Effect of lateral costal breathing dissociation exercises on the position of the scapula in level two up to senior national level swimmers

Francina Elzette Korkie

A thesis submitted to the Faculty of Health Sciences, University of Pretoria, Pretoria, in fulfilment of the requirements for the degree of Doctor in Philosophy.

January 2015

DECLARATION

I, Francina Elzette Korkie declare that this thesis is my own work. It is being submitted for the degree of Doctor of Philosophy in the University of Pretoria, Pretoria. It has not been submitted before for any other degree or examination at this or any other university.

F.E. Korkie

------------ Day of------------------------------------, 2015.

"That's been one of my mantras – focus and simplicity. Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains." – *Steve Jobs*

PUBLICATIONS AND PRESENTATIONS ARISING FROM THIS STUDY

ARTICLE SUBMITTED FOR PUBLICATION

Korkie E, van Rooijen AJ, Marais A, Becker P. The effect of lateral costal breathing exercises on the scapular position of competitive swimmers in South Africa.

POSTER PRESENTATION

Korkie E, van Rooijen AJ, Marais A, Becker P. EFFECT OF LATERAL COSTAL BREATHING DISSOCIATION EXERCISES AND SCAPULA RETRAINING ON THE SCAPULA POSITION ON SOUTH AFRICAN COMPETITIVE SWIMMERS (16th World Confederation of Physical Therapists, Singapore, May 2015)

ABSTRACT

Swimmers depend on accessory breathing muscles for adequate ventilation. Pectoralis minor is an accessory breathing muscle. The daily repetition of gleno-humeral flexion and medial rotation results in adaptive shortening of Pectoralis, a common phenomenon in competitive swimmers. If Pectoralis minor is shortened the scapula is in an anteriorly tipped position. This anteriorly tipped position will affect scapula kinematics as well as the strength of Pectoralis minor to function as an accessory breathing muscle. One of the risk factors contributing to shoulder dysfunction in competitive swimmers is an altered scapular position.

The study aimed to determine if lateral costal breathing dissociation exercises in conjunction with scapular retraining exercises had an effect on the position of the scapula in competitive swimmers.

A comparative parallel group longitudinal design was used in this study. During a six week supervised intervention period the intervention group (n=28) and control group (n=30) did retraining of the scapula stabilisers and stretching of Pectoralis minor. The intervention group did breathing dissociation exercises to facilitate lateral costal breathing. No specific breathing exercises were facilitated within the control group. Pectoralis minor length and thoracic expansion had been measured. The function of the scapula stabilisers was evaluated. The resting as well as dynamic scapula positions were evaluated. Evaluations were done at baseline, six weeks and five months post intervention.

Treatment groups were compared with respect to change from baseline to six weeks and baseline to five months in PMI, FVC and thoracic expansion utilizing analysis of covariance (ANCOVA) with covariates baseline reading. The intervention group showed an increase in the Pectoralis minor Index (PMI) of 0.5 (left & right) and the control group reflected an increase of 0.5 (left) and 0.7 (right).

The intervention group reflected continuous improvement in PMI and the control group showed deterioration. In addition to the PMI upper thoracic, expansion decreased and lower thoracic expansion increased in the intervention group. The control group showed a decrease in upper and lower thoracic expansion.

Groups were compared with respect to change from baseline to six weeks and five months respectively for categorical parameters, muscle function and scapula position (resting and dynamic) using Fisher's exact test. After six weeks the intervention group showed significantly ($p<0.04$) less winging of the distal third of the scapula on the left side when compared to the control group. After five months the scapula showed significantly less tipping ($p<0.02$) during gleno-humeral flexion, on the left side.

The McNemar test for symmetry had been applied to determine if any within group changes occurred. Within the intervention group ten of the thirteen markers used to determine the resting position of the scapula, reflected significant improvement compared to the six markers in the control group. Only the intervention group reflected remarkable improvement in function of the lower fibres of Trapezius muscle. Serratus anterior and middle fibres of Trapezius muscles showed significance within group improvement in function for both groups. The scapula showed significantly less dysrhythmia within the intervention group on the left and right sides ($p< 0.0209$) when compared to the control group.

After five months the resting scapula position reflected deterioration for both groups. Dysrhythmia and winging of the scapula deteriorated from six weeks to five months for both groups. The muscle function of the lower fibres of Trapezius showed significance within group changes for both groups from six weeks to five months. The ability to contract Serratus anterior and the middle fibres of Trapezius agonistically was maintained from six weeks to five months. However the eccentric control and ability to contract the muscle without fatigue within the Serratus anterior and middle fibres of Trapezius showed deterioration from six weeks to five months for both groups.

Conclusion: The increase in PMI and increase in lower thoracic expansion for the intervention group could favour swimmers to breathe more effectively. An increase in Pectoralis minor length resulted in a more posteriorly tipped scapula. This better positioned scapula promotes optimum function of the lower fibres of Trapezius. Contracting from a stable scapula, Pectoralis minor can fulfil its function as an accessory breathing muscle more effectively.

Keywords: Pectoralis minor, breathing exercises, scapula position in swimmers, motor learning

AKNOWLEDGEMENTS

I thank God for the opportunity as well as the ability to conduct this study

I would hereby like to express my gratitude and thanks to the following people:

Professor Tania van Rooijen, for her constant encouragement, vision and guidance throughout my study;

Mrs Annemarie Marias, for her time and input to my study;

Professor Piet Becker, for patiently helping me with the statistical analyses and interpretation of my results;

Johann, ***Jaco*** and ***Jandré***, for believing in me;

Rouxné Nel, for technical support;

Laurette Malan, for language editing;

Marlize Cochrane, ***Merle Snyckers***, ***Silmara Hanekom*** and ***Muhammed Dawood***, for your help and valuable time during the data collection periods;

My ***colleagues***, for enabling me to do this research;

Steven Ball and everyone involved at ***TuksSwim Club***, without your corporation and help this study would not have been possible;

The ***swimmers*** of TuksSwim Club, you taught me about dedication, hard work and motivation and

The ***second year students***, who helped me during the intervention period.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

BACKGROUND

Swimmers depend on the accessory breathing muscles for adequate ventilation. Pectoralis minor is an accessory breathing muscle that elevates the upper ribs (Kendall et al. 2005:320, Silva et al. 1998). Another factor to add to the overuse and adaptive shortening of Pectoralis minor is the swim stroke itself. Performing gleno-humeral flexion and medial rotation more than 500,000 times per year may lead to the distinctive rounded shoulder posture of a competitive swimmer (Bak 2010; Lynch et al. 2010). Research has shown that in this rounded shoulder position Pectoralis minor is shortened, because of repetitive over use (Lynch et al. 2010).

The first factor that challenges breathing for a swimmer is the limited time they have to breathe (Lomax and McConnell 2003). Swimmers are instructed to inhale as quickly and as deep as possible (Pedersen and Kjendlie 2006). The time that a swimmer's face is out of the water allowing him/her to inhale is limited to 0.3 – 0.5 seconds (Lomax and McConnell 2003). Breathing time has an influence on a swimmer's stroke coordination, propulsion and speed (Pedersen and Kjendlie 2006). This time limitation forces a swimmer to depend on the accessory breathing muscles (such as the Pectoralis minor) for adequate ventilation (Lomax and McConnell 2003).

The second factor that challenges the breathing pattern of swimmers is the fact that muscles used for optimum ventilation, are used in the swim stroke as well (Wells et al. 2005). Oblique externus plays a role in trunk stability but is also used during forceful exhalation. The forceful contraction during exhalation affects the lateral displacement of the thorax and this results in a more apical breathing pattern (Pryor and Prasad 2008; Wells et al. 2005).

The Pectoralis minor plays a direct role in optimum ventilation as an accessory breathing muscle. The swim stroke itself has an indirect effect on Pectoralis minor.

The position of the gleno-humeral joint, when the hand enters the water (back stroke, free style and butterfly), is flexion and medial rotation (Heinlein and Cosgarea 2010; Pollard and Fernandez 2004). Upon average a competitive swimmer practises 20-30 hours per week with an average stroke count of eight to ten strokes per 25 meter (Riemann, Witt and Davies 2011; Heinlein and Cosgarea 2010). This high volume training explains the overuse of the shoulder girdle and adaptive shortening of Pectoralis minor (Riemann et al. 2011; Lynch et al. 2010).

Overuse of Pectoralis minor results in adaptive shortening of the muscle (Fernández et al. 2012; Tate et al. 2012, Borstad 2008). A shortened Pectoralis minor has been identified as a risk factor that contributes to abnormal scapula positioning (Tate et al. 2010). When Pectoralis minor lacks extensibility the scapula is anteriorly tipped and internally rotated (Borstad 2008).

The resting as well as the dynamic position of the scapula contributes to optimum upper limb function (Kibler and Sciascia 2009; Nijs et al. 2007). A stable scapula serves as a stable base for the muscles attached to it. This stable base ensures good tension length relationships within the muscles attached to the scapula. Ideal muscle length leads to ideal muscle recruitment patterns and ideal timing of muscle recruitment resulting in optimum muscle function (Roy et al. 2009; Magarey and Jones 2003). The second function of a stable scapula is to orientate the glenoid fossa with respect to the humeral head ensuring good gleno-humeral function (Kibler and Sciascia 2009). The muscles responsible for scapula stability are the Serratus anterior and the Trapezius (Struyf et al. 2011b; Lynch et al. 2010).

The upper fibres of Serratus anterior function as a scapular protractor and the lower fibres assist in upward rotation of the scapula (Ekstrom et al. 2004). The contribution of the middle fibres of Trapezius to scapula stability is the strongest when external rotation of the gleno-humeral joint is performed. In reaction to the pull of the lateral rotators of the humerus on the scapula the middle fibres of Trapezius activate to stabilise the scapula (Cools et al. 2007a). Although the agonistic function of lower Trapezius is upward rotation and posterior tipping, it has been documented that the lower fibres of Trapezius does not show much change in muscle fibre length during upward rotation of the scapula (Arlotta, LoVasco and McLean 2011; Kinney et al. 2008; Cools et al. 2007a). The lower Trapezius also helps to maintain the scapula against the thoracic wall during gleno-humeral lowering activities (Kibler and Sciascia 2009). As much as Serratus and Trapezius are responsible for scapular stability, is scapular stability essential for optimum function of these muscles (Struyf et al. 2011b; Lynch et al. 2010; Kibler and Sciascia 2009).

Within the freestyle swim stroke Serratus anterior is active from the mid recovery phase to the pull through phase. Serratus anterior functions at 75% of its maximum strength during the entire freestyle swim stroke (Fernandez et al. 2012; Heinlein et al. 2010; Pollard and Fernandez 2004). The middle fibres of Trapezius are active throughout the recovery phase to counteract the pull of the lateral rotators of the humerus (Heinlein et al. 2010). Serratus anterior and Trapezius are susceptible to fatigue during and after a swim session (Bak 2010; Su et al. 2004).

To summarise: the high rate breathing pattern that is required by swimmers leads to respiratory muscle fatigue and then they depend on accessory breathing muscles for adequate ventilation. Due to the unique demand of the swim technique that requires an abnormal biomechanical gleno-humeral position (flexion and medial rotation) Pectoralis minor tends to shorten adaptively. This results in a malaligned scapula that has a detrimental effect on the function of the scapula stabilisers.

The main focus of treatment to ensure effective upper limb function is re-alignment of the scapula. An important principle in rehabilitation is: once a muscle is stretched the antagonists (muscles with the opposite function) should be strengthened in order to keep the new range (Magarey and Jones 2003; Comerford and Mottram 2001b). This principle is followed by previous interventions; once Pectoralis minor is stretched Trapezius (middle and lower fibres) and Serratus anterior are strengthened. Common treatment modalities include: taping (to increase the proprioceptive input and to facilitate muscle activation), exercise programs and postural awareness (Riemann et al. 2011; Lynch et al. 2010; Cools et al. 2007b).

However, stretching of Pectoralis minor to address the adaptive shortening is not enough; overuse of Pectoralis minor as an accessory breathing muscle should also be addressed. In other words, when Pectoralis minor is stretched the scapula stabilizers should be strengthened *and* the breathing pattern should be addressed. If only the scapula stabilizers are strengthened or only the breathing pattern is addressed, repeated shortening of the Pectoralis minor, due to over use, is evident in the increase in shoulder dysfunction (Fernández et al. 2012; Bak 2010; Sein et al. 2010).

The short term outcome reported about in these studies show effective re-alignment of the scapula but the effect in the long term is not sustainable (Riemann et al. 2011; Lynch et al. 2010; Cools et al. 2007b). One reason could be ascribed to the time frame of these interventions. These interventions were done six to eight weeks pre-season and not followed through to the end of season when performance is being evaluated.

