural measurement characteristics with the upper-quarter postural measurement characteristics of female adolescent non-swimmers.

The primary findings of this study are highlighted in the sections below.

#### **5.1.1 Shoulder and Cervical Range of Motion**

##### **Shoulder Range of Motion**

- a) There were significant differences ( $p=0.00$ ) between the EVAL and CON groups for all the measured shoulder range of motion variables.
- b) The EVAL group achieved lower mean scores for horizontal shoulder adduction, shoulder internal rotation, -flexion, and -extension, than the mean scores of the CON group.
- c) The EVAL group had mean scores below the normative values for horizontal shoulder adduction, shoulder internal rotation, -extension, and -flexion.

Findings support the notion that lesser shoulder internal rotation range of motion paired with lesser horizontal shoulder adduction, shoulder flexion, and -extension range of motion, is associated with an increased tightness of the posterior shoulder capsule.



## Cervical Range of Motion

- a) There were significant differences ( $p=0.00$ ) between the EVAL and CON groups for cervical forward flexion, –extension, and –lateral rotation.
- b) No significant difference (left:  $p=0.46$ ; right:  $p=0.52$ ) between the EVAL and CON groups for cervical lateral flexion.
- c) The EVAL group achieved lesser cervical forward flexion and a greater cervical extension, - lateral flexion and – lateral rotation than the CON group.

Greater cervical extension and lesser cervical forward flexion may cause hyperextension at the atlanto-occipital articulations. The findings support the view that the EVAL group have a higher predisposition of attaining hyperextension at the atlanto-occipital articulations than the CON group.

## 5.1.2 Static and Dynamic Upper-Quarter Posture

### Y-Balance Test

- a) There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group achieving a greater mean absolute value for the Y-Balance test than the CON group.
- b) The EVAL group had a better unilateral performance of the upper quarter whilst maintaining stability when compared to the CON group.

The findings suggest that the EVAL group had better upper-quarter dynamic stability than the CON group.

### Static Postural Measures

#### Head-Tilt Angle and Cervical Angle:

- a) There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group having a smaller head-tilt angle and a smaller cervical angle than the CON group.



- b) The mean head-tilt angle of the EVAL group was below the reported normative value
- c) The CON and EVAL groups' mean cervical angles were both below the reported normative value.
- d) The mean cervical angle of the EVAL group was below the unfavourable range of 39.2 – 36 degrees.

These findings support the proposition that the EVAL group is at a greater risk of a forward head posture. Forward head posture is associated with a lesser head tilt angle and cervical angle paired with a greater thoracic angle.

#### *Shoulder protraction and retraction angle*

- a) There was a significant difference ( $p=0.00$ ) between the EVAL and the CON group, with the EVAL group having a smaller protraction and retraction angle than the CON group.

These findings suggest that the EVAL group may possibly be presenting with excessive anterior orientation of the glenohumeral joint as well as excessive protraction of the scapula with anterior and inferior rotation of the glenoid fossa. These structural deviations may lead to posterior capsular tightness, predisposing the EVAL group to injury.

#### *Thoracic Angle*

- a) There was a significant difference ( $p=0.00$ ) between the EVAL and the CON groups, with the EVAL group having a greater thoracic angle than the CON group.
- b) The CON and EVAL groups' mean thoracic angles were above the reported normative value.

The findings suggest that both the EVAL and CON groups present with the tendency of a midthoracic kyphotic posture. An increased midthoracic spine kyphosis is one of the intrinsic risk factors that may occur from repeated participation in freestyle swimming. Exposure to external loads, such as sitting posture during laptop or computer use, studying hours, backpack carrying, and slouched posture while walking, are all possible reasons for the high thoracic angle noted in the CON group.



### 5.1.3 Shoulder and Scapular Muscle Strength

- a) There were significant differences ( $p=0.00$ ) between the EVAL and CON groups for all the measured muscular strength variables except for shoulder extension and scapular retraction.
- b) The EVAL group achieved higher scores for shoulder flexion; -external rotation; -internal rotation; -abduction; and -adduction, scapular elevation, -depression, and -protraction, than the mean scores of the CON group.
- c) The EVAL group had significantly greater values for anterior and middle deltoids, long head of biceps brachii, subscapularis, pectoralis major, latissimus dorsi, teres major and -minor, infraspinatus, supraspinatus, levator scapula, upper and lower trapezius, serratus anterior, and coracobrachialis, when compared with the CON group.
- d) The EVAL group had significantly lower values for posterior deltoids, triceps brachii, rhomboids major and minor, and middle trapezius, than the CON group.

The findings suggest that the EVAL group are at greater risk of attaining a forward head – round shoulder posture. The stronger anterior shoulder muscles, noted in the EVAL group, may result in a change in the orientation of the glenohumeral joint and the curve of the thoracic spine. Strong anterior shoulder muscles generally pull the glenohumeral joint anteriorly and inferiorly. Moreover, strong anterior shoulder muscles may increase the curvature of the midthoracic spine, causing a kyphotic posture. The weaker mid- and lower trapezius and rhomboids muscles may allow for excessive scapula protraction, causing a loss of scapular protraction - retraction control. The differences noted between the groups also highlight that the EVAL group are predisposed to posterior capsular tightness of the shoulder. Posterior capsular tightness may also lead to an anterior and inferior translation of the glenohumeral head. Additionally, posterior capsular tightness may alter scapulohumeral rhythm and decrease subacromial space. The potential postural changes associated with the findings noted for the muscle strength measures, lead to the assumption that the EVAL group is at a greater risk of shoulder injury and pain.



## 5.2 Possible Reasons For Findings

The significant differences in the physical characteristics of the upper quarter noted in the female adolescent freestyle swimmers when compared with non-swimmers indicate that swim training may have a substantial influence on the upper-quarter posture. These findings highlight the interplay between the intrinsic and extrinsic risk factors associated with swimming.

Many of the conclusions made in this study were related to the intrinsic factors stated in the literature (Meeuwisse *et al.*, 2007; Walker *et al.*, 2012). A number of extrinsic risk factors, such as training volume, competition level, stroke mechanics, equipment use and rest and recover, may provide insight into the reasons for the physical differences in the upper quarter characteristics observed in the female adolescent freestyle swimmers.

### Training Volume and Competitive Level

Competitive swimmers perform a large volume of distance and high intensity training to gain strength and power in preparation for the competitive swimming season (Salo & Riewald, 2008; Walker *et al.*, 2012). To compete at optimal performance the swimmers must be able to sustain high physical demands that may ultimately optimize their physiological and psychological components. The physical demands and the high volumes of swim training pose as risk factors for the development of undesirable postural changes. The physical demands and the high volumes of swim training may lead to fatigue in scapular stabilizing musculature, development of muscle imbalances, and adaptations of the intrinsic physical characteristics that increase the risk of injury in competitive swimmers (Salo & Riewald, 2008; Walker *et al.*, 2012). It may be noteworthy to consider that the number of swim training sessions per week performed by the female adolescent competitive freestyle swimmers of this study was very high. The high volume of swim training sessions may have therefore, contributed to the postural characteristics noted.



## Stroke Mechanics

Anomalous stroke mechanics while performing the freestyle stroke would theoretically have the greatest impact on the development of postural changes. The development of optimal stroke mechanics has concentrated on performance improvements with little focus on the effect and mechanical demands that are placed on swimmers' posture. Swimming with improper freestyle stroke mechanics may be a leading risk factor for postural pathology and an increase for injury. Freestyle stroke mechanical errors that may be related to competitive adolescent female swimmers' postural changes are identified (Wilk *et al.*, 2009; Barbosa *et al.*, 2010). These errors include improper hand entry angle, hand entry position, pull-through pattern, and elbow position during pull-through, elbow position during recovery, body roll angle, and head carrying angle (Wilk *et al.*, 2009; Barbosa *et al.*, 2010). It is of great importance for all competitive swimmers to regularly perform swimming stroke assessments. This may help to identify contributors to existing and developing postural malalignments and the necessity to implement an additional strength and conditioning programme.

## Equipment Use

Swimming coaches often include equipment as an adjunct to the training programme and to introduce variation. Swimming equipment, namely hand paddles and kicking boards, have been identified to increase the development of undesirable upper-quarter postural changes in adolescent swimmers (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013). Hand paddles increase the water resistance placed on the hands and in turn generate more force on the shoulder complex (Hibberd & Myers, 2013). The overuse of hand paddles paired with insufficient rest of the shoulder complex have a direct link to upper-quarter postural changes and pain. Additionally, kickboard usage has been associated with an increase curvature in the thoracic spine and a hyperextension at the atlanto-occipital articulations and a flattening of the midcervical spine lordosis (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013). These postural deviations are caused by excessive cervical extension and thoracic compensation when holding the kickboard in an overhead position. When holding the kickboard overhead, it places the shoulder in an impingement position and may increase stress to shoulder musculature (Hrysomallis & Goodman, 2001; Hibberd & Myers, 2013).



Although evidence on the use of swimming equipment remains inconclusive, it is important to understand the proposed risks that exist.

## Rest and Recover

Upper-quarter postural deviations and injury have been identified following repetitive fatiguing protocols and insufficient recovery. These deviations to the upper quarter may be caused by fatigued musculature that in turn alters scapular kinematics and undesirable adaptations to the shoulder complex (Hibberd *et al.*, 2012). The scapular kinematic adaptations include an increased scapular upward rotation, -external rotation and, clavicular retraction (Hibberd *et al.*, 2012). These adaptations have been associated with a decrease in optimal performance and muscular activity in the upper trapezius, serratus anterior, anterior and posterior deltoids, and infraspinatus (Hibberd *et al.*, 2012; Walker *et al.*, 2012; Matthews *et al.*, 2017). Adequate rest should be incorporated into the periodisation programme to allow muscles to return to a state of readiness after the onset of fatigue.

## 5.3 Limitations, Strengths and Practical Recommendations

Nevertheless this study had limitations. The first limitation was that the study's population group included adolescent females only. Although the literature states that adolescent females are more prone to postural changes than adolescent males, future research should aim at evaluating the differences in upper-quarter characteristics and their relationship to competitive swimming in both sexes. This will advance the sport scientists' and coaches' understanding of the effects of swim training on competitive swimmers.

Secondly, this was a cross-sectional study and did not assess the postural changes over a macrocycle or assess the influence of a pre- and post-intervention on upper-quarter posture. Nevertheless, sport scientists and coaches should be sensitive to the notion that competitive female adolescent swimmers are susceptible to postural changes. Furthermore, evaluating how the upper-quarter characteristics change during the training season could be regularly monitored through a screening tool. Sport scientists and coaches could possibly consider incorporating a screening tool to identify and monitor predisposed individuals. Additionally, the screening tool could provide information to assist with practical guidelines and the development of prehabilitation intervention programmes to limit the undesirable



changes in the upper-quarter posture that may lead to injury. Moreover, sport scientists and coaches could aim at including strength and conditioning sessions to their periodization programme, with the focus on prevention of injury.

The extrinsic risk factors noted in this study and their direct influence on the upper-quarter posture in adolescent female freestyle swimmers remains theoretical. The assumption that the extrinsic risk factors reported by the literature may have had an effect on the undesirable postural differences noted in the female adolescent freestyle swimmers explains the third limitation. Future research should aim to assess the influence of the extrinsic risk factors associated with swimming over a training season. The importance of quantifying these influences may provide a true reflection of whether the postural differences, noted in this study, are in fact due to the extrinsic risk factors.

The fourth limitation was the dearth in published normative values for variables used by this study, pertaining to adolescent female swimmers, specifically. Literature reported that upper-quarter postural measures that develop beyond a certain normative value may ultimately result in pain and injury. The results yielded in this study relate closely with the normative values currently reported by the literature. However, to the researcher's knowledge, no shoulder and scapular muscular strength normative values have been established, for adolescent female swimmers and therefore could not be compared. Future studies could convey a considerable significance to the literature on adolescent competitive swimmers, if they are aimed at establishing normative data for muscular strength variables.

Lastly, this study only included adolescent female competitive swimmers who qualified in the freestyle stroke, specifically. While there are four swimming strokes (butterfly, backstroke, breaststroke, and freestyle), freestyle is performed most often by competitive swimmers during training. Therefore, the assumption that the freestyle stroke has the greatest impact on upper-quarter postural changes serves as another limitation. Future research should consider investigating the relationship between upper-quarter postural changes in adolescent swimmers participating in various swimming strokes.

Despite the limitations cited above, this study had a number of strengths. To the researcher's knowledge this was the first study to be conducted on a South African female adolescent competitive swimming population, specifically. Additionally, this study was



unique in its selected methodology. The photographic analysis measures used in this study are considered highly accurate and yield invaluable results to determine upper-quarter posture. The methods and the equipment used in this study were also reliable, accessible and easy to recreate. Therefore, the same methods and measurements may be used for future studies or by sport scientists who would like to assess their swimmers.

In conclusion, this study highlighted that female adolescents participating in freestyle swimming on a competitive level have upper-quarter postural characteristics that are different to adolescent non-swimmers. Notably, the findings emphasised that the differences observed in the female adolescent freestyle swimmers were closely related to the forward head, rounded shoulder posture associated with freestyle swimmers. Thus, sport scientists and coaches should be knowledgeable about these upper-quarter postural differences. They should also be familiar with the potential influence that the extrinsic risk factors associated with swimming may have on their female swimmers' posture. More importantly, sport scientists and coaches should be aware that postural changes within and/or beyond unfavourable ranges may predispose their swimmers to pain and injury. Therefore, screening for postural changes throughout the swimming season, and the implementation of preventative strength and conditioning training sessions, is strongly recommended for female adolescent competitive swimmers.



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# LIST OF ANNEXURES

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## **ANNEXURE A**

- Letter of Research Proposal Approval from the MSc Committee, UP

## **ANNEXURE B**

- Letter of Ethical Approval from the Ethics Committee, UP

## **ANNEXURE C**

- Letter of permission – Use of setting

## **ANNEXURE D**

- Letter of permission – Use of equipment

## **ANNEXURE E**

- Evaluation group pre-participation screening questionnaire

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- Control group pre-participation screening questionnaire

## **ANNEXURE G**

- Statistical support

## **ANNEXURE H**

- Declaration for the storage of research data, UP

## **ANNEXURE I**

- Assent form

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- Declaration of Originality

## **ANNEXURE N**

- Declaration by Principal Investigator and Sub-Investigator and Declaration of Helsinki

## **ANNEXURE O**

- Data Sheets



MSc Committee

28 March 2017

Mrs TCdS Camacho  
Department of Physiology  
Faculty of Health Sciences

Dear Mrs Camacho,

**Ms CM Botha, Student no 11020874**

Please receive the following comments with reference to the MSc Committee submission of the abovementioned student:

<b>Student name</b>	Ms CM Botha	<b>Student number</b>	11020874
<b>Name of study leader</b>	Mrs TCdS Camacho		
<b>Department</b>	Physiology		
<b>Title of MSc</b>	Upper-quarter posture of female adolescent competitive freestyle swimmers: A comparative cross-sectional study		
<b>Date of first submission</b>	February 2017		
<b>March 2017</b>	<ul style="list-style-type: none"> <li>• Thank you for submitting the revised protocol.</li> </ul>		
<b>Decision</b>	<p>This protocol has been provisionally approved. Please submit the revised protocol to ethics, and supply the MSc committee with proof of acceptance.</p> <p>The internal and external examiners can be nominated and submitted to the MSc Committee six months prior to submission of the dissertation. Please ensure that the CV of the examiners includes: supervision, examination and publication records.</p>		

Yours sincerely

Dr Marleen Kock  
Chair: MSc Committee



The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 03/14/2020.