A second reason could be that although the scapula alignment is addressed in these programs, the swimmers continue to use a high rate breathing pattern having only 0.3 – 0.5 seconds while their faces out of the water, to breathe (Wells et al. 2005). This breathing pattern, as explained earlier, depends on the support of the accessory breathing muscles such as Pectoralis minor, elevating the upper ribs under strenuous breathing conditions and during intense exercise.

PROBLEM STATEMENT

Pectoralis minor length is identified as a risk factor that contributes to an anteriorly tipped position of the scapula (Tate et al. 2010). One of the main reasons why the Pectoralis minor has a tendency to shorten in swimmers is in the first place because the Pectoralis minor is used as an accessory breathing muscle to ensure optimum ventilation (Pedersen and Kjendlie 2006; Wells et al. 2005). The second reason for the shortening of the Pectoralis minor stems from the effect of the distinctive rounded shoulder posture as well as the over use of repetitive gleno-humeral flexion and medial rotation (Bak 2010; Lynch et al. 2010).

The scapula position is essential for effective upper limb function. A stable, well aligned scapula fulfil its role of stability and mobility to ensure full range of gleno-humeral motion as well as effective functioning of the muscles attached to it (Kibler and Sciascia 2009).

Numerous interventions had been done on scapula stability rehabilitation and postural corrections through stretching and strengthening programs (Riemann et al.

2011; Cools et al. 2007b; Lynch et al. 2010; Sein et al. 2010; Nijs et al. 2007). Although the outcomes of these studies are positive and the swimmers gain short term relief from the programs, the long term effect has not been evaluated. Another limitation of these studies is that the focus of rehabilitation is on the strengthening of the scapular muscles. Correct recruitment and control through movement are addressed but the integration of exercises into specific function and scapular control is inadequate. These components (recruitment and control into function) are essential for ideal movement and task specific function (Roy et al. 2009; Magarey and Jones 2003).

Although breathing muscle fatigue had been evaluated in previous studies (Kilding, Brown and McConnell 2010; Mickleborough et al. 2008; Wylegala et al. 2007; Wells et al. 2005; Lomax and McConnell 2003) no literature could be found on any breathing dissociation exercises or the effect of a specific breathing pattern on the scapula position.

A main aim dictated in the aforementioned studies to correct scapula position is to stretch Pectoralis minor (Riemann et al. 2011; Lynch et al. 2010; Sein et al. 2010; Nijs et al. 2007) and even though the scapular stabilizers are strengthened the benefit of these interventions remains unsatisfactory, because the incidence of shoulder problems in swimmers is increasing year after year (Fernández et al. 2012; Bak 2010; Sein et al. 2010). A possible explanation for this recurrence can be the overuse of the Pectoralis minor muscle. Pectoralis minor is stretched to address the adaptive shortening but as mentioned earlier this is also the muscle that is used with every breath a swimmer takes. Notwithstanding the fact that the Pectoralis minor is stretched during intervention to reposition the scapula, over use of the Pectoralis minor resumes as soon as intervention is completed because of the breathing pattern utilized by swimmers.

The following shortcomings have been identified from the literature: (Rieman et al. 2011; Kilding et al. 2010; Lynch et al. 2010; Sein et al. 2010; Mickleborough et al. 2008; Nijs et al. 2007; Wylegala et al. 2007; Wells et al. 2005; Lomax and McConnell 2003)

- no intervention had been done to address the breathing *pattern* of swimmers; even when swimmers are coached to swim competitively the emphasis is to breathe as quick and fast as possible but they are never instructed about methods to breathe effectively;
- scapular stabilizers are strengthened but correct timing of recruitment (into task specific functional activities) and the ability to control movement through the available range are not addressed;
- all the interventions have good short term efficacy but the long term effect of the interventions has not yet been analysed and evaluated.

This study will focus on the teaching of lateral costal breathing exercises to swimmers as an effective measure to stretch the Pectoralis minor and to address the function (correct recruitment and control) of the scapula stabilizers. It was clinically observed that swimmers have a predominant apical breathing pattern. The additional overuse of the accessory breathing muscles, Pectoralis minor, can lead to shortening of the muscles and this can contribute to a rounded shoulder posture. The following conceptual framework has been developed in illustration of the problem statement:

Contributing factors to overuse of Pectoralis minor

Pectoralis minor is an accessory breathing muscle, elevating the upper ribs during strenuous breathing (Pedersen and Kjendlie 2006)

Repetitive medial rotation and flexion (swim stroke) leads to adaptive shortening of Pectoralis minor

Scapula is in anterior tilted position when Pectoralis minor is shortened (Borstad 2008)

An altered scapula position lacks stability and affects peri- scapular muscle and shoulder function (Borstad 2008)

Contributing factors

Ventilatory muscle strengthening

Ventilatory muscle strengthening had the same effect on ventilatory muscles as the swim training program itself (Mickleborough et al. 2008)

Breathing frequency

Swimmers should breathe as little as possible – over 50 m and only every third stroke over 100m (Pederson and Kjendlie 2006)

Intervention

Breathing exercises not effective and breathing frequency limited

Correction of posture, stretching of Pectoralis minor, strengthening of Trapezius (middle and lower fibres) and Serratus anterior

Scapula position

Malaligned due to shortness of Pectoralis minor and weakness of Trapezius (middle and lower fibres) and Serratus anterior

Breathing time

Swimmers have 0.3 – 0.5 seconds to breathe, depending on accessory breathing muscles (Pectoralis minor) (Lomax and McConnell 2003)

No Intervention

Breathing time and stroke technique fixed

Stroke technique

Repetitive shoulder flexion & medial rotation → adaptive shortening of Pectoralis minor→ anteriorly tilted scapula→ resting and dynamic position of scapula affected

Gaps in current knowledge

No interventions are done to address the breathing *pattern,* task specific activation of the scapular stabilisers in swimmers. The long term (more than six months) follow up has not been evaluated.

CLINICAL OBSERVATION

Swimmers when instructed to breathe only breathe in the apical thorax and have no lateral costal or diaphragmatic displacement

IMPLICATION

Apical breathing pattern causes over use of accessory breathing muscles→ results in shortening of Pectoralis minor → unstable resting and dynamic scapula

INTERVENTION

Integrate lateral costal breathing dissociation exercises into rehabilitation programs

HYPOTHESIS

Lateral costal breathing exercises, together with scapula stabilizer retraining will contribute to the ideal positioning of the scapula of level two up to senior national level swimmers in the short term that will be maintained over the long term

EXPECTED OUTCOMES

Lateral costal breathing → increased length of Pectoralis minor → ideal function & strength of scapula stabilisers → ideal scapula positioning → stable scapula base for muscles to contract from → ultimately an increase in performance

Figure 1.1: Conceptual framework.

RESEARCH QUESTION

Will lateral costal breathing exercises, in conjunction with scapula retraining, have a short and long term effect on the scapular position of swimmers from level two up to senior national level, compared to only scapular retraining?

HYPOTHESIS

Lateral costal breathing exercises, together with scapula retraining will contribute to the ideal positioning of the scapula of level two up to senior national level swimmers in the short term that will be maintained over the long term. Thirty six swimmers per group will have 90% power to detect a decrease of at least 0.4 change in the Pectoralis minor index (PMI).

AIM

To determine if lateral costal breathing exercises in conjunction with scapular retraining have a short term and long term effect on the scapular position of swimmers, from level two up to senior national level.

Objectives

- To evaluate the effect of lateral costal breathing exercises on the length of the Pectoralis minor after six weeks and five months post intervention

- To measure the effect of lateral costal breathing exercises on the forced vital capacity after six weeks and five months post intervention

- To evaluate the effect of lateral costal breathing exercises on the function of Serratus anterior, Trapezius (middle fibres and lower fibres) after six weeks and five months post intervention

- To evaluate the effect of lateral costal breathing exercises on the resting position of the scapula after six weeks and five months post intervention

- To evaluate the effect of lateral costal breathing exercises on the dynamic control of the scapula during swimming after six weeks and five months post intervention

IMPORTANCE AND SIGNIFICANCE OF THE PROPOSED STUDY

Several studies were conducted (Riemann et al. 2011; Lynch et al. 2010; Sein et al. 2010; Nijs et al. 2007) on swimmers trying to correct posture and optimise alignment of the scapula. The contribution of this study may be in the combination of scapular rehabilitation (correct recruitment and control into task specific function) together with breathing pattern dissociation exercises. At present exercise programs are prescribed only focusing on strength and endurance of the scapular muscles. In this study, the rehabilitation process will have components of correct recruitment of the stabilizing muscles and control of these muscles before training of strength and endurance will commence. This may not only contribute to short term performance enhancement of swimmers, it may also contribute to long term participation without injury and prevention of recurrence of shoulder problems. The prevention of continuous injury may contribute to an extension of a swimmer's career and it may result in the swimmer saving on additional medical costs.

Another advantage that may emerge from this intervention is the influence on the biomechanics of the trunk due to the correction of the breathing pattern (Levangie and Norkin 2001). The lateral costal breathing pattern will have an influence on the mobility of the ribs and intervertebral joints of the thorax. The scapula exercises will have an influence on the position of the scapula and this combination of scapular position and thoracic mobility may contribute to better trunk (thoracic and lumbar) biomechanics allowing better mobility and better muscle activation due to good positioning of the joints**.** Trunk mobility and stability may add to a better body roll which is an important component of the swim technique and once more may have a positive effect on the swimmer's performance.

DELIMITATIONS

- The evaluation techniques and rehabilitation principles used in this study are based on motor learning principles.
- The classification of the studies used in the literature review is based on the hierarchy explained by Mantzoukas (2007:217, Figure 1).

ASSUMPTIONS

The following assumptions were made before the study commenced:

- All four coaches applied the same principles in their swim training programmes as they are all part of the same swim club.
- All the swimmers attended the dry land programme on the days alternatively to the days of intervention.
- The motivation of all the swimmers who participated in the study was equal during both the intervention sessions and the sessions **of** independent exercising.

DEFINITIONS

Key concepts and terminology around which this study has been structured are defined in Annexure 1. The terms have been defined according to the meaning that will be attached to them for the purpose of this study.

OUTLINE OF THESIS

Chapter 2

The literature to form the foundation of the clinical reasoning in this study is discussed.

Chapter 3

The methodology used to conduct this study is described.

Chapter 4

The results obtained from this study is presented and analysed.

Chapter 5

The results of this study are discussed in this chapter. Limitations of this study will also be discussed.

Chapter 6

The thesis is concluded with Chapter six. New knowledge obtained from the study is highlighted. The value of the findings of the research is discussed.

Chapter 7

Recommendations based on the new knowledge gained from this study are integrated with current views and knowledge.

SUMMARY

The background to the current study is presented in Chapter 1. This chapter further encapsulates the formulated hypothesis and research question as well as the formulation of specific objectives.

In Chapter 2 the literature reviewed is analysed and the techniques and exercises used in this study are justified.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Adequate length of the Pectoralis minor and effective functioning of the scapula stabilisers are needed to ensure optimum scapula positioning. Ideal scapula positioning is an important factor that contributes to optimum gleno-humeral function. Shoulder dysfunction is the most frequent musculoskeletal problem that swimmers experience with a prevalence as high as 91% (Cools et al. 2013; Bak 2010; Borstad 2006; Borstad and Ludewig 2005).

Swimmers depend on accessory breathing muscles for adequate ventilation (Lomax and McConnell 2003). Repeated usage of accessory breathing muscles may lead to an apical breathing pattern. An apical breathing pattern may result in decreased lateral costal expansion and overactivity of the accessory breathing muscles. The Pectoralis minor is the accessory breathing muscle that elevates the upper ribs during strenuous breathing (Pryor and Prasad 2008:198).

Several interventions have been conducted to strengthen the ventilatory muscles of swimmers with limited effect on the performance of the swimmers (Kilding et al. 2010; Wylegala et al. 2007; Wells et al. 2005). Studies to address shoulder dysfunction focussed on restoring the scapular position through stretching Pectoralis minor and strengthening of the scapular stabilisers (Cools et al. 2010; Lynch et al. 2010). The short term outcome of these interventions is satisfying but shoulder dysfunction amongst swimmers is still increasing which is indicating that the long term effect of these interventions lack sustainability (Bak 2010). No existing studies which address the breathing pattern as well as retraining of the scapular muscle could be found. Therefore, this literature review aims to investigate all relevant information necessary to plan an exercise intervention for competitive swimmers in the South African context.

This study has four main focus areas; the breathing pattern, the function of Pectoralis minor, the function of scapular stabilisers and scapular positioning.

Keywords used for the literature search were: swimmers; competitive swimmers; breathing pattern; breathing; biomechanics of breathing; respiratory muscles; ventilatory muscles; Pectoralis minor; Pectoralis minor length; Pectoralis minor stretches; PMI; validity; reliability; risk factors; Trapezius; Serratus anterior; scapula stabilisers; scapula stability; exercises; activation; retraining; motor control; function; muscle balance; scapula position; evaluation; static scapula; resting scapula; dynamic scapula.