28/04/2017

**Approval Certificate  
New Application**

**Ethics Reference No.: 124/2017**

**Title:** The measurement characteristics of upper-quarter posture in female adolescents: a comparison between competitive freestyle swimmers and non-swimmers.

Dear Ms CarolinMari Botha

The **New Application** as supported by documents specified in your cover letter dated 29/03/2017 for your research received on the 30/03/2017, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 26/04/2017.

Please note the following about your ethics approval:

- Ethics Approval is valid for 3 years
- Please remember to use your protocol number (**124/2017**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

**Ethics approval is subject to the following:**

- The ethics approval is conditional on the receipt of **6 monthly written Progress Reports**, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

**Yours sincerely**

*\*\* Kindly collect your original signed approval certificate from our offices, Faculty of Health Sciences, Research Ethics Committee, Tswelopele Building, Room 4.59 / 4.60.*

**Dr R Sommers; MBChB; MMed (Int); MPharMed, PhD**

**Deputy Chairperson** of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

*The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).*

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✉ Private Bag X323, Arcadia, 0007 - Tswelopele Building, Level 4, Room 60, Gezina, Pretoria



St Mary's

DIOCESAN SCHOOL FOR GIRLS

## LETTER OF PERMISSION

I/we hereby grant Carolin-Mari Botha permission for the following in the successful completion of her MSc research study:

- St Mary's DSG pupils may be approached and recruited
- St Mary's DSG pupils may participate in research study after signing consent and assent form
- Utilization of St Mary's DSG gymnasium and Main Hall

Setting Address:

186 Duxbury Rd

Hillcrest

Pretoria 0083

Permission authorised by: The Reverend Canon A.W. Paterson  
Head of School St Mary's DSG

Signed (Authorisation)

29 August 2016

Date

Signed (Researcher)

29 August 2016

Date

If she believes in herself... she will fly





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### LETTER OF PERMISSION

I/we grant Carolin-Mari Botha permission to temporarily use equipment from UP Biokinetics Rehabilitation, University of Pretoria, for the successful completion of her MSc research study.

As indicated below for private use:

Test	Equipment	Quantity
Muscular Strength Examination	MicroFET3	1

I, Carolin-Mari Botha agree to return the above equipment/tool in the same condition as when issued. I understand I am held responsible for the security and condition of the equipment/tool. I agree to pay for the repair or replacement of this item if lost or damaged while in my charge. I hold University of Pretoria, ISR and the undersigned supervisor blameless and free of liability for any injury or personal loss resulting from my use of the equipment/tool.

Permission authorised by: P.S. Wood

P.S. Wood  
Signature (Authorisation)

10/02/2017  
Date

[Signature]  
Signature (Researcher)

08/02/2017  
Date



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**INSTRUCTIONS FOR FILLING OUT THE QUESTIONNAIRES BELOW:**

- Complete pre-participation screening questionnaire in full and send back to [carolinb91@gmail.com](mailto:carolinb91@gmail.com).
- If the participant experiences an injury during the study period they MUST inform the researcher immediately.
- If you have any queries, please contact Carolin-Mari Botha on 082 387 8397 or email [carolinb91@gmail.com](mailto:carolinb91@gmail.com)



**EXPERIMENTAL GROUP PRE-PARTICIPATION  
SCREENING QUESTIONNAIRE**

**Please complete all questions and indicate with a X in appropriate box.**

FULL NAME AND SURNAME.....

FEMALE  MALE

DATE OF BIRTH ..... AGE.....

HAVE YOU QUALIFIED FOR 2017 SEASON SSA NTS LEVEL 3 IN ONE OF THE FREESTYLE  
EVENTS?  Y /  N

IF YES, PLEASE STATE THE EVENT/S AND TIMES (ALL) YOU HAVE QUALIFIED FOR?  
.....  
.....

NUMBER OF YEARS YOU HAVE BEEN A COMPETITIVE SWIMMER?  
.....

ESTIMATE NUMBER OF HOURS YOU SWIMMING TRAIN PER WEEK?  
.....

ESTIMATE DISTANCE OF FREESTYLE SWIMMING DURING A TRAINING SESSION?  
.....

DO YOU DO ANY GYM / CALLISTHENIC / LAND TRAINING SESSIONS?  Y /  N

IF YES, HOW MANY HOURS PER WEEK DO YOU GYM / CALLISTHENIC / LAND TRAINING?  
PLEASE SPECIFY OCCORDINGLY  
.....  
.....  
.....

DO YOU PLAY ANY OTHER SPORT DURING THE SWIMMING SEASON?  Y /  N

IF YES, WHICH SPORT?  
.....  
.....

HAVE YOU EXPERIENCED ANY PREVIOUS MEDICAL CONDITION OR INJURY THAT MAY  
INHIBIT YOUR CURRENTLY PERFORMANCE TO SWIM?  Y /  N

IF YES,  
WHAT CONDITION / INJURY .....  
WHICH BODY SEGMENT AFFECTED.....  
WHEN DID IT OCCUR.....

ARE YOU CURRENTLY USING ANY SOURCE OF EXTERNAL POSTURE CORRECTIONAL  
DEVICE?  Y /  N



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**FACULTY OF HEALTH SCIENCES**

**Department of Physiology**  
**Division of Biokinetics and Sports Science**  
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Fax: 012-420-6099  
[www.bsl.up.ac.za](http://www.bsl.up.ac.za)

**INSTRUCTIONS FOR FILLING OUT THE QUESTIONNAIRES BELOW:**

- Complete pre-participation screening questionnaire in full and send back to [carolinb91@gmail.com](mailto:carolinb91@gmail.com).
- If the participant experiences an injury during the study period they MUST inform the researcher immediately.
- If you have any queries, please contact Carolin-Mari Botha on 082 387 8397 or email [carolinb91@gmail.com](mailto:carolinb91@gmail.com)



**CONTROL GROUP PRE-PARTICIPATION  
SCREENING QUESTIONNAIRE**

**Please complete all questions and indicate with a X in appropriate box.**

FULL NAME AND SURNAME.....

FEMALE  MALE

DATE OF BIRTH ..... AGE.....

DO YOU PARTICIPATE IN ANY SPORTING ACTIVITY?  Y /  N

DO YOU PARTICIPATE IN ANY OVERHEAD SPORTING ACTIVITY?  
(VOLLEYBALL, SWIMMING, TENNIS, SQUASH, WATERPOLO, LACROSSE, BASKETBALL, SOFTBALL)  Y /  N

IF YES, WHAT SPORT AND YEARS OF PARTICIPATION (PLEASE STATE ALL)?

.....  
.....  
.....  
.....  
.....

ESTIMATE NUMBER OF HOURS YOU TRAIN PER WEEK IN ABOVE STATED SPORT?

.....

DO YOU DO ANY GYM / CALLISTHENIC / LAND TRAINING?  Y /  N

IF YES, HOW MANY HOURS PER WEEK DO YOU GYM / CALLISTHENIC / LAND TRAINING?  
PLEASE SPECIFY OCCORDINGLY

.....  
.....  
.....

HAVE YOU EXPERIENCED ANY PREVIOUS MEDICAL CONDITION OR INJURY THAT MAY  
INHIBIT YOUR CURRENTLY PERFORMANCE?  Y /  N

IF YES,  
WHAT CONDITION / INJURY.....  
WHICH BODY SEGMENT AFFECTED.....  
WHEN DID IT OCCUR.....

ARE YOU CURRENTLY USING ANY SOURCE OF EXTERNAL POSTURE CORRECTIONAL  
DEVICE?  Y /  N

ARE YOU CURRENTLY PERFORMING REHABILITATION (STRENGTHENING AND  
STRETCHING) THAT TARGETS NECK, SHOULDER AND UPPER-BACK MUSCLES AND JOINTS?

OTHER RELEVANT INFORMATION  Y /  N

.....  
.....



Dr Pieter WA Meyer

Senior Specialist/ Lecturer

Department of Immunology

Dr Savage Rd, Private Bag x323, Pretoria, 0001

Tel.: (012) 319-2977

Fax: (012) 323-0732

E-mail: [pieter.meyer@up.ac.za](mailto:pieter.meyer@up.ac.za)**LETTER OF STATISTICAL SUPPORT**

27 February 2017

**RE: MSc student Me C Botha, student no: 11020874**

Protocol: Upper-quarter posture of competitive female adolescent swimmers: A comparative cross-sectional study.

I have completed a course in Basic Biostatistics for Medical Researchers through CE at UP and a Workshop in R, a freeware statistical program as well as a STATA data analysis course from CESAR. I am also appointed by the RESCOM (research committee) of the School of Medicine as a statistical assistant To MMed and MSc students. The statistics required in this study will be minimal; I am of the opinion that I will be able to assist the candidate.

**Data analysis:** Bivariate hypothesis testing on the quantitative data will be done as determined by die nature of the data (i.e. non-parametric vs. parametric).

**Sample size:** A sample size of 50, consisting of 25 controls and 25 experimental candidates will form part of this analysis.

I will be available to help with the data analysis.

Yours Sincerely

A handwritten signature in black ink, appearing to be 'Pieter Meyer'.

Dr Pieter WA Meyer

**Principal Investigator's Declaration for the storage of research  
data and/or documents**

I, the Principal Investigator(s), Carolin-Mari Botha of the following trial/study titled:

**'The measurement characteristics of upper-quarter posture in female adolescents: a comparison between competitive freestyle swimmers and non-swimmers'** will be storing all the research data and/or documents referring to the above mentioned trial/study at the following non-residential address:

University of Pretoria  
Department of Physiology  
Division of Biokinetics and Sports Science  
Faculty of Health Sciences  
cnr Lynnwood Road and Roper Street  
Hatfield  
South Africa

I understand that the storage for the abovementioned data and/or documents must be maintained for a minimum of 15 years from the end of this trial/study.

START DATE OF TRIAL/STUDY: 17 / 03 / 2015      END DATE OF TRIAL/STUDY: 22 / 09 / 2017

SPECIFIC PERIOD OF DATA STORAGE AMOUNTING TO NO LESS THAN 15 YEARS:  
January 2018 until                      December 2032

Name **Ms Carolin-Mari Botha**

A handwritten signature in blue ink, appearing to read 'Carolin-Mari Botha', written over a dotted line.

Signature \_\_\_\_\_ Date **2017-03-23**



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Researcher

Ms Carolin-Mari Botha

Cell phone: 0823878397

E-mail: [carolinb91@gmail.com](mailto:carolinb91@gmail.com)

LETTER OF PERMISSION

**ASSENT FORM**

**Upper-quarter posture of female adolescent freestyle swimmers: A comparative cross-sectional study**

**Purpose:**

A research project conducted by Carolin-Mari Botha for the fulfillment of a MSc Degree at the University of Pretoria aims to gain a better understanding of female adolescent freestyle swimmers upper-quarter posture.

**Procedures:**

The testing protocol will consist of six goniometric (i.e. range of movement) measurements of the shoulder joint; four tape measurements of cervical spine range of motion; four photographic examinations of static upper-quarter posture; three dynamic upper-quarter posture measurements; six muscular strength measurements of the shoulder joint and four muscular strength measurements about the scapula. Pre-testing demonstration and physical testing of the experimental- (EXP) and the control (CON) group will be conducted at the St Mary's DSG gymnasium and has granted permission for the study. The sample size will consist of 50 female adolescent participants. The EXP group will consist of 25 female adolescent freestyle swimmers who qualified for SSA Level 3 in any of the freestyle events during the 2017 swimming season. The CON group will consist of 25 female adolescent non-swimmers and will be recruited from St Mary's DSG Pretoria.



### **Experimental group**

The population will consist of competitive swimmers participating at the Northern Tiger Swimming (NTS) Level competitions affiliated with Swim South African (SSA) and who are registered members of a swimming club. Adolescent female swimmers who achieved a qualifying time for SSA Level 3 Regional Age Group for one of the freestyle events will be asked to participate in the study.

#### **Inclusion Criteria:**

Competitive female adolescent swimmers who:

- Specialise in freestyle.
- Qualified for SSA Level 3 time in one of the freestyle events before the end of the swimming season.
- Are between 13 and 18 years of age.
- Train a minimum of 5 swim training sessions per week.
- Do a minimum of 2 callisthenic or weight training session per week.
- Completed the pre-participation screening questionnaire.

#### **Exclusion Criteria:**

Participants who meet any of the following criteria will be excluded from this study:

- All participants who do not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the past 12 weeks.
- Participants who use any source of external posture correctional device.

### **Control group**

Adolescent female non-swimmers will be included to account for changes in physical characteristics not affected by swimming. Control group participants will be recruited from St Mary's DSG Pretoria and will be required to complete a pre-participation questionnaire for screening purposes (i.e. sports participation history) to determine suitability according to the inclusion/exclusion criteria.



Inclusion Criteria:

The population group will consist of female adolescent participants who:

- Do not engage in any form of overhead sporting activity.
- Are between 13 and 18 years of age.
- Do not participate in callisthenic or weight training.
- Completed the pre-participation questionnaire.

Exclusion Criteria:

Participants who meet any of the following criteria will be excluded from this study:

- All participants who did not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the last 12 weeks.
- Participants who are using any source of external posture correctional device.
- Participants who perform rehabilitation (strengthening and stretching) exercises that target upper-quarter physical characteristics.

**The testing protocol consists of:**

**Range of motion**

3. Shoulder joint range of motion with scapular motion.
  - Shoulder flexion
  - Shoulder extension
  - Shoulder abduction
  - Horizontal shoulder adduction
  - Shoulder lateral rotation (External rotation)
  - Shoulder medial rotation (Internal rotation)
4. Cervical spine range of motion.
  - Cervical Forward flexion
  - Cervical extension
  - Lateral flexion
  - Lateral rotation



### **Static posture**

2. Photographic upper-quarter posture analysis in a clothed state.
  - Head tilt angle
  - Cervical angle
  - Shoulder protraction and retraction angle
  - Thoracic angle

### **Dynamic posture**

2. Upper-quarter Y balance test.
  - Inferolateral reach
  - Medial reach
  - Superolateral reach

### **Muscular strength**

2. Muscular strength examination – MicroFET.
  - Shoulder flexion and -extension
  - Shoulder internal and -external rotation
  - Shoulder abduction and -adduction

Scapular elevation, -depression, -retraction, -protraction

### **Benefits:**

You may benefit from the study by gaining an understanding of how freestyle swimming may affect upper-quarter posture. The information from the test scores obtained will help you understand and be more aware of her shoulder and cervical spine range of motion, static and dynamic upper-quarter posture and shoulder muscular strength. The researcher will be able to provide you with detailed results and recommendations on how to improve muscle characteristics if necessary, for future benefits.

### **Risks and discomforts:**

The risks involved are not foreseen to be any greater than that associated with normal upper-quarter range of motion exercise performance. Preventative actions (wearing correct clothing, ensuring optimal function of equipment and performing correct technique and familiarization session) will be taken to reduce the risk of injuries.