Information sources which have been consulted for this review include journal articles, books and conference proceedings. The Internet, CD-ROM and online databases, Medline and Pubmed, were also searched. The review is limited to English resources, dating from 1985 to 2014.

The first objective of this review is to investigate the normal breathing pattern. The neural control of breathing is discussed first, followed by the mechanics of normal breathing. An overview of lung function is provided. The breathing pattern of swimmers and the factors that influence breathing in swimmers are discussed. Interventions that aimed to address lung function in swimmers are evaluated and shortcomings in the current literature are identified.

NORMAL BREATHING PATTERN

The most important function of the respiratory system is to supply the body systems with oxygen. To accomplish this function several aspects are needed. The first aspect needed is sufficient neural control from the medulla oblongata and pons. The second aspect needed is effective contraction of the ventilatory muscles. The third aspect needed is functional joint mobility of the joints between the ribs, sternum and vertebra and the fourth aspect needed is effective lung function for optimum gas exchange (Pryor and Prasad 2008; Marieb 2004; Levangie and Norkin 2001). In this section the above mentioned aspects will be discussed. The cellular function of the lung tissue is beyond the scope of this study and will not be discussed.

Neural control of breathing

Although breathing seems to be a subconscious action, the complex control, coordination of the rhythm and the depth of breathing is controlled by the medulla oblongata and the pons (Hough 2014; Pryor and Prasad 2008) (Figure 3.1).

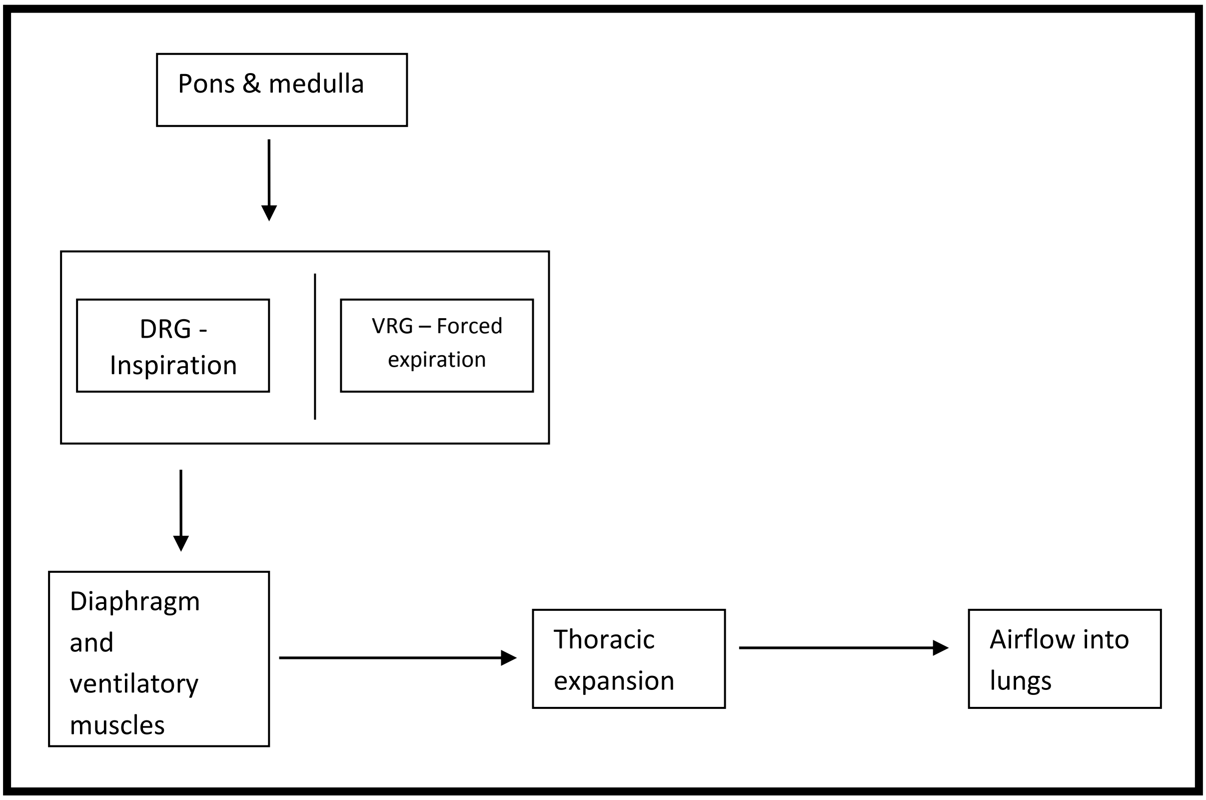


Figure 2.1: Schematic presentation of the neural control of breathing (Pryor and Prasad 2008; Marieb 2004; Levangie and Norkin 2001). DRG – dorsal respiratory group, VRG – ventral respiratory group.

In the medulla two groups of clustered neurons are responsible for respiration: the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The DRG is the pacesetting centre for inspiration. Impulses are sent via the phrenic and intercostal nerves to the diaphragm and external intercostal muscles to contract, the thorax expands and the lungs are filled with air. The DRG becomes latent and passive exhalation follows. The inspiration phase lasts about two seconds and expiration three seconds – this rhythm repeats itself 12 to 15 times per minute (Hough 2014; Marieb 2004).

The VRG contains neurons for inspiration and expiration; however the VRG is more active during strenuous, forced expiration. Several stimuli, like exercise, fear and medication, play a role on the depth and rate of inspiration. The pons modifies the neural output from the medulla mainly to fine tune breathing and to prevent over inflation (Marieb 2004).

The diaphragm and external intercostal muscles contract as a result of the neurological impulses received. The extent to which the ventilatory muscles contract and the thorax expand depend on the impulses received from the DRG and VRG. In normal day - to - day breathing the DRG sets the pace of breathing, the primary muscles of ventilation are activated and the thorax expands accordingly. However, during exercise like swimming the VRG sets the pace for inspiration and expiration. The additional contraction of the accessory muscles of ventilation are needed and the thorax expands even more to ensure optimum ventilation as needed by the individual during a strenuous task, like swimming (Marieb 2004; Levangie and Norkin 2001).

Ventilatory muscles

The ventilatory muscles have specific characteristics: they are more fatigue resistant, contract rhythmically, work primarily against the elastic property of the lungs as to gravity and the neurological control is both voluntary and involuntary (Pryor and Prasad 2008). During exercise the body's need for oxygen increases and the breathing volume must rise to keep up with the increased metabolism. To keep up with this increase in breathing volume the primary as well as accessory breathing muscles must contract faster and more forcefully (Rocha Crispino Santos et al. 2011). Respiratory muscle fatigue may lead to a decrease in ventilation, a decrease in blood flow to the peripheral muscles and ultimately an inability to perform the exercise at the required level (Wells et al. 2005).

The primary muscles of ventilation assist mainly in inspiration as relaxed expiration is a passive action. The primary muscles of inspiration are the Diaphragm, the Inter-costal muscles and Scalene. The Diaphragm is the primary muscle of ventilation and is responsible for 70% - 80% of the ventilation during quiet breathing. The Diaphragm is described as an elliptical cylindroid capped by a dome (Roussel et al. 2009; Roussos 1985). The cylindrical portion is divided into a costal and crural portion. The costal portion originates from the posterior aspect of the xifisternum, the inner surfaces of the lower six ribs and their costal cartilages. The costal fibres run vertically from their origin in close apposition to the ribcage before curving in to insert into the central tendon (the dome). The crural portion originates from the anterolateral surfaces of the vertebral bodies L1 to L3 and the aponeurotic arcuate ligaments and insert into the central tendon (Agur and Dalley 2009).

The costal part of the Diaphragm, that is in close apposition to the lower six ribs, is called the zone of apposition. The vertical orientation of these fibres is crucial to maintain an ideal length tension relationship ensuring optimum function of the Diaphragm. During breathing the vertical fibres (zone of apposition) contract, with very little change in the shape of the diaphragm dome, the central tendon descends and the lower ribcage expands (Roussos 1985). The function of the diaphragm is twofold. In the first place, the diaphragm contracts tonically throughout the respiratory cycle and when accompanied by abdominal muscle activity the intra-abdominal pressure will increase (Hodges and Gandevia 2000). This tonic contraction is evident while inhaling. In the second place the diaphragm contracts phasically above and beyond its respiratory and tonic activation. The diaphragm contracts while exhaling and this phasic contraction is even more evident when bilateral arm movement is added (Hodges and Gandevia 2000). Furthermore, the diaphragm contracts prior to any arm movement and this is indicative of the diaphragm's contribution to trunk stability through postural control (Hodges and Gandevia 2000).

The Intercostal and Scalene are the other primary muscles of inspiration. The Intercostal muscles are divided into internal and external Intercostal muscles depending on their anatomical orientation (Roussos 1995).

The Scalene muscles originate from the transverse processes of C3 to C7 and insert to the upper border of the first rib (anterior and middle Scalene) and the second rib (posterior Scalene). The Scalene muscles elevate the sternum and first two ribs in the 'pump handle' motion of the upper ribcage (Agur and Dalley 2009; Levangie and Norkin 2001).

The accessory muscles of ventilation can be divided into accessory muscles of inspiration and expiration. The accessory muscles for inspiration are Sternocleidomastoid, Pectoralis major and Pectoralis minor (Silva et al. 1998). In the case of forced expiration (as used by swimmers) the Oblique externus and internus as well as Rectus abdominus are the accessory muscles for expiration (Levangie and Norkin 2001). The accessory ventilatory muscles help with inspiration or expiration in stress situations such as exercise or pathology.

Sternocleidomastoid, when acting bilaterally, moves the ribcage superior thus expanding the upper ribcage in the 'pump handle' motion. The clavicular head of Pectoralis major can either be an accessory muscle for inspiration or expiration. When the gleno-humeral joint is in more than 90° flexion or abduction (insertion above origin) Pectoralis major has the ability to pull the manubrium and upper ribs superior and out (assisting in the 'pump handle' action). When the insertion of Pectoralis major is below its origin the muscle has the ability to draw the manubrium and ribs down thus assisting in active expiration. Pectoralis minor elevates the second to the fourth rib during forced inspiration (Levangie and Norkin 2001).

The abdominal muscles, Oblique internus, Oblique externus and Rectus abdominus have an expiratory and inspiratory function. During forceful expiration, the abdominals pull the ribs and costocartilages down into the motion of expiration. Due to the abdominal muscle contraction, the intra-abdominal pressure is increased and the Diaphragm is pushed into ribcage increasing the speed and the volume of expiration. When the Diaphragm is pushed into the ribcage a passive stretch is exerted on the costal (vertical) fibres of the Diaphragm. This passive stretch optimises the tension-length relationship of the Diaphragm resulting in a stronger contraction. Lastly when activated the abdominal muscles provide abdominal stability to the lateral chest wall, that helps to maintain the zone of apposition of the diaphragm (Wells et al. 2005; Levangie and Norkin 2001; Roussos 1985).

Functional costovertebral and costosternal joint mobility

Thoracic expansion is dependent on ideal costovertebral and costosternal joint mobility. The costovertebral joint is formed between the head of the rib, two adjacent vertebrae and the intervertebral disc. The costotransverse joints are formed between the costal tubercle of the rib and the corresponding costal facet on the vertebra and are present between the first to the tenth rib and T1 to T10 (Levangie and Norkin 2001).

The axis of movement at the first to the tenth articulation (costotransverse and costovertebral) is located more to the frontal plane. Thus if movement occurs in these joints the anterior posterior diameter of the thorax will enlarge and an anterior posterior rotation movement occur at the costovertebral and costotransverse joints. This increase in anterior posterior diameter simulates a pump handle effect. The axis of movement at the eleventh and twelfth articulation (costotransverse and costovertebral) is located closer to the sagittal plane and therefore, if movement occurs at these levels the transverse diameter of the thorax will enlarge. The movement that takes place at the costovertebral joint is a cephalad – caudad glide. This increase in transverse diameter simulates a bucket handle effect (Levangie and Norkin 2001).

Simultaneous multi directional thoracic expansion has two main advantages; a ventilatory and a biomechanical advantage. The ventilatory advantage of this multi directional simultaneous expansion of the thorax is twofold: firstly optimum air entry into the lungs is assured (Pryor and Prasad 2008; Marieb 2004; Levangie and Norkin 2001). Secondly, the lateral costal expansion ensures an optimum zone of apposition of the Diaphragm, enhancing the ventilatory function of the Diaphragm (Hruska 2005).

The biomechanical advantage of this multi directional thoracic expansion enables a person to dissociate between upper and lower ribcage expansion. The multi directional expansion implies that the joints of the thorax have sufficient range of motion (Wells et al. 2005; Magarey and Jones 2003; Levangie and Norkin 2001). The ability to dissociate thoracic movement together with sufficient joint range of motion ensures that no extra load is placed on other muscles or joints to obtain optimum lung function (Magarey and Jones 2003).

A decrease in thoracic expansion can be an indication of decreased air entry of the basal lobes, decreased mobility of the thoracic spine, decreased strength of the diaphragm and an abnormal breathing pattern (Pryor and Prasad 2008; Levangie and Norkin 2001). Two techniques are used to evaluate thoracic expansion, either manually or measured with a tape (Pryor and Prasad 2008:13; Bockenhauer et al. 2007).

The first technique, when evaluated manually, the observer's hands are placed over the posterior lateral segments of the thorax with the thumbs touching in the midline (vertebra). The patient is instructed to inhale slowly and the distance the thumbs move apart from the midline is observed. The thumb movement away from the midline must be symmetrical and the ideal displacement is three to five centimetres (Pryor and Prasad 2008: 13).

The second technique, when thoracic expansion is evaluated with a measurement tape, the measurement is divided into two areas over the thorax. Different anatomical markers are used to measure the expansion: for upper thoracic expansion the fifth thoracic spinous process and the third intercostal space at the mid clavicular line are marked and for lower thoracic expansion the tenth thoracic spinous process and the xiphoid process are marked. The patient is instructed to inhale to maximum capacity followed by a maximum exhalation. While inhaling the observer allows the tape to 'glide' and at maximum voluntary inspiration the observer takes the reading. This procedure is repeated three times for the upper and lower thoracic expansion and the mean measurement are used. This type of measurement has an interclass correlation coefficient of 0.99 (Bockenhauer et al. 2007).

Lung function

The primary function of the lung is to provide the body systems with oxygen and to free the body from carbon dioxide**.** Discussion of the cellular function lies beyond the scope of this study but the aspects of lung function applicable to this study are the forced vital capacity (FVC) and forced expiratory volume (FEV). The FVC measures the amount of air that is forced out of the lungs after a deep breath followed by a rapid, forceful and maximum inhalation or exhalation. FEV measures the amount of air forced out in a specific time interval, thus FEV_1 is the amount of air exhaled in the first second of exhalation. People with healthy lungs have the ability to exhale about 80% of their FVC within one second. Competitive athletes, like swimmers, have a higher FEV_1 (Hough 2014; Pryor and Prasad 2008; Marieb 2004).

Different tests are used to measure lung function. Body plethysmography measures the amount of air in the lungs after a deep inhalation as well as the amount of air left in the lungs after an exhalation. Spyrometry measures airflow, the amount of air exhaled as well as the force of exhalation (Hough 2014). FVC and FEV are measured with a spirometer.

Spyrometry values are based on age, height, ethnicity and gender. Results are expressed as a percentage. A value is considered to be normal if it is 80% or more of the predicted value. These values are tested and internationally approved by the American Thoracic Society (Hough 2014; Qaseem et al. 2011).

Normal breathing has been discussed. Breathing needs to be efficient in response to environmental changes and sufficient to the needs of the individual (Courtney 2009). Swimmers have to adapt their breathing pattern to their environment and specific needs. To fulfil their needs, when in the water, both inhalation and exhalation are forceful (Wells et al. 2005). The breathing pattern of swimmers will be discussed in the following section.

Breathing pattern of swimmers

Swimmers are not taught how to breathe effectively in the water or how to integrate breathing with the stroke technique (Pederson and Kjendlie 2006). They are often instructed to reduce the breathing frequency to the minimum during 50- and 100 meter sprints (Pederson and Kjendlie 2006). To breathe effectively while swimming requires a unique skill; breathing should be coordinated with the swim stroke to have the least effect on body balance and propulsion (Pederson and Kjendlie 2006). Another challenge is that the chest wall has to expand against the additional pressure of the water and the volumes and flow rates are much higher than any dry land exercises (Kilding et al. 2010; Wells et al. 2005).

The first factor that challenges breathing for a swimmer is the limited time they have to breathe (Lomax and Mc Connell 2003). In all the other overhead sports athletes can breathe freely, while during swimming the time that a swimmer's face is out of the water allowing him/her to inhale is limited to 0.3–0.5 seconds. This time limitation forces a swimmer to use accessory breathing muscles for adequate ventilation (Lomax and McConnell 2003). If a swimmer breathes on every third stroke, 1667 breathes are taken in a daily swim session and this can possibly lead to overuse of the accessory breathing muscles, like Pectoralis minor (Pollard and Fernandez

2004). This overuse of Pectoralis minor favours an apical breathing pattern emphasising more upper thoracic expansion and less lower thoracic expansion.

The second factor that challenges the breathing pattern of a swimmer is the fact that the muscles being used during the swim technique are also muscles used for optimum ventilation (Wells et al. 2005). During swimming, the abdominal muscles have to stabilise the trunk and assist in forceful exhalation. The forceful contraction of Oblique externus increases the intra-abdominal pressure and results in the Diaphragm that is pushed into the ribcage. When the Diaphragm is pushed into the ribcage a passive stretch is exerted on the costal (vertical) fibres of the Diaphragm. This passive stretch optimises the tension-length relationship of the Diaphragm resulting in a stronger contraction (Wells et al. 2005; Levangie and Norkin 2001; Roussos 1985). The detrimental effect of the forceful contraction of Oblique externus is the ribs and costocartilages are pulled down and lateral costal expansion of the thorax is limited (Wells et al. 2005). This also results in decreased lower thoracic expansion and favours an apical breathing pattern.

The third factor that challenges the breathing pattern of a swimmer is the ability to breathe to both sides on every third stroke (Pollard and Fernandez 2004). When swimmers only breathe to one side, stroke balance between the two shoulders is affected and swimmers have a tendency to develop shoulder pain on the preferred side of breathing (Riemann et al. 2011; Seifert, Chollet and Allard 2005; Yanai and Hay 2000).

The normal breathing pattern had been discussed. The different aspects that contribute to normal breathing had been discussed. The unique skills required to coordinate breathing during the swim stroke were highlighted. In the next section interventions that aimed to address specific aspects of breathing to have an effect on the lung function of swimmers are critically discussed. The majority of studies focussed on training and strengthening of the ventilatory muscles and the effect on lung function. One study was found that evaluated the effect of breathing frequency on swim performance. No study could be found that addressed the breathing pattern of swimmers.

Interventions to address ventilatory muscle training, lung function and breathing in swimmers

The majority of studies on lung function are conducted on patients with pathological conditions like asthma and chronic obstructive pulmonary disease. The research on lung function in athletes and specific swimmers is limited. The main focus of the studies, summarised in Table 2.1, was to improve lung function in swimmers through strengthening of the ventilatory muscles (Kilding et al. 2010; Mickleborough et al. 2008; Wylegala et al. 2007; Wells et al. 2005). Wylegala and colleagues (2007) conducted a study to determine whether endurance or resistance muscle training will have a better effect on the ventilatory muscles. Kilding et al. (2010) and Wells et al. (2005) evaluated the effect of ventilatory muscle training on swim performance. Mickleborough et al. (2008) examined whether ventilatory training had any effect compared to swim training itself. Pederson and Kjendlie (2006) examined the effect of breathing frequency on swim speed.

Table 2.1: Summary of studies evaluating the effect of ventilatory muscle training on lung function and performance (Kilding et al. 2010; Mickleborough et al. 2008; Wylegala et al. 2007; Wells et al. 2005) (Page 23-25).

Author and aim of study	Type of study	Intervention	Results / outcome	Critical analysis
Kilding et al. (2010) To determine the effect of inspiratory muscle training on swim performance.	Randomised controlled trail. (Level of evidence: 2) 16 competitive club – level swimmers (n=8 intervention group, n=8 control group).	Intervention group: Inspiratory muscle training twice / day at 50% of maximal inspiratory pressure for six weeks. Control group: Inspiratory muscle training twice / day at 15% of maximal inspiratory training for six weeks.	No significant change in swim performance was observed.	Design and methods well described. **Limitations:** Very small sample size per group. Breathing exercises done on daily basis but only once a week under supervision. This may explain the adherence of 88% (intervention group) and 86% (control group).
Mickleborough et al. (2008) To determine if inspiratory muscle resistance training affected the respiratory muscles	Randomised controlled trail. (Level of evidence: 2) 30 competitive swimmers.	Intervention period 12 weeks. Group one and two performed inspiratory muscle training under supervision, three times per week. Swim training was similar for all three groups. Group one: swim training plus	No significant difference between groups at baseline or after 12 weeks. All three groups showed significant within group changes for pulmonary function ($p<0.05$), measured with a spirometer.	Study design and methods well described. It is clearly stated that there were no anthropometric differences between the three groups at baseline or after 12 weeks.

more than a regular swim training programme.	(n=10 group one, n=10 group two, n=10 control group).	inspiratory muscle training at 80%maximal inspiratory pressure. Group two: swim training plus 30% maximal inspiratory pressure. Control group: only swim training.		Inspiratory muscles not defined.
Wylegala et al. (2007) To determine if two different respiratory muscle training protocols had an effect on respiratory function and swimming performance of divers.	Randomised controlled trail. (Level of evidence: 2) 30 male divers (Group that focussed on endurance n=10, group that focussed on resistance n=10 and placebo group n=10).	Each diver received a bag connected to a tube with an inlet and outlet valve. Inspiratory muscle training 30 minutes, five days / week for four weeks. Placebo group: valves removed focused on breathing through device without air resistance. Endurance group: Volume of bag set at 55% of diver's slow vital capacity. Diver breathed against this set resistance for 30 minutes. The last ten minutes (of the 30 minutes) breathing rate was increased.	Placebo: No significant changes observed. Endurance group: Pulmonary function changed significantly (maximum voluntary ventilation, slow vital capacity, FVC and FEV1). Resistance group: Significant changes in maximal inspiratory and expiratory pressures. No significant change in maximum voluntary ventilation, slow vital capacity, FVC and FEV1.	Design and methodology well described. **Limitations:** Only male divers were used. Endurance was tested at four meter depth where resistance from water is much more against chest wall than with swimmers at the water surface of a poo

		Resistance group: Deep inspiration and exhaled against the set spring resistance every 30 seconds for 30 minutes.		
Wells et al. (2005) To determine the impact of concurrent inspiratory and expiratory muscle training on the performance of competitive swimmers.	Randomised controlled trail. (Level of evidence: 2) 34 competitive swimmers (intervention group n=17, control group n=17).	Intervention group: swim training plus moderate intensity inspiratory and expiratory muscle training exercises with a resistance training device for six weeks. Next six weeks swim training plus high intensity breathing exercises. Control group: swim training plus sham breathing exercises for six weeks (resistance springs were removed from breathing devices). Next six weeks swim training plus moderate breathing exercises.	No significant improvement between groups was observed. Both groups showed significant within group improvement of MIP, MEP, FVC and FEV1. Both groups showed a trend to improve swim speed after 12 weeks (p=0.08).	Study design and methodology well described. **Limitations:** Level of dyspnoea evaluated on numeric scale but no information was given regarding the outcome measure used. The period within the swim season during which the study had been conducted is not noted. It is not clear whether the study was conducted at the beginning or end of season. Performance was measured over 1400 meter. Only six swimmers were specialising in long distance swimming the rest were sprinters or middle distance swimmers.

The effect of breathing frequency on swim speed was evaluated on ten competitive swimmers (Pedersen and Kjendlie 2006). Swimmers sprinted 25 meter with different breathing frequencies in a randomised order; 25 meter with no breathing, 25 meter with one breathe after 15 meter and 25 meter with one breathe every stroke cycle. The researchers found a significant reduction in swim speed ($p<0.05$) when swimmers breathed every swim cycle compared to the no breathe or one breathe per 25 meter. From these results it can be concluded that if a swimmer breathes every swim cycle they can lose about 0.1 second per ten meter. During a 100 meter sprint swimmers started off breathing every third to fourth swim cycle but the last part of the 100 meter they increased their breathing frequency to every second swim cycle. This urge to breathe could be due to a lower CO_2 in the blood caused by the high intensity of swimming. This increase in breathing may cost the swimmer a first or second place. These results indicate that swimmers should learn a better breathing technique as well as better breathing control (Pedersen and Kjendlie 2006).

From the reviewed literature it could be inferred that inspiratory muscle training does not contribute any more to respiratory function than a swim programme itself (Mickleborough et al. 2008; Wells et al. 2005). Endurance as well as resistance training of the respiratory muscles are equally important to optimise pulmonary function (Wylegala et al. 2007). However the timing and coordination of breathing have an effect on swim speed (Pederson and Kjendlie 2006). Inspiratory muscle training has a small but positive effect in events shorter than 400 meter (Kilding et al. 2010) and a trend towards performance improvement in long distances (Wells et al. 2005).