**Responsibilities of the participant:**

You will be responsible for fully disclosing all information requested for pre-screening evaluation and injury history. All the requested forms should be completed honestly to ensure fair inclusion in this study. You will be asked to wear a comfortable training short, shirt and be barefoot while conducting each test.

**Confidentiality:**

You will be given a number code to ensure her information and details will remain confidential. The scores and information obtained from the study, and responses to the pre-screening questionnaire, will be treated as private and confidential. You hereby also grant the researcher permission to use your results for publication and/or presentation purposes, with your anonymity being ensured. The data will be stored for a period of 15 years according to the data protection act at the Department of Physiology, Division of Biokinetics and Sports Science, Faculty of Health Sciences at the University of Pretoria.

**Enquiries:**

You are encouraged to ask questions on any aspect of the research study which is unclear to you.

**Participant's rights:**

You are taking part in this study on your own free will and may withdraw from the study at any time.



**Please complete the following section with appropriate and correct information.**

**FREEDOM OF CONSENT:**

I, \_\_\_\_\_, (full name and surname), have read the abovementioned description, and have been informed of the procedures, requirements, benefits and risks of participating in this research study. I understand that my parents, guardian or a legally authorized official have given permission for me to participate in a study concerning the evaluation of my upper-quarter posture.

I therefore declare that I willingly cooperate in this project at my own risk, and will not withhold any information that may be of importance to the researcher or for my own safety. I also agree to follow the reporting procedures described to me by the researcher which involves honestly completing a pre-screening questionnaire and full cooperation when performing tests.

I am aware that my involvement in this project is voluntary, and that I may withdraw from participation in this study at any time without penalty and loss of benefit to myself. I hereby grant the researcher permission to use my results for publication and/or presentation purposes, with my anonymity being ensured.

\_\_\_\_\_  
Signature of Parent/Legal Guardian

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of Participant

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of researcher

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of witness

\_\_\_\_\_  
Date

Contact Number: \_\_\_\_\_



Researcher

Ms. Carolin-Mari Botha

Cell phone: 0823878397

E-mail: [carolinb91@gmail.com](mailto:carolinb91@gmail.com)

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LETTER OF PERMISSION

**INFORMED CONSENT FORM**

**Upper-quarter posture of female adolescent freestyle swimmers: A comparative cross-sectional study**

**Purpose:**

A research project conducted by Carolin-Mari Botha for the fulfillment of a MSc Degree at the University of Pretoria aims to gain a better understanding of female adolescent freestyle swimmers upper-quarter posture.

**Procedures:**

The testing protocol will consist of six goniometric (i.e. range of movement) measurements of the shoulder joint; four tape measurements of cervical spine range of motion; four photographic examinations of static upper-quarter posture; three dynamic upper-quarter posture measurements; six muscular strength measurements of the shoulder joint and four muscular strength measurements about the scapula. Pre-testing demonstration and physical testing of the experimental- (EXP) and the control (CON) group will be conducted at the St Mary's DSG gymnasium and has granted permission for the study. The sample size will consist of 50 female adolescent participants. The EXP group will consist of 25 female adolescent freestyle swimmers who qualified for SSA Level 3 in any of the freestyle events during the 2017 swimming season. The CON group will consist of 25 female adolescent non-swimmers and will be recruited from St Mary's DSG Pretoria.



### **Experimental group**

The population will consist of competitive swimmers participating at the Northern Tiger Swimming (NTS) Level competitions affiliated with Swim South African (SSA) and who are registered members of a swimming club. Adolescent female swimmers who achieved a qualifying time for SSA Level 3 Regional Age Group for one of the freestyle events will be asked to participate in the study.

#### **Inclusion Criteria:**

Competitive female adolescent swimmers who:

- Specialise in freestyle.
- Qualified for SSA Level 3 time in one of the freestyle events before the end of the swimming season.
- Are between 13 and 18 years of age.
- Train a minimum of 5 swim training sessions per week.
- Do a minimum of 2 callisthenic or weight training session per week.
- Completed the pre-participation screening questionnaire.

#### **Exclusion Criteria:**

Participants who meet any of the following criteria will be excluded from this study:

- All participants who do not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the past 12 weeks.
- Participants who use any source of external posture correctional device.

### **Control group**

Female adolescent non-swimmers will be included to account for changes in physical characteristics not affected by swimming. Control group participants will be recruited from St Mary's DSG Pretoria and will be required to complete a pre-participation questionnaire for screening purposes (i.e. sports participation history) to determine suitability according to the inclusion/exclusion criteria.



Inclusion Criteria:

The population group will consist of female adolescent participants who:

- Do not engage in any form of overhead sporting activity.
- Are between 13 and 18 years of age.
- Do not participate in callisthenic or weight training.
- Completed the pre-participation questionnaire.

Exclusion Criteria:

Participants who meet any of the following criteria will be excluded from this study:

- All participants who did not comply with the inclusion criteria.
- Participants with a sub-acute injury or severe illness within the last 12 weeks.
- Participants who are using any source of external posture correctional device.
- Participants who perform rehabilitation (strengthening and stretching) exercises that target upper-quarter physical characteristics.

**The testing protocol consists of:**

**Range of motion**

5. Shoulder joint range of motion with scapular motion.
  - Shoulder flexion
  - Shoulder extension
  - Shoulder abduction
  - Horizontal shoulder adduction
  - Shoulder lateral rotation (External rotation)
  - Shoulder medial rotation (Internal rotation)
6. Cervical spine range of motion.
  - Cervical Forward flexion
  - Cervical extension
  - Lateral flexion
  - Lateral rotation



### **Static posture**

3. Photographic upper-quarter posture analysis in a clothed state.
  - Head tilt angle
  - Cervical angle
  - Shoulder protraction and retraction angle
  - Thoracic angle

### **Dynamic posture**

3. Upper-quarter Y balance test.
  - Inferolateral reach
  - Medial reach
  - Superolateral reach

### **Muscular strength**

3. Muscular strength examination – MicroFET.
  - Shoulder flexion and -extension
  - Shoulder internal and -external rotation
  - Shoulder abduction and -adduction
  - Scapular elevation, -depression, -retraction, -protraction

### **Benefits:**

Your child may benefit from the study by gaining an understanding of how freestyle swimming may affect upper-quarter posture. The information from the test scores obtained will help your child understand and be more aware of her shoulder and cervical spine range of motion, static and dynamic upper-quarter posture and shoulder muscular strength. The researcher will be able to provide your child with detailed results and recommendations on how to improve muscle characteristics if necessary, for future benefits.

### **Risks and discomforts:**

The risks involved are not foreseen to be any greater than that associated with normal upper-quarter range of motion exercise performance. Preventative actions (wearing correct clothing, ensuring optimal function of equipment and performing correct technique and familiarization session) will be taken to reduce the risk of injuries.



**Responsibilities of the participant:**

Your child will be responsible for fully disclosing all information requested for pre-screening evaluation and injury history. All the requested forms should be completed honestly to ensure fair inclusion in this study. Your child will be asked to wear a comfortable training short, shirt and be barefoot while conducting each test.

**Confidentiality:**

Your child will be given a number code to ensure her information and details will remain confidential. The scores and information obtained from the study, and responses to the pre-screening questionnaire, will be treated as private and confidential. You hereby also grant the researcher permission to use your child's results for publication and/or presentation purposes, with your child's anonymity being ensured. The data will be stored for a period of 15 years according to the data protection act at the Department of Physiology, Division of Biokinetics and Sports Science, Faculty of Health Sciences at the University of Pretoria.

**Enquiries:**

You are encouraged to ask questions on any aspect of the research study which is unclear to you.

**Participant's rights:**

Your child is taking part in this study out of her own free will and may withdraw from the study at any time.



**Please complete the following section with appropriate and correct information.**

**FREEDOM OF CONSENT:**

I, \_\_\_\_\_, (full name and surname), have read the abovementioned description, and have been informed of the procedures, requirements, benefits and risks of my child's participation in this research study.

I therefore declare that I willingly support my child's participation and agree to cooperate in this study at my child's own risk, and will not withhold any information that may be of importance to the researcher or for my child's own safety.

I am aware that my child's participation is voluntary, and that she may withdraw from participation at any time without penalty and loss of benefit to her. I hereby grant the researcher permission to use my child's results for publication and/or presentation purposes, with anonymity being ensured.

\_\_\_\_\_  
Signature of Parent/Legal Guardian

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of researcher

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of witness

\_\_\_\_\_  
Date

Contact Number: \_\_\_\_\_




---

 SAAG17 STANDARDS Sa Age Group 2017 Long Course Meters
 

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Women 13-13			
	SANJ	LEV3	LEV2
50 Free			33.99
100 Free	1:04.94	1:12.03	1:20.76
200 Free	2:20.81	2:36.20	2:55.13
400 Free	4:56.73	5:29.14	
800 Free	10:14.02		
1500 Free			
50 Back			41.74
100 Back	1:14.20	1:22.11	1:31.84
200 Back	2:39.62	2:56.63	3:17.57
50 Breast			44.37
100 Breast	1:24.24	1:32.46	1:43.42
200 Breast	3:00.67	3:18.30	3:41.80
50 Fly			39.53
100 Fly	1:12.20	1:19.25	1:28.64
200 Fly	2:37.74		
200 IM	2:40.03	2:58.70	3:21.37
400 IM	5:38.10		

Women 14-14			
	SANJ	LEV3	LEV2
50 Free			33.74
100 Free	1:03.85	1:09.30	1:17.49
200 Free	2:18.45	2:30.28	2:48.03
400 Free	4:51.74	5:16.67	
800 Free	10:14.02		
50 Back			41.12
100 Back	1:12.98	1:19.07	1:28.19
200 Back	2:37.01	2:50.09	3:09.72
50 Breast			44.00
100 Breast	1:22.87	1:29.04	1:39.31
200 Breast	2:57.74	3:10.96	3:32.99
50 Fly			37.96
100 Fly	1:11.22	1:16.31	1:25.11
200 Fly	2:37.74		
200 IM	2:37.36	2:52.03	3:13.37
400 IM	5:38.10		

Women 15-15			
	SANJ	LEV3	LEV2
50 Free			32.58
100 Free	1:03.30	1:07.12	1:14.76
200 Free	2:17.26	2:25.55	2:42.11
400 Free	4:49.25	5:06.70	
800 Free	9:50.92		
50 Back			39.70
100 Back	1:12.38	1:16.63	1:25.15
200 Back	2:35.70	2:44.86	3:03.18
50 Breast			43.89
100 Breast	1:22.18	1:26.30	1:35.89
200 Breast	2:56.27	3:05.08	3:25.65
50 Fly			36.65
100 Fly	1:10.44	1:13.96	1:22.18
200 Fly	2:33.45		

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**SAAG17 STANDARDS Sa Age Group 2017 Long Course Meters**

200 IM	2:36.03	2:46.70	3:06.70
400 IM	5:26.83		

**Women 16-16**

	SANJ	LEV3	LEV2
50 Free			32.58
100 Free	1:02.80	1:07.12	1:14.76
200 Free	2:16.08	2:25.55	2:42.11
400 Free	4:46.75	5:06.70	
800 Free	9:50.92		
50 Back			39.70
100 Back	1:11.77	1:16.63	1:25.15
200 Back	2:34.39	2:44.86	3:03.18
50 Breast			43.89
100 Breast	1:21.50	1:26.30	1:35.89
200 Breast	2:54.80	3:05.08	3:25.65
50 Fly			36.65
100 Fly	1:09.85	1:13.96	1:22.18
200 Fly	2:33.45		
200 IM	2:34.70	2:46.70	3:06.70
400 IM	5:26.83		

**Women 17-17**

	SANJ	LEV3	LEV2
50 Free			
100 Free	1:02.21	1:07.12	
200 Free	2:14.90	2:25.55	
400 Free	4:44.26	5:06.70	
800 Free	9:50.92		
50 Back			
100 Back	1:11.16	1:16.63	
200 Back	2:33.08	2:44.86	
50 Breast			
100 Breast	1:20.81	1:26.30	
200 Breast	2:53.33	3:05.08	
50 Fly			
100 Fly	1:09.26	1:13.96	
200 Fly	2:33.45		
200 IM	2:33.36	2:46.70	
400 IM	5:26.83		

**Women 18-18**

	SANJ	LEV3	LEV2
50 Free			
100 Free	1:02.21	1:07.12	
200 Free	2:14.90	2:25.55	
400 Free	4:44.26	5:06.70	
800 Free	9:50.92		
50 Back			
100 Back	1:11.16	1:16.63	
200 Back	2:33.08	2:44.86	
50 Breast			
100 Breast	1:20.81	1:26.30	
200 Breast	2:53.33	3:05.08	
50 Fly			



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UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences  
Department of Physiology

8 February 2017

Dr M Kock  
Chair: MSc Committee  
Department of Medical Microbiology  
University of Pretoria

Dear Dr Kock and members of the MSc committee

**Confirmation of funding for MSc study: Ms Carolin-Mari Botha**

This letter serves to confirm that sufficient funds are available in the Department of Physiology, Division of Biokinetics and Sports Science to execute the MSc study entitled 'The measurement characteristics of upper-quarter posture in female adolescents: a comparison between competitive freestyle swimmers and non-swimmers'.

Sincerely yours

A handwritten signature in black ink that reads "AM Joubert".

Prof AM Joubert  
Head of Department of Physiology

.....  
**DIVISION OF BIOKINETICS AND SPORT SCIENCE  
UNIVERSITY OF PRETORIA**

---

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Fakulteit Gesondheidswetenskappe  
Departement Fisiologie  
Lefapha la Disaense tša Maphelo  
Kgoro ya Fisiolotši



**DECLARATION OF ORIGINALITY**  
**UNIVERSITY OF PRETORIA**

The Department of PHYSIOLOGY places great emphasis upon integrity and ethical conduct in the preparation of all written work submitted for academic evaluation.

While academic staff teach you about referencing techniques and how to avoid plagiarism, you too have a responsibility in this regard. If you are at any stage uncertain as to what is required, you should speak to your lecturer before any written work is submitted.

You are guilty of plagiarism if you copy something from another author's work (eg a book, an article or a website) without acknowledging the source and pass it off as your own. In effect you are stealing something that belongs to someone else. This is not only the case when you copy work word-for-word (verbatim), but also when you submit someone else's work in a slightly altered form (paraphrase) or use a line of argument without acknowledging it. You are not allowed to use work previously produced by another student. You are also not allowed to let anybody copy your work with the intention of passing it off as his/her work.

Students who commit plagiarism will not be given any credit for plagiarised work. The matter may also be referred to the Disciplinary Committee (Students) for a ruling. Plagiarism is regarded as a serious contravention of the University's rules and can lead to expulsion from the University.

The declaration which follows must accompany all written work submitted while you are a student of the Department of PHYSIOLOGY. No written work will be accepted unless the declaration has been completed and attached.