Interventions to improve airway function in swimmers only focussed on ventilatory muscle strengthening and breathing frequency. No studies could be found where thoracic expansion is facilitated or evaluated against another protocol in swimmers. The importance of lateral costal thoracic expansion during inspiration is threefold. Firstly, when the thorax expands effectively the length-tension relationship and zone of apposition of the diaphragm are favoured and the diaphragm can contract sufficiently (Roussos 1985). Secondly, lateral costal thoracic expansion is an important aspect of the normal breathing mechanics enlarging the thorax to allow a drop in intrapleural pressure and consequently in lung ventilation (Hough 2014). Thirdly, the combination of a strong diaphragm contraction, sufficient rib cage dissociation and optimum lung expansion contribute ultimately to an effective breathing pattern (Hough 2014; Pryor and Prasad 2008).

In this section the aspects that contribute to the mechanism of breathing were reviewed. Sufficient neural control activates the Diaphragm and Intercostal muscles to contract, the upper - and lower thorax expand respectively in an anterior-posterior and lateral costal direction. One may conclude that swimming places a unique demand on the respiratory system; the breathing time is limited and breathing must be coordinated with the swim stroke, therefore swimmers will depend on accessory ventilatory muscles, like Pectoralis minor, for optimum ventilation (Pederson and Kjendlie 2006; Wells et al. 2005; Lomax and Mc Connell 2003). Oblique externus is used to forcefully exhale because every exhalation is against resistance. Oblique externus originates from the outer surfaces of the lower eight ribs and this repeated contraction of Oblique externus might have an effect on the transverse expansion of the thorax. The thorax does not expand sufficiently in the transverse diameter and the swimmer compensates with more upper thoracic expansion. This increases the demand on the accessory inspiratory muscles to assist with effective thoracic expansion and therefore optimum ventilation.

Pectoralis minor, as mentioned, is an accessory breathing muscle elevating the upper ribs during forceful inspiration (Pryor and Prasad 2008:198). Furthermore, Pectoralis minor is the only muscle that attaches the scapula to the anterior chest wall. Swimmers often present with a distinctive rounded shoulder posture. This rounded shoulder posture is the result of muscle imbalances, adaptive shortening of Pectoralis minor and weakened scapula stabilisers. The length of the Pectoralis minor muscle is one of the main factors affecting the resting as well as dynamic position of the scapula (Cools et al. 2013; Tate et al. 2012).

The second objective of this review is to investigate the function of Pectoralis minor as well as the role of Pectoralis minor in competitive swimmers.

PECTORALIS MINOR

Pectoralis minor contributes to ribcage elevation with forced inspiration, as experienced in stressful situations and exercise and tilts the scapula anteriorly (Bak 2010; Agur and Dalley 2009; Levangie and Norkin 2001). The role of Pectoralis minor in swimmers is to elevate the ribcage during the high volume forceful inspiration and to assist in gleno-humeral flexion and medial rotation during the swim stroke (Tate et al. 2012; Kilding et al. 2010). Competitive swimmers train 20 to 30 hours per week, log between 8000 to 20 000 meters per day, with an average of eight to ten arm cycles per 25 meter and three to five breathe cycles per 25 meter. The demand on Pectoralis minor is therefore high and this results in adaptive shortening of Pectoralis minor (Fernandez et al. 2012; Lynch et al. 2010). Decreased length of the Pectoralis minor is identified as a risk factor that may contribute to an anteriorly tipped scapula and non-ideal shoulder function (Struyf et al. 2014; Tate et al. 2012; Lynch et al. 2010; Wong et al. 2010; Borstad 2008).

In this section the function of Pectoralis minor will be discussed followed by the effect that a shortened Pectoralis minor has on the scapula. Possible techniques to measure the length of Pectoralis minor are reviewed. Different positions and techniques to stretch Pectoralis minor are appraised. Interventions that included Pectoralis minor stretches have been reviewed critically. The effect of the swim stroke and breathing on Pectoralis minor in swimmers will be discussed.

The function of Pectoralis minor

Pectoralis minor originates from ribs three, four and five and it inserts to the medial, superior border of the coracoid process of the scapula (Bak 2010; Agur and Dalley 2009). Contraction of Pectoralis minor affects the scapula as well as the upper rib cage. With the origin fixed, Pectoralis minor tips the scapula anteriorly (coracoid moves anteriorly and inferior angle of the scapula moves posteriorly and medial) and depresses the scapula (Agur and Dalley 2009; Kendall et al. 2005). When the insertion is fixed (stable scapula) Pectoralis minor elevates the upper ribs (Pryor and Prasad 2008; Kendall et al. 2005; Levangie and Norkin 2001). This upper rib cage elevation is evident in situations where a higher frequency of breathing is needed (such as exercise) and therefore Pectoralis minor is also classified as an accessory breathing muscle (Pryor and Prasad 2008; Kendall et al. 2005; Levangie and Norkin 2001).

The effect of a shortened Pectoralis minor on scapula positioning

A two-group comparison study was conducted to determine the effect of a shortened Pectoralis minor on scapular movements (Borstad and Ludewig 2005). The length of Pectoralis minor, of each volunteer, was measured from origin to insertion and divided by the height of the volunteer to determine the Pectoralis minor index (PMI). A pilot study (n=6) was conducted to determine the ideal PMI. The mean PMI of the pilot group was 8.1 (SD, 0.5). A PMI less than 7.65 (8.1 – 1SD) was classified as short Pectoralis minor and a PMI of more than 8.61 (8.1 + 1SD) was classified as long Pectoralis minor. Fifty volunteers, aged 20 – 40 years, with no history of shoulder pain were divided into two groups, volunteers with a PMI more than 8.1 and those with a PMI less than 7.65. Scapular movement of both groups was evaluated with an electromagnetic system. The participants had to actively elevate and lower the arm in the frontal, sagittal and scapular plane. Data was obtained on scapular movement throughout the arm movements.

The group classified with a long PMI showed significant more posterior tipping of the scapula at 90° ($p<0.05$) and 120° ($p<0.005$) with elevation of the gleno-humeral joint in the sagittal as well as scapular planes. During elevation in the sagittal and scapular planes the group classified with a short PMI showed statistical more internal rotation of the scapula. Elevation in the coronal / frontal plane showed a significant difference in scapula position at 30° ($p<0.001$) and 60° ($p<0.005$) of elevation as well. Borstad and Ludewig (2005) concluded that a shortened Pectoralis minor has a defined effect on scapular positioning; the scapula is in an anterior tipped and internal rotated position. This position of anterior tipping and internal rotation of the scapula may result in a decreased subacromial space (Struyf et al. 2012a; Struyf et al. 2011b; Lynch et al. 2010). A possible limitation to this study (Borstad and Ludewig 2005) might be the procedure followed to determine the ideal PMI. Only six subjects, whose ages were unknown, had been evaluated in the pilot study to determine the ideal PMI.

Insufficient subacromial space is often associated with shoulder pain in overhead athletes (Struyf et al. 2012a; Struyf et al. 2011b; Lynch et al. 2010). Tate and colleagues (2012) conducted a cross sectional study to determine the risk factors associated with shoulder pain across the lifespan of competitive swimmers. A total of 236 female swimmers (aged 8 to 77 years) completed the Disabilities of the Arm, Shoulder and Hand outcome measure (DASH) and were examined for gleno-humeral range of motion, gleno-humeral abduction, internal and external rotation strength, Pectoralis minor length, core stability and scapular dyskinesis. The swimmers were divided into four groups according to age: eight to eleven years, 12 to 14 years, 15 to 19 years and 23 to 77 years (master swimmers). In the category 15 to 19 years Pectoralis minor was significantly ($p<0.05$) shorter in the group complaining of shoulder pain as compared to the group without shoulder pain. The other risk factors associated with shoulder pain that showed a significant difference were: inadequate gleno-humeral flexion, weakness of Trapezius middle fibres and a decrease of core stability. The sample of convenience employed (swimmers from one geographical area and swimmers not participating on national level) may be perceived as limitations to this study. However, if these risk factors exist in swimmers participating on a lower performance level the factors might even be more evident in swimmers participating on national level. The other limitation to the study is insufficient information regarding the testing position of the Pectoralis minor length. The research provides no indication stipulating whether scapular elevation had been allowed or corrected during the muscle length evaluation.

In summary, Pectoralis minor is an accessory breathing muscle that elevates the upper ribs during high volume breathing. Pectoralis minor shortens due to overuse during strenuous breathing (Pryor and Prasad 2008; Levangie and Norkin 2001). Flexion and medial rotation are a common combination of gleno-humeral movements in the overhead athlete and often leads to adaptive shortening of Pectoralis minor (Riemann et al. 2011; Struyf et al. 2011b; Lynch et al. 2010; Sein et al. 2010). When Pectoralis minor is shortened, the scapula is pulled into an anteriorly tipped position (Borstad and Ludewig 2005). This anteriorly tipped position affects the resting as well as dynamic position of the scapula. A shortened Pectoralis minor was identified as a risk factor contributing to shoulder dysfunction in competitive swimmers and overhead athletes (Tate et al. 2012). Effective, reliable and valid evaluation techniques should be utilized to determine the length of Pectoralis minor.

Techniques to measure the length of Pectoralis minor

Two tests were documented and well researched to evaluate the length of Pectoralis minor (Struyf et al. 2012b; Cools et al. 2010; Borstad 2008; Lewis and Valentine 2007; Borstad and Ludewig 2005; Nijs et al. 2005). The first test measures the distance from the posterior acromion to the wall / table (the acromion will be further away from the table if the scapula is anteriorly tipped) and the second test measures the anatomical length of the muscle from origin to insertion.

The test to measure the distance from the posterior acromion to the wall / table was developed to identify any length changes within Pectoralis minor when associated with scapular depression, abduction, winging or anterior tipping (Lewis and Valentine 2007). It is argued that if Pectoralis minor has ideal length, the distance between the posterior acromion and the wall / table should not exceed 2.54 centimetres (Lewis and Valentine 2007).

The intra-rater reliability and diagnostic accuracy of the technique to measure the distance between the posterior acromion and table was evaluated by Lewis and Valentine (2007). Forty five subjects with shoulder pain (aged 32.1 ± 7.3) and 45 subjects without shoulder pain (aged 42.8 ± 16.6 years) were included in this study (Lewis and Valentine 2007). The 'gold standard' of 2.6 centimetres between the acromion and table was used to determine if there is a difference in Pectoralis minor length in symptomatic and asymptomatic subjects (Lewis and Valentine 2007). The intra-rater reliability for the symptomatic (ICC 0.92 to 0.93) subjects and asymptomatic (ICC 0.90 to 0.93) subjects was good. The distance between the posterior acromion and table was compared for the symptomatic and asymptomatic group. The minimum distance recorded for the symptomatic subjects was 2.8 centimetres and for the asymptomatic subjects 3.0 centimetres. This implies that the asymptomatic group had a 'shorter' Pectoralis minor than the symptomatic group. Clinical applicability of this test is lacking as the mean distances for asymptomatic subjects varied from 5.9 – 6.3 cm and for symptomatic subjects from 6.0 – 6.5 cm.

Three other studies (Lynch et al. 2010; Struyf et al. 2009, Nijs et al. 2005) confirmed the discrepancy in the distance between the posterior acromion and the table / wall as reported by Sharmann (2002) and Lewis and Valentine (2007). In a randomised clinical trial 28 healthy competitive swimmers (aged 17 to 23 years) were evaluated (Lynch et al. 2010). The distance between the posterior acromion and the wall ranged from 8.39 to 9.62. In an intertester reliability study conducted on 30 healthy student musicians (aged 21.5 ± 5.8 years) the distance between the posterior acromion and a wall was measured in standing (Struyf et al. 2009). Both shoulders of the students were measured and the distance between the posterior acromion and wall ranged from 7.0 to 7.9 centimetres (ICC 0.72).

A prospective repeated measures design study on 29 patients was conducted to determine the interobserver reliability, internal consistency and clinical importance of the test measuring the distance between the posterior aspect of the acromion and the table (Nijs et al. 2005). The interobserver reliability coefficient was good (ICC = 0.88) and the internal consistency scored 0.88 on the Cronbach α coefficient. No difference was observed in the measurements (posterior acromion to table) between the patients complaining of shoulder pain and the asymptomatic subjects.

The second test to measure the length of Pectoralis minor is to use the anatomical markers that represent the muscle's origin and insertion (Borstad and Ludewig 2005). The Pectoralis minor index (PMI) was developed to adapt for any postural build and height differences in patients (Borstad and Ludewig 2005). The PMI is calculated by dividing the resting length of Pectoralis minor by the height of the subject and multiplied this answer by 100 (Borstad and Ludewig 2005). However, discrepancy exists regarding the ideal value for PMI (Struyf et al. 2012a; Cools et al.2010; Borstad 2008).