Full names of student: CAROLIN-MARI BOTHA


Student number: 11020874

Topic of work: THE MEASUREMENT CHARACTERISTICS OF UPPER-QUARTER POSTURE IN FEMALE ADOLESCENTS: A COMPARISON BETWEEN COMPETITIVE FREESTYLE SWIMMERS AND NON-SWIMMERS

**Declaration**

1. I understand what plagiarism is and am aware of the University's policy in this regard.
2. I declare that this THESIS (eg essay, report, project, assignment, dissertation, thesis, etc) is my own original work. Where other people's work has been used (either from a printed source, Internet or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.
3. I have not used work previously produced by another student or any other person to hand in as my own.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

**SIGNATURE**

 7/11/2018



DECLARATION BY PRINCIPAL INVESTIGATOR AND SUB-INVESTIGATOR

**Name:** Carolin-Mari Botha  
**Trial:** March 2015 – November 2017  
**Brief Study Title:** The measurement characteristics of upper-quarter posture in female adolescents: a comparison between competitive freestyle swimmers and non-swimmers  
**Study Number:** 11020874  
**Site:** University of Pretoria

1. I have read and understood item 1.5.5 on page 5 and section 3 (pages 14-20) "Responsibility of the Principal Investigator (PI) and participating investigators of the *Clinical Trials Guidelines of the Department of Health; 2000*
2. I have notified the South African regulatory authority of any aspects of the above guidelines with which I do not / unable to comply (If applicable, this may be attached to this declaration).
3. I have thoroughly read, understood, and critically analysed (in terms of the South African context) the protocol and all applicable accompanying documentation, including the investigator's brochure, patient information leaflet(s) and informed consent forms(s).
4. I will conduct the trial as specified in the protocol.
5. To the best of my knowledge, I have the potential at the site(s) I am responsible for, to recruit the required number of suitable participants within the stipulated time period.
6. I will not commence with my role in the trial before written authorizations from the relevant ethics committee (s) as well as the South African Medicines Control Council (MCC) have been obtained.
7. I will obtain informed consent from all participants or if they are not legally competent, from their legal representatives.
8. I will ensure that every participant (or other involved persons, such as relatives), shall at all times be treated in a dignified manner and with respect.
9. Using the broad definition of conflict of interest below, I declare that I have no financial or personal relationship(s) which may inappropriately influence me in carrying out this clinical trial.  
*Conflict of interest exists when an investigator (or the investigator's institution), has financial or personal relationships with other persons or organizations that inappropriately influence (bias) his or her actions)\**  
 \*Modified from: Davidhoff F, et al. Sponsorship, Authorship and Accountability. (Editorial) JAMA Volume 286 number 10 (September 12, 2001)
10. I have / have not (delete as applicable) previously been involved in a trial which has been closed due to failure to comply with Good Clinical Practice.
11. I have / have not (delete as applicable) previously been the principal investigator at a site which has been closed due to failure to comply with Good Clinical Practise (\*Attach details)
12. I will submit all required reports within the stipulated time-frames.

Signature: \_\_\_\_\_

Date: 23 / 03 / 2017

Witness: \_\_\_\_\_

Date: 23 / 03 / 2017



Special Communication

# World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects

World Medical Association

Adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964, and amended by the:  
29th WMA General Assembly, Tokyo, Japan, October 1975  
35th WMA General Assembly, Venice, Italy, October 1983  
41st WMA General Assembly, Hong Kong, September 1989  
48th WMA General Assembly, Somerset West, Republic of South Africa, October 1996  
52nd WMA General Assembly, Edinburgh, Scotland, October 2000  
53rd WMA General Assembly, Washington, DC, USA, October 2002 (Note of Clarification added)  
55th WMA General Assembly, Tokyo, Japan, October 2004 (Note of Clarification added)  
59th WMA General Assembly, Seoul, Republic of Korea, October 2008  
64th WMA General Assembly, Fortaleza, Brazil, October 2013

Preamble

1. The World Medical Association (WMA) has developed the Declaration of Helsinki as a statement of ethical principles for medical research involving human subjects, including research on identifiable human material and data.

The Declaration is intended to be read as a whole and each of its constituent paragraphs should be applied with consideration of all other relevant paragraphs.

2. Consistent with the mandate of the WMA, the Declaration is addressed primarily to physicians. The WMA encourages others who are involved in medical research involving human subjects to adopt these principles.

General Principles

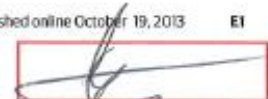
3. The Declaration of Geneva of the WMA binds the physician with the words, "The health of my patient will be my first consideration," and the International Code of Medical Ethics declares that, "A physician shall act in the patient's best interest when providing medical care."
4. It is the duty of the physician to promote and safeguard the health, well-being and rights of patients, including those who are involved in medical research. The physician's knowledge and conscience are dedicated to the fulfilment of this duty.
5. Medical progress is based on research that ultimately must include studies involving human subjects.
6. The primary purpose of medical research involving human subjects is to understand the causes, development and effects of diseases and improve preventive, diagnostic and therapeutic interventions (methods, procedures and treatments). Even the

best proven interventions must be evaluated continually through research for their safety, effectiveness, efficiency, accessibility and quality.

7. Medical research is subject to ethical standards that promote and ensure respect for all human subjects and protect their health and rights.
8. While the primary purpose of medical research is to generate new knowledge, this goal can never take precedence over the rights and interests of individual research subjects.
9. It is the duty of physicians who are involved in medical research to protect the life, health, dignity, integrity, right to self-determination, privacy, and confidentiality of personal information of research subjects. The responsibility for the protection of research subjects must always rest with the physician or other health care professionals and never with the research subjects, even though they have given consent.
10. Physicians must consider the ethical, legal and regulatory norms and standards for research involving human subjects in their own countries as well as applicable international norms and standards. No national or international ethical, legal or regulatory requirement should reduce or eliminate any of the protections for research subjects set forth in this Declaration.
11. Medical research should be conducted in a manner that minimises possible harm to the environment.
12. Medical research involving human subjects must be conducted only by individuals with the appropriate ethics and scientific education, training and qualifications. Research on patients or healthy volunteers requires the supervision of a competent and appropriately qualified physician or other health care professional.

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13. Groups that are underrepresented in medical research should be provided appropriate access to participation in research.
14. Physicians who combine medical research with medical care should involve their patients in research only to the extent that this is justified by its potential preventive, diagnostic or therapeutic value and if the physician has good reason to believe that participation in the research study will not adversely affect the health of the patients who serve as research subjects.
15. Appropriate compensation and treatment for subjects who are harmed as a result of participating in research must be ensured.

#### Risks, Burdens and Benefits

16. In medical practice and in medical research, most interventions involve risks and burdens.

Medical research involving human subjects may only be conducted if the importance of the objective outweighs the risks and burdens to the research subjects.

17. All medical research involving human subjects must be preceded by careful assessment of predictable risks and burdens to the individuals and groups involved in the research in comparison with foreseeable benefits to them and to other individuals or groups affected by the condition under investigation.

Measures to minimise the risks must be implemented. The risks must be continuously monitored, assessed and documented by the researcher.

18. Physicians may not be involved in a research study involving human subjects unless they are confident that the risks have been adequately assessed and can be satisfactorily managed.

When the risks are found to outweigh the potential benefits or when there is conclusive proof of definitive outcomes, physicians must assess whether to continue, modify or immediately stop the study.

#### Vulnerable Groups and Individuals

19. Some groups and individuals are particularly vulnerable and may have an increased likelihood of being wronged or of incurring additional harm.

All vulnerable groups and individuals should receive specifically considered protection.

20. Medical research with a vulnerable group is only justified if the research is responsive to the health needs or priorities of this group and the research cannot be carried out in a non-vulnerable group. In addition, this group should stand to benefit from the knowledge, practices or interventions that result from the research.

#### Scientific Requirements and Research Protocols

21. Medical research involving human subjects must conform to generally accepted scientific principles, be based on a thorough knowledge of the scientific literature, other relevant sources of information, and adequate laboratory and, as appropriate, animal experimentation. The welfare of animals used for research must be respected.
22. The design and performance of each research study involving human subjects must be clearly described and justified in a research protocol.

The protocol should contain a statement of the ethical considerations involved and should indicate how the principles in this Declaration have been addressed. The protocol should include information regarding funding, sponsors, institutional affiliations, potential conflicts of interest, incentives for subjects and information regarding provisions for treating and/or compensating subjects who are harmed as a consequence of participation in the research study.