In a study to determine the effects of Pectoralis minor length on scapular kinematics, the mean PMI for the pilot group (n=6) was 8.1 (± 0.5). Therefore the researchers argued that a shortened Pectoralis minor will have a PMI (8.1 – 0.5) minus one standard deviation, in this case 7.65 (Borstad and Ludewig 2005). From another study (n=82), the mean PMI was calculated at 8.24 (± 0.8) and a PMI less than 7.44 (PMI minus SD) Pectoralis minor was considered to be shortened (Borstad 2008).

Cools and colleagues (2010) conducted a descriptive cross sectional study to describe variables regarding scapular position, muscle strength and Pectoralis minor flexibility in young tennis players (n=35). The subjects were positioned in supine, arms by side and elbows extended. A Vernier calliper ® was used to measure the distance between the anatomical markers that represent the origin and insertion of Pectoralis minor. Their results showed a significant shorter Pectoralis minor on the dominant versus the non-dominant side for male and female players (male mean PMI = 7.1 (± 0.4), female PMI = 6.9 (± 0.7)).

Struyf and colleagues (2012a) conducted a study on 22 patients (intervention group n=11 and control group n=11) diagnosed by a physician with impingement syndrome. The mean age for the intervention group was 46.2 (±13.5) years and for the control group was 45.4 (±15.1) years. Diagnosed with impingement, patients were likely to have scapular dyskinesis and therefore muscle imbalances (Struyf et al. 2012). Pectoralis minor length was measured from origin to insertion in supine with a measurement tape. The PMI for the intervention group was calculated at 9.1(±2.3) and for the control group 8.9 (±1.2). These PMI values are far above the PMI of 7.44 determined by Borstad (2008) indicating a shortened Pectoralis minor.

Borstad (2008) evaluated the length of Pectoralis minor on 26 healthy subjects without a history of shoulder pain. The accuracy of three different measurement tools was compared. The origin and insertion of Pectoralis minor were used as anatomical markers and the dominant side of each subject was evaluated in supine with an electromagnetic motion capture system, a tape measure and a calliper. No difference could be found between the three different measurement tools and the interclass correlation coefficient between the three tools varied from 0.82 to 0.87 indicating that the less expensive instrument can be used in clinical practice with accuracy.

Clinical measurements to measure the length of Pectoralis minor exist. The measurement of the distance between the posterior acromion and the wall (or table) showed good reliability but the clinical relevance, to differentiate between a ‘long’ and a ‘short’ Pectoralis minor is lacking (Lynch et al. 2010; Struyf et al. 2009, Lewis and Valentine 2007; Nijs et al. 2005). The validity of the test where the anatomical origin and insertion is used is valid and reliable but a ‘gold standard’ or ideal value is lacking (Struyf et al. 2012a, Cools et al.2010, Borstad and Ludewig 2005). From the current literature it seems as if this ‘gold standard’ is different for healthy subjects (Borstad and Ludewig 2005), young tennis players (Cools et al. 2010) and symptomatic subjects (Struyf et al. 2012a). Further research regarding the ideal PMI is needed.

Pectoralis minor length is identified as a risk factor that is associated with abnormal positioning of the scapula and shoulder dysfunction (Struyf et al. 2014; Tate et al. 2012). Effective stretching of Pectoralis minor can contribute to better length of the muscle as well as better scapular positioning. Different stretch positions and techniques regarding Pectoralis minor will be explored in the next discussion.

Pectoralis minor stretches

A study was conducted to compare the effect of three stretches on the length of Pectoralis minor (Borstad and Ludewig 2006). Fifty subjects without shoulder pathology had been evaluated. The origin and insertion of Pectoralis minor were marked and measurements were done with an electromagnetic motion capture system. The baseline reading for every subject was taken as the muscle’s length in a relaxed position. Each subject performed all three stretches, each stretch had been held for three seconds and after each stretch the muscle length was measured.

The first stretch was a self-stretch performed while standing. The gleno-humeral joint was abducted to 90°, elbow flexed to 90° and the palm placed on a flat surface. The subject rotated away from the shoulder increasing the horizontal abduction. The second stretch was done by the examiner. The subject had been seated, arm by side, the subject inhaled and the examiner applied a posterior force to the coracoid while stabilising the inferior angle of the scapula posteriorly. The third stretch had been done in supine with the gleno-humeral joint in 90° of abduction and externally rotated and 90° elbow flexion. The examiner applied a posterior force to the coracoid process.

The self-stretch showed the biggest mean length change of 2.24 cm, followed by the stretch in supine by 1.70 cm and lastly the stretch while sitting with the arm by side showed a mean change of 0.77 cm. From this study (Borstad and Ludewig 2006) one may argue that the stretch position was of more importance study than the stretch technique or frequency. The stretch time of only three seconds per stretch is questionable. The resting time, if any, between stretches had not been noted. All the participants performed the stretches in the same order; there was no randomisation of the stretch order. The baseline value per subject had been taken before the first stretch commenced and all three stretches were evaluated against the same baseline measurement. However, a point of importance is that the stretches where the humerus was in an abducted and externally rotated position showed a bigger change than the one where the humerus had been in the anatomical position. The researchers argued that in this abducted externally rotated position of the humerus the soft tissue around the shoulder is tight pulling the scapula into a posterior tipped and externally rotated position, thus pulling the coracoid posteriorly. This increase in distance between the origin and insertion of the muscle may contribute to the efficacy of the stretch.

Interventions conducted to evaluate the effect of Pectoralis minor stretches

Several studies were conducted to evaluate the effect of Pectoralis minor stretches and scapular muscle strengthening on the position of the scapula (Struyf et al. 2012a; Lynch et al. 2010; Tate et al. 2010; Ludewig and Borstad 2003). In all of these studies stretches of Pectoralis minor were a component of the intervention. The focus of these studies was to determine the effect of muscle stretches and scapular strengthening on shoulder function and posture (Table 2.2).

Techniques that were used to stretch Pectoralis minor in the different studies (Table 2.2) differed from one another. Struyf and colleagues (2012a) used a passive stretch where the therapist crossed hands with one hand on the coracoid and the other on the sternum (region of fourth rib). Lynch and colleagues (2010) used the principle of reciprocal inhibition. The swimmer had been positioned to lie supine over a roller, the gleno-humeral joint and elbows flexed to 90°; the gleno-humeral joint was abducted and the scapulae were actively retracted. Tate and colleagues (2010) also used a passive doorway stretch. The patient abducted and externally rotated the gleno-humeral joint to 90°, elbow flexed. With the forearm against the wall the patient turned the thorax away until a stretch was felt in Pectoralis minor. Ludewig and

Borstad (2003) used a similar stretch as Tate and colleagues (2010) except in this study both gleno-humeral joints had been abducted and externally rotated to 90° with the elbows flexed. This stretch was performed on adjacent walls and the patient then leaned into the corner.

Table 2.2: Summary of studies to determine the effect of muscle stretches and scapular strengthening on shoulder function and posture (Struyf et al. 2012a; Lynch et al. 2010; Tate et al. 2010; Ludewig and Borstad 2003) (Page 37-39).

Author and aim of study	Type of study	Intervention	Results / outcome	Critical analysis
Struyf et al. (2012a) To compare the effectiveness of a scapular focused treatment programme with control therapy.	Randomised controlled trial. (Level of evidence: 2) 22 patients with shoulder impingement; intervention n=10; control n=10 (2 patient were lost due to pain and contact loss).	<u>Experimental group:</u> Passive scapula mobilisation, stretches of Pectoralis minor, Rhomboids and Levator scapulae, scapular motor control training based on scapular orientation exercises, scapular muscle rehabilitation (Trapezius (middle and lower fibres) and Serratus anterior. <u>Control group:</u> Eccentric strengthening of rotator cuff muscles, elastic band shoulder exercises, friction massage, gleno-humeral mobilisations and ultrasound.	Statistical and clinical improvement for intervention group with ability to perform functional activities in daily life as well (Cohen's *d* = 0.93, p=0.025). A decrease in pain with movement was also clinically as well as statistically significant for the intervention group.	Randomisation well described. Assessor blinded for both groups. **Limitations:** No information on additional / different hobbies or sport that could influence program for participants. Both groups were evaluated after nine treatment sessions, but treatment had been ranging between four to eight weeks. The difference in weeks could possibly have influenced the outcome because motor retraining was one of the outcomes measured. The researchers used a PMI of 7.65 to differentiate between a short and long Pectoralis minor. This value is used from a study where the 'standard' was determined from a pilot group of only six participants . The

				ages of members of this pilot group are not known and it was used in this study for an age group of 30 – 60 years.
Lynch et al. (2010) To evaluate the effects of scapular retraining and stretches on posture and shoulder pain in competitive swimmers.	Randomised controlled trail. (Level of evidence: 2) 28 varsity level swimmers (intervention group n=14, control group n=14).	Intervention: Strengthening of Trapezius (middle and lower fibres) and Serratus anterior. Stretches of Pectoralis minor the upper cervical extensors. Control: continued with dry land programme as determined by swim club.	After eight weeks both groups showed a significant increase in muscle strength over time, however only the intervention group showed significant changes in the length of Pectoralis minor and the cervical extensors ($p<0.05$).	Block randomisation was used to adapt for the swimmers' training schedule. Descriptive data shows that both groups were equal at baseline. Examiner was not blinded to groups. Only the upper fibres of Serratus anterior were tested with active protraction. The lower fibres of Serratus anterior, active during scapula upward rotation were not evaluated. The stretch for Pectoralis minor is based on the principle of reciprocal inhibition. The stretch time of five seconds is questionable.
Tate et al. (2010) To provide a detailed description of a standardised progressive exercise and manual therapy	Case report. (Level of evidence: 4) Ten patients diagnosed with subacromial impingement.	Intervention: Manual therapy to mobilise the thoracic spine and gleno-humeral joint, stretching of thorax into extension, muscles stretches (Pectoralis minor,	After six weeks 6/10 patients were rehabilitated successfully and after 12 weeks 8/10 were successfully rehabilitated.	The methodology is clearly described. The outcome measures used are valid and reliable. The intervention was aimed at mobilisation of the thorax and gleno-humeral joint, stretches of the muscles and retraining of motor control of the scapular and

intervention programme for subacromial impingement syndrome.		Posterior Deltoid and posterior shoulder capsule, external and internal rotators and Lattisimus dorsi). Resisted gleno-humeral external-, internal rotation and extension. Scapular protraction, retraction and elevation.		gleno-humeral muscles. The outcome was evaluated with a shoulder function questionnaire and not specifically on each muscle's improvement. This report demonstrates the importance of a holistic intervention to increase shoulder function. The patients were supervised during the intervention eight to ten times which is in line with the recommended supervision sessions of 12 sessions over six weeks.
Ludewig and Borstad (2003) To evaluate an exercise programme intended to reduce shoulder pain and improve shoulder function.	Randomised controlled trail. (Level of evidence: 2) 67 symptomatic and 25 asymptomatic construction workers. Intervention (symptomatic) n=34, control (symptomatic) n=33, control n=25. Control (asymptomatic) n=25	Intervention: Pectoralis minor and posterior gleno-humeral capsule stretches, upper Trapezius relaxation, strengthening of Serratus anterior and the external rotators of the gleno-humeral joint. Control groups: No intervention.	The exercise programme reduced symptoms and improved function for the intervention group. The control group's outcomes remained unchanged over time.	Methodology is clearly described. Pectoralis minor is stretched in a 90° abducted and lateral rotation position. A passive stretch of 30 seconds, 5 times per day was done. The final evaluation was done eight to twelve weeks post baseline measurement. The researchers report that subjects stopped after eight weeks with the intervention programme. This discontinuation of the programme three to four weeks prior to final evaluation could have had an influence on the results.

In the latter three studies (Lynch et al. 2010; Tate et al. 2010; Ludewig and Borstad 2003) the gleno-humeral joint had been abducted and externally rotated during the Pectoralis minor stretch, the position where the soft tissue around the gleno-humeral joint is tight and the scapula is pulled into a posteriorly tipped and externally rotated position (Borstad and Ludewig 2006). In this posteriorly tipped and externally rotated position the coracoid is pulled posteriorly thus stretching the Pectoralis minor. The significant change in Pectoralis minor length ($p<0.05$) (Lynch et al. 2010), the significant change in shoulder function and decrease in shoulder pain (Ludewig and Borstad 2003) as well as the improvement in function for the patients diagnosed with subacromial impingement (Tate et al. 2010) confirm the efficacy of this position to stretch Pectoralis minor.

The effect of the swim stroke on Pectoralis minor

Although Pectoralis minor is not directly used in the swim stroke, the swim stroke affects Pectoralis minor directly. The effect of the swim stroke on Pectoralis minor can be explained in the following way: during freestyle (75% of all swim training includes freestyle) gleno-humeral adduction, flexion and medial rotation is frequently used; with 5000 strokes cycles per swim session (Pollard and Fernandez 2004) this movement combination often leads to a rounded shoulder and kyphotic posture, with the scapula in an anteriorly tipped position and adaptive shortening of Pectoralis minor (Riemann et al. 2011; Struyf et al. 2011b; Lynch et al. 2010; Sein et al. 2010).

Due to the high demand on the gleno-humeral joint for medial rotation during the swim technique, defective or late initiation of lateral rotation often causes a problem for swimmers (Yanai and Hay 2000). To compensate for insufficient lateral rotation during the recovery phase, the scapula tips anteriorly to allow sufficient range of movement. This continuous anteriorly tipped position of the scapula may also contribute to adaptive shortening of Pectoralis minor (Yanai and Hay 2000). Furthermore, this anteriorly tipped position of the scapula may have a detrimental effect on the ability of Pectoralis minor to contract. In the anteriorly tipped position Pectoralis minor is in a shortened position and this may affect the strength of Pectoralis minor to contract to the maximum in its functioning as an accessory breathing muscle which is essential for swimmers.

The literature regarding Pectoralis minor had been reviewed. With a stable scapula Pectoralis minor can act effectively as an accessory breathing muscle that elevates the upper ribs during high volume and strenuous breathing. Pectoralis minor is also the only muscle that attaches the scapula to the anterior chest wall. According to the literature Pectoralis minor shortens adaptively as a result of the overuse of gleno-humeral flexion and medial rotation (Struyf et al. 2012a; Tate et al. 2012; Lynch et al. 2010, Borstad and Ludewig 2005), a common phenomenon during swim training.

Scapula stability is dependent on ideal Pectoralis minor length but also on effective stabilisation of the scapula stabilisers (Trapezius middle and lower fibres and Serratus anterior). The third objective of this literature review is to investigate the function of the scapula stabilisers.

THE FUNCTION OF THE SCAPULA STABILISERS

An ideal aligned scapula serves as a stable base for the muscles attached to it. This stable base optimizes the length tension relationship of the muscles attached to scapula and assures optimum muscle function. A stable scapula will enhance the muscle strength of Pectoralis minor elevating the upper ribs, when contracting from origin to insertion (Agur and Dalley 2009; Nijs et al. 2007; Kendal et al. 2005; Levangie and Norkin 2001). The ideal scapula position, resting or dynamic, orientates the glenoid to allow for optimum gleno-humeral function (Arlotta et al. 2011). Trapezius and Serratus anterior are the muscles responsible for this ideal, stable positioning of the scapula. First the anatomy and function of Trapezius will be discussed followed by the anatomy and function of Serratus anterior. Trapezius and Serratus anterior as a force couple will be discussed. Finally the role of Trapezius and Serratus anterior in the swim stroke will be discussed.

Trapezius

Anatomy of Trapezius

The Trapezius muscle is one of the largest and most superficial back muscles. The origin extends from the external occipital protuberance, medial third of the nucheal line, ligamentum nuchae and the spinous processes from C7 to T12. The clavicular and descending (upper) fibres insert onto the lateral third of the clavicle and acromion process of the scapula. The transverse (middle) fibres insert onto the medial margin of the acromion and the superior lip of the spine of the scapula. The ascending (lower) fibres insert onto the tubercle at the apex of the spine of the scapula (Arlotta et al. 2011; Holtermann et al. 2009; Kendall et al. 2005). The action or agonistic function of the Trapezius muscle is described according to the muscle fibre orientation. The clavicular and descending fibres (upper) fibres elevate and upwardly rotate the scapula (Agur and Dalley 2009; Kendall et al. 2005), draw the clavicle, acromion and spine of the scapula posterior and medial (Arlotta et al. 2011) and when acting bilaterally it extends the cervical spine (Kendall et al. 2005). The transverse (middle) fibres move the scapula in the frontal plane closer to the spine (adduction / retraction) (Agur and Dalley 2009; Kendall et al. 2005). The ascending (lower) fibres depress (Agur and Dalley 2009) adduct and upwardly rotate the scapula (Arlotta et al. 2011; Kendall et al. 2005).

Function of Trapezius

The Trapezius muscle has different intra-muscular, anatomical as well as functional, subdivisions based on the different fibre orientation of the muscle (Holtermann et al. 2009). Several studies were conducted to determine the sequence of activation of the different fibres of Trapezius, the range of gleno-humeral movement where Trapezius is most active, and whether the different muscle fibres can contract separately on voluntary command (Arlotta et al. 2011; Holtermann et al. 2009; Kinney et al. 2008; Cools et al. 2007a; Johnson and Pandyan 2005; Cools et al. 2003a).

Recruitment pattern of Trapezius

Two studies were conducted to determine the effect of a sudden arm movement, from 90° abduction into adduction on the recruitment pattern of the Trapezius and Deltoid muscles. The one study was conducted on 30 healthy non-athletes (aged 18 – 25) (Cools et al. 2002). The other study was conducted on 39 (aged 16 – 35) overhead athletes with shoulder impingement and they were compared to 30 (aged 18 – 36) overhead athletes with no impingement (Cools et al. 2003a). The aim was to evaluate the timing of Trapezius and Deltoid activation when a sudden unexpected gleno-humeral joint movement occurs. During the evaluation the athletes were seated and the gleno-humeral had been tested at 90° abduction. The humerus, of the side that had been tested, were strapped to a Biodex System 2® isokinetic testing device; the device was set in the inactive mode ensuring that the athletes would not experience any resistance during the movement. The athletes wore masks and earphones to eliminate any visual or auditory input. The strapped arm had been dropped from the 90° abducted position and the athletes were instructed to intercept the moment they felt that their arms were falling. Electromyographic (EMG) data had been obtained from the upper, middle and lower fibres of Trapezius as well as the Deltoid muscle. In the study conducted on the non-athletes the effect of fatigue on muscle recruitment was also tested (Cools et al. 2002).

The first aspect to be compared from both studies was the activation pattern between Deltoid and the Trapezius muscles. In both studies (athletes and non-athletes) Deltoid was the first muscle to activate significantly faster than Trapezius on sudden gleno-humeral joint movement from abduction to adduction (Cools et al. 2002; Cools et al. 2003a). However, in the study on overhead athletes, the middle fibres of Trapezius in the control group on the dominant side activated much faster than Deltoid but showed no statistical difference to the activation of Deltoid (dominant side) (Cools et al. 2003a). This faster activation of middle Trapezius on the dominant side may be indicative of specific neuromuscular control and muscle recruitment adaptations in competitive athletes (Cools et al. 2003a).

The second aspect to be compared was the sequence of activation within the Trapezius muscle. In the study on the non-athletes and in the patient group of the overhead athletes the sequence of activation was: first the upper fibres of Trapezius, then the middle fibres and lastly the lower fibres (Cools et al. 2002; Cools et al. 2003a). There was no statistical significance between the activation times of the different muscle fibres in the non-athlete, healthy group and even after fatigue the sequence of muscle activation had been the same**.** However, after fatigue the time of activation was significantly slower for the upper and middle fibres of Trapezius compared to pre-fatigue activation demonstrating the effect of fatigue on the onset of muscle activation (Cools et al. 2002). The lower fibres also activated slower after fatigue but the difference in activation compared to pre fatigue was not significant (Cools et al. 2002). The sequence of activation within the control group of the overhead athletes showed a different activation order (Cools et al. 2003a). The middle fibres of Trapezius activated first on the dominant and non-dominant side, followed by the upper fibres and lastly the lower fibres, indicating again, the specific neuromuscular control in competitive athletes (Cools et al. 2003a).

The third aspect to be compared is the activation time within the Trapezius muscle. In the healthy non-athletes no statistical difference had been observed between the activation time of the different muscle fibres of Trapezius. Although activated as a unit, the lower fibres showed a delay in activation (Cools et al. 2002). In the group with impingement the non-injured side also revealed no statistical differences between the activation of the different fibres of Trapezius (Cools et al. 2003a). On the injured side Trapezius activated in the sequence as discussed above (first the upper muscle fibres, then the middle muscle fibres and lastly the lower muscle fibres) but with significant differences in the time of activation (Cools et al. 2003a). In the control group no significant difference had been observed between the three muscle parts for the non-dominant side. On the dominant side the lower fibres activated significantly later than the middle fibres of Trapezius (Cools et al. 2003a). From this information one may conclude that either the lower fibres have a tendency of delayed activation in comparison with the other fibres of Trapezius or in the case of competitive athletes, that the middle fibres activate earlier due to adaptive neuromuscular control needed by competitive athletes to stabilise the scapula.

Another study was conducted on 69 overhead athletes to determine the recruitment pattern within the Trapezius muscle during active abduction / adduction and external / internal rotation (Cools et al. 2007a). Thirty nine athletes with unilateral shoulder pain, on the dominant side, were included. Thirty overhead athletes with no history of shoulder pain were included as the control group. The variety of overhead sport activities for both groups had been equally distributed and there was no significant difference between the two groups regarding the anthropometric and demographic data. EMG data of the Trapezius muscle was collected while the athletes performed abduction / adduction and external / internal rotation. During abduction / adduction the upper fibres of Trapezius of the athletes with shoulder pain showed significant higher activation on the injured side ($p<0.01$) than on the non-injured side as well as compared to the dominant side of the control group ($p<0.0001$). The lower fibres of Trapezius showed a decreased activation in the athletes with pain (injured and non-injured side) compared to the control group ($p<0.003$). During external / internal rotation the upper fibres of Trapezius of the athletes with shoulder pain showed significant higher activation on the injured side (p<0.001) than on the non-injured side as well as compared to the dominant side of the control group (p<0.0001). The middle fibres of Trapezius showed a decreased activation in the athletes with pain (injured and non-injured side) compared to the control group (p<0.003).

The Trapezius muscle has anatomical and functional subdivisions. It has been demonstrated that the three different divisions contract separately. Dominance and overhead activity play a role in the sequence of activation of Trapezius (Cools et al. 2002; Cools et al. 2003a). In healthy non-athletes and patients diagnosed with shoulder impingement the upper fibres contract first, followed by the middle fibres and lastly the lower fibres. In healthy overhead athletes the middle fibres of Trapezius contract first (on sudden arm movements) of all the Trapezius muscle fibres and prior to Deltoid in order to counteract the lateral pull of Deltoid on the scapula (Cools et al. 2003a). However in the presence of fatigue or pain the upper fibres of Trapezius activate significantly faster when comparing to the ideal regardless of the shoulder movement (Cools et al. 2007a; Cools et al. 2003a; Cools et al. 2002). However, the lower fibres of Trapezius showed a significant delayed activation during abduction and adduction in the presence of fatigue or pain and the middle fibres of Trapezius showed a delayed activation during external and internal rotation during external and internal rotation (Cools et al. 2007a; Cools et al. 2003a; Cools et al. 2002).

Trapezius activity in different ranges of gleno-humeral movement

Studies were conducted on healthy volunteers to determine the activity and contraction of the different fibres of Trapezius in different ranges of gleno-humeral abduction (Kinney et al. 2008; Johnson and Pandyan 2005). EMG data was collected from the upper, middle and lower Trapezius. The activation of the different fibres of Trapezius was tested in prone with a static (isometric) hold (Johnson and Pandyan 2005), in prone with active horizontal abduction in various degrees of gleno-humeral abduction (Kinney et al. 2008) and in different starting positions (prone to standing) with different combinations of gleno-humeral movements (Ekstrom, Donatelli and Soderberg 2003). In the studies summarised in Table 2.3 it is clear that the upper fibres are more active before and up to 90° of gleno-humeral abduction (Johnson and Pandyan 2005) and the middle and lower fibres are most active from 90° - 120° (Kinney et al. 2008; Ekstrom et al. 2003).

Table 2.3: Studies to determine the activity of the different fibres of Trapezius in various ranges of gleno-humeral abduction (Kinney et al. 2008; Johnson and Pandyan 2005; Ekstrom et al. 2003) (Page 47-48).

Study	Subjects	Position	Ranges of abduction and resistance given	Findings	Critical analysis
Kinney et al. (2008) To investigate the activation patterns of the middle and lower Trapezius in four exercises.	Experimental design. (Level of evidence: 3) 32 healthy volunteers (18 – 35 years).	Prone with the gleno-humeral joint in various degrees of abduction.	75°, 90°, 120°, 160°. Ten repetitions of horizontal abduction in various degrees of abduction against the weight of the arm.	Optimal activation of lower and middle fibres of Trapezius was evident between 90° to 125° of abduction.	The methodology of the study is well described. The gleno-humeral joint is held in 45° lateral rotation (thumb facing the roof) from 75° to 160° compromising ideal gleno-humeral biomechanics as the lateral rotation should be less than 45° in 75° and more than 45° at 160°, however the aim of the study was to determine the activation of the trapezius muscle.
Johnson and Pandyan (2005).	Experimental design. (Level of evidence: 3) .	Prone with gleno-humeral joint in various degrees of abduction.	30°, 60°, 90°, 120°. Isometric maximal contraction against a floating carriage.	UT: Most active up to 90° of abduction. MT: Most active at 90°. LT: Most active 90° to 120°.	The methodology was well described but the study had a very small sample size (n=5). The subject's humerus was strapped in a cuff stabilising the gleno-humeral joint was in

To study the activity of the different muscle fibre regions of Trapezius under load.	5 healthy male volunteers (22 – 25)				abduction thus eliminating the activation of the lateral rotators and posterior Deltoid. The test was a pure isometric abduction and adduction contraction in prone still demonstrating the activation of the different parts of Trapezius in the various ranges of abduction.
Ekstrom et al. (2003).	Prospective, single group repetitive measures. (Level of evidence: 3) 30 healthy volunteers (22 – 46 years).	Prone, supine, standing and sitting.	Various degrees of abduction and a combination of abduction and rotation.	UT: Highest activity during the shoulder shrug (0° of abduction). MT: Highest activity in prone, raising the arm above the head in 125° abduction and in horizontal extension in 90° abduction with external rotation. LT: Highest activity in prone, raising the arm above the head in 125° abduction.	The methodology was well described. Care was taken to control the speed of the exercises during the EMG recordings. Speed and uncontrolled movements may have a negative effect on the EMG analysis. Trapezius activity was evaluated in a variety of positions from supported in prone to standing. The results show that the best activation of MT and LT to be in prone.

UT: upper fibres of Trapezius, MT: middle fibres of Trapezius, LT: lower fibres of Trapezius.

The different Trapezius fibres contract in a specific sequence and in different degrees of gleno-humeral abduction. It is also important to assess the strength and function of the muscle. Methods, used to assess muscle function, include electromyographic studies (EMG), handheld dynamometers and manual muscle testing (Cuthbert and Goodheart 2007; Kendall et al. 2005). Assessment should be cost effective, clinically applicable, valid and reliable (Nijs et al. 2007). The EMG and dynamometer are valid and reliable instruments to use to evaluate muscle function but these instruments are expensive and difficult to use in an ordinary clinical setting (Kendall et al. 2005).

In a literature review conducted by Cuthbert and Goodheart (2007) 110 studies were evaluated to determine the reliability and validity of manual muscle testing. Randomised control trials, studies where the examiner was blinded and studies where pre- and -post tests had been done, were evaluated. Studies were excluded if not published in a peer review journal. In the review it was found that manual muscle testing is reliable but the clinical expertise and experience of the examiner is highlighted. Other factors contributing to interrater- and intrarater reliability are: a standardised protocol on the testing procedure and patient positioning (Cuthbert and Goodheart 2007). Validity is defined as 'the degree to which a meaningful interpretation can be inferred from a measurement or test' (Cuthbert and Goodheart 2007).

Manual muscle testing has been found to be valid as it showed significant decreased muscle strength in patients complaining of upper limb pain (Cuthbert and Goodheart 2007). The validity of manual muscle testing was measured against quantitative instruments like the EMG and dynamometer and it was also found to be a valid method of evaluation in the clinical setting (Cuthbert and Goodheart 2007).

Manual muscle testing evaluates the ability of the muscle to adapt to and meet the challenges set by the examiner. The following factors should be kept in mind when manual muscle testing is used in the clinical and research settings: ideal positioning to test the agonistic function of the muscle (the muscle as the prime mover), adequate stabilisation to isolate muscle function to the most, observation on how the patient maintains or adapt to the test position (trick movements) and observation on how the patient performs the test (concentric contraction to the full range of motion, inner range hold and eccentric control) (Cuthbert and Goodheart 2007; Magarey and Jones 2003). The data on specific activation (Kinney et al.2008; Johnson and Pandyan 2005, Ekstrom et al. 2003) of the different fibres of Trapezius in different degrees of abduction confirms the test for muscle strength as described by Kendall et al. (2005).

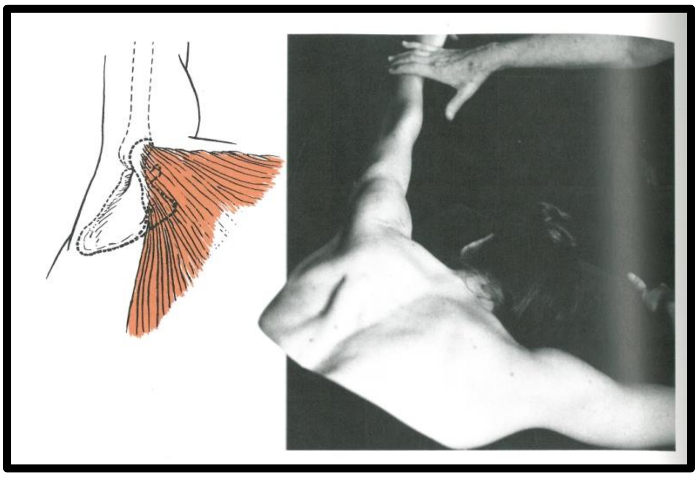


Figure 2.2: Evaluation of muscle strength of lower fibres of Trapezius (Kendall et al. 2005:330).

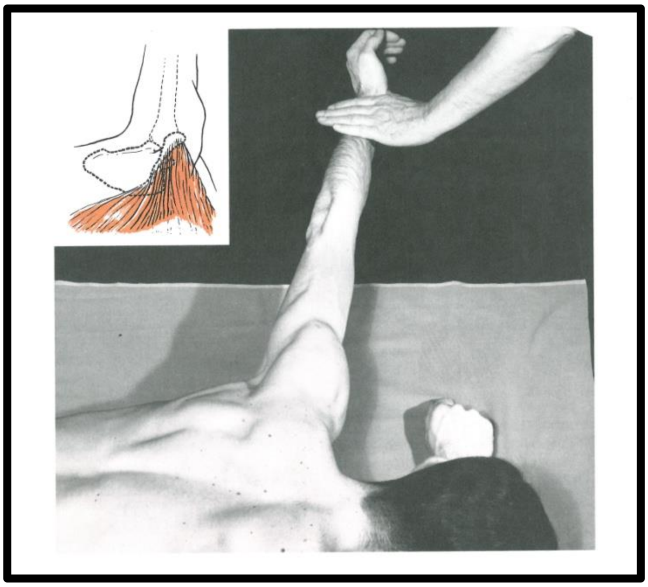


Figure 2.3: Evaluation of muscle strength of middle fibres of Trapezius (Kendall et al. 2005:329).

The middle and lower fibres of Trapezius are most active between 90° to 120° of gleno-humeral abduction. This experimental data is confirmed in studies where different exercises had been done to strengthen the muscle (Kinney et al.2008; Johnson and Pandyan 2005, Ekstrom et al. 2003). The muscle activity of the different fibres of Trapezius was evaluated as well as the ratio of activation between the different fibres during each exercise (Table 2.3).

When the studies referred to in Table 2.4 are compared, it is evident that the lower and middle fibres of Trapezius activate above 90° of gleno-humeral flexion or abduction. In this position of flexion or abduction the middle and lower Trapezius fibres activate during active gleno-humeral movements (Cools et al. 2007b), when the gleno-humeral joint is static (in a specific position) and the scapula retracts (Oyama et al. 2010) and with manual resistance against gleno-humeral movements (Arlotta et al. 2011). Arlotta and colleagues (2011) found that the middle fibres of Trapezius were active in all the exercises performed (Table 2.4); even with those where the gleno-humeral joint was in abduction between 0° - 75°. This is contradicting to other research (Kinney et al. 2008; Ekstrom et al. 2003) where activation of the middle fibres of Trapezius was the most above 75° abduction. A possible explanation for the results obtained by Arlotta and colleagues (2011) could be the component of gleno-humeral external / lateral rotation in all the exercises: the gleno-humeral joint was either in external rotation or the resistance given was against external rotation. This external rotation will cause the lateral rotators (Teres minor and Infraspinatus) to contract and the lateral displacement of the scapula results in activation of the middle fibres of Trapezius (Cools et al. 2003a). De Mey and colleagues (2012) demonstrated that strengthening exercises of the Trapezius and Serratus anterior muscle resulted in significant pain relief and more ideal recruitment of the scapula stabilisers in anticipation and during active movement. They further demonstrated that specific exercises over six weeks had an effect on scapular movement during a functional activity (abduction).

Trapezius has different intra-muscular, anatomical as well as functional, subdivisions based on the different fibre orientation of the muscle (Holtermann et al. 2009). During sudden arm movements or active movements the muscle follow a specific recruitment pattern; first the upper fibres contract followed by the middle and lower fibres. In overhead sport the muscle demonstrate specific neuromuscular control and adaptations and the order of recruitment change; first the middle fibres, followed by the upper and then the lower fibres.

Table 2.4: Summary of studies conducted to determine the selective activation and strengthening of the Trapezius muscle in various starting and gleno-humeral joint positions (De Mey et al. 2012; Arlotta et al. 2011; Oyama et al. 2010; Cools et al. 2007b) (Page 53-56).

Study	Subjects	Exercise	Findings	Critical analysis
De Mey et al. (2012)	Case series.(Level of evidence: 4) 40 overhead athletes (mean age 24.6). To evaluate the effect of scapular exercises on pain, muscle activation and onset timing during gleno-humeral elevation.	***Prone*** Prone extension: Gleno-humeral joint in 90° flexion, no rotation – extension to neutral. Prone horizontal abduction with external rotation: 90° flexion, do horizontal abduction with external rotation at end of range. ***Side lying*** Forward flexion in side lying: 90° of flexion in side lying External rotation side lying: Gleno-humeral joint neutral, elbow 90° flexion.	A statistical decrease in shoulder pain was observed ($p < 0.001$). A change in activation levels of UT, MT, LT and Serratus anterior was observed. After the six week intervention the activation of the LT was significantly earlier than MT and UT ($p<0.001$). Serratus anterior activated significant earlier than UT ($p<0.001$), MT ($p<0.001$) and LT ($p<0.46$) after the six week intervention.	Methodology well described Study conducted on overhead athletes with shoulder impingement symptoms for more than three months. The effect of exercises was evaluated on scapular function during gleno-humeral abduction and ideal muscle recruitment – not only isolated muscle function.
Arlotta et al. (2011)	Experimental design. (Level of evidence: 3) 18 healthy volunteers (mean age 23.9).	***Seated and prone*** Manual resistance. Lattisimus pull – down: 90° abduction. Posterior fly: 90° abduction and external rotation. Prone V – raise: 120° abduction, full flexion and external rotation.	UT: highest activity in Prone V and Posterior fly. LT: Highest activity in Lattisimus pull – down, prone row and modified cobra.	Methodology well described. During the exercises manual resistance was given and this could differ from one to the other, however the same researcher gave manual resistance to all the participants. The amount of resistance was defined as enough

	Evaluated lower Trapezius activation in five isometric exercises.	<u>Prone row:</u> Gleno-humeral extension elbows flexed. <u>Modified prone cobra:</u> Trunk extension, external rotation, retraction and depression.	MT: not one exercise where MT dominate, not one exercise where minimally active – difficult to isolate from LT.	to break the maximal contraction of the participant. MT was activated in all five exercises and not only in exercises with the gleno-humeral joint above 75° of abduction. This could possibly be because of the external rotation component of the gleno-humeral joint or the direction resistance was applied during the exercise.
Oyama et al. (2010)	Controlled laboratory study. (Level of evidence: 3) 25 healthy volunteers (mean age 23.2 ±2.4 years). To evaluate muscle activity and scapular kinematics during six retraction exercises.	***Prone*** Positioned, scapula retraction with different degrees of abduction and rotation (90° abduction, neutral, 90° abduction and external rotation, 120° abduction and neutral, 120° and external rotation, 45° abduction and 90° elbow flexion, no abduction, with extension). 3 repetitions, 6 second muscle contraction/repetition, 10 seconds rest between repetitions.	<u>90° abduction and external rotation:</u> Significant multiple axis scapular movement from neutral: external rotation, upward rotation, posterior tip and retraction. <u>120° abduction and neutral:</u> Significant more upward rotation than all the other exercises. <u>120° abduction and external rotation:</u> Significant more upward rotation than all the other exercises. More activation of UT and MT than 90° abduction in neutral and extension, LT activated more than in the 90°	Methodology well described. Scapular retraction exercises were done in prone in various positions of the gleno-humeral joint.

			abduction neutral and external rotation position. 45° abduction and 90° elbow flexion: Significant multiple axis scapular movement from neutral: external rotation, upward rotation posterior tip and retraction. No abduction, with extension: Significant scapular depression from neutral. Exercise indicated to activate LT with low activity from UT