In clinical trials, the protocol must also describe appropriate arrangements for post-trial provisions.

#### Research Ethics Committees

23. The research protocol must be submitted for consideration, comment, guidance and approval to the concerned research ethics committee before the study begins. This committee must be transparent in its functioning, must be independent of the researcher, the sponsor and any other undue influence and must be duly qualified. It must take into consideration the laws and regulations of the country or countries in which the research is to be performed as well as applicable international norms and standards but these must not be allowed to reduce or eliminate any of the protections for research subjects set forth in this Declaration.

The committee must have the right to monitor ongoing studies. The researcher must provide monitoring information to the committee, especially information about any serious adverse events. No amendment to the protocol may be made without consideration and approval by the committee. After the end of the study, the researchers must submit a final report to the committee containing a summary of the study's findings and conclusions.

#### Privacy and Confidentiality

24. Every precaution must be taken to protect the privacy of research subjects and the confidentiality of their personal information.

#### Informed Consent

25. Participation by individuals capable of giving informed consent as subjects in medical research must be voluntary. Although it



may be appropriate to consult family members or community leaders, no individual capable of giving informed consent may be enrolled in a research study unless he or she freely agrees.

26. In medical research involving human subjects capable of giving informed consent, each potential subject must be adequately informed of the aims, methods, sources of funding, any possible conflicts of interest, institutional affiliations of the researcher, the anticipated benefits and potential risks of the study and the discomfort it may entail, post-study provisions and any other relevant aspects of the study. The potential subject must be informed of the right to refuse to participate in the study or to withdraw consent to participate at any time without reprisal. Special attention should be given to the specific information needs of individual potential subjects as well as to the methods used to deliver the information.

After ensuring that the potential subject has understood the information, the physician or another appropriately qualified individual must then seek the potential subject's freely-given informed consent, preferably in writing. If the consent cannot be expressed in writing, the non-written consent must be formally documented and witnessed.

All medical research subjects should be given the option of being informed about the general outcome and results of the study.

27. When seeking informed consent for participation in a research study the physician must be particularly cautious if the potential subject is in a dependent relationship with the physician or may consent under duress. In such situations the informed consent must be sought by an appropriately qualified individual who is completely independent of this relationship.
28. For a potential research subject who is incapable of giving informed consent, the physician must seek informed consent from the legally authorised representative. These individuals must not be included in a research study that has no likelihood of benefit for them unless it is intended to promote the health of the group represented by the potential subject, the research cannot instead be performed with persons capable of providing informed consent, and the research entails only minimal risk and minimal burden.
29. When a potential research subject who is deemed incapable of giving informed consent is able to give assent to decisions about participation in research, the physician must seek that assent in addition to the consent of the legally authorised representative. The potential subject's dissent should be respected.
30. Research involving subjects who are physically or mentally incapable of giving consent, for example, unconscious patients, may be done only if the physical or mental condition that prevents giving informed consent is a necessary characteristic of the research group. In such circumstances the physician must seek informed consent from the legally authorised representative. If no such representative is available and if the research cannot be delayed, the study may proceed without informed consent pro-

vided that the specific reasons for involving subjects with a condition that renders them unable to give informed consent have been stated in the research protocol and the study has been approved by a research ethics committee. Consent to remain in the research must be obtained as soon as possible from the subject or a legally authorised representative.

31. The physician must fully inform the patient which aspects of their care are related to the research. The refusal of a patient to participate in a study or the patient's decision to withdraw from the study must never adversely affect the patient-physician relationship.
32. For medical research using identifiable human material or data, such as research on material or data contained in biobanks or similar repositories, physicians must seek informed consent for its collection, storage and/or reuse. There may be exceptional situations where consent would be impossible or impracticable to obtain for such research. In such situations the research may be done only after consideration and approval of a research ethics committee.

#### Use of Placebo

33. The benefits, risks, burdens and effectiveness of a new intervention must be tested against those of the best proven intervention(s), except in the following circumstances:

Where no proven intervention exists, the use of placebo, or no intervention, is acceptable; or

Where for compelling and scientifically sound methodological reasons the use of any intervention less effective than the best proven one, the use of placebo, or no intervention is necessary to determine the efficacy or safety of an intervention

and the patients who receive any intervention less effective than the best proven one, placebo, or no intervention will not be subject to additional risks of serious or irreversible harm as a result of not receiving the best proven intervention.

Extreme care must be taken to avoid abuse of this option.

#### Post-Trial Provisions

34. In advance of a clinical trial, sponsors, researchers and host country governments should make provisions for post-trial access for all participants who still need an intervention identified as beneficial in the trial. This information must also be disclosed to participants during the informed consent process.

#### Research Registration and Publication and Dissemination of Results

35. Every research study involving human subjects must be registered in a publicly accessible database before recruitment of the first subject.



36. Researchers, authors, sponsors, editors and publishers all have ethical obligations with regard to the publication and dissemination of the results of research. Researchers have a duty to make publicly available the results of their research on human subjects and are accountable for the completeness and accuracy of their reports. All parties should adhere to accepted guidelines for ethical reporting. Negative and inconclusive as well as positive results must be published or otherwise made publicly available. Sources of funding, institutional affiliations and conflicts of interest must be declared in the publication. Reports of research not in accordance with the principles of this Declaration should not be accepted for publication.

#### Unproven Interventions in Clinical Practice

37. In the treatment of an individual patient, where proven interventions do not exist or other known interventions have been ineffective, the physician, after seeking expert advice, with informed consent from the patient or a legally authorised representative, may use an unproven intervention if in the physician's judgement it offers hope of saving life, re-establishing health or alleviating suffering. This intervention should subsequently be made the object of research, designed to evaluate its safety and efficacy. In all cases, new information must be recorded and, where appropriate, made publicly available.

#### ARTICLE INFORMATION

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English-language version of the Declaration through December 31, 2013.

**Online-Only Content:** Audio podcast is available at [www.jama.com](http://www.jama.com).







**DATA SHEET**

**Range of motion:**

Tape measure examination of the range of motion of the cervical spine.

All tape measures will be scribed in units of millimeter (mm).

INITIALS & SURNAME	NUMBER	AGE	CERVICAL FORWARD FLEXION		CERVICAL EXTENSION		CERVICAL LATERAL FLEXION		CERVICAL LATERAL ROTATION	
			R	L	R	L	R	L	R	L



**DATA SHEET**

**Dynamic posture:**

Upper quarter Y balance test

All measurements will be scribed in units of centimeter (to the nearest 0.5cm).

INITIALS & SURNAME	NUMBER	AGE	YBT-UQ INFEROLATERAL REACH RIGHT			YBT-UQ INFEROLATERAL REACH LEFT			YBT-UQ MEDIAL REACH RIGHT			YBT-UQ MEDIAL REACH LEFT		
			1R	2R	3R	1L	2L	3L	1R	2R	3R	1L	2L	3L







**DATA SHEET**

**Muscular strength:**

Muscular strength examination of the glenohumeral joint – MicroFET

All measurements will be scribed in units of kilogram-force (kgF)

INITIALS & SURNAME	NUMBER	AGE	MicroFET SHOULDER ABDUCTION		MicroFET SHOULDER ADDUCTION	
			R	L	R	L



**DATA SHEET**

**Muscular strength:**

Muscular strength examination of scapular motion – MicroFET

All measurements will be scribed in units of kilogram-force (kgF)

INITIALS & SURNAME	NUMBER	AGE	MicroFET SCAPULAR ELEVATION		MicroFET SCAPULAR DEPRESSION		MicroFET SCAPULAR RETRACTION		MicroFET SCAPULAR PROTRACTION	
			R	L	R	L	R	L	R	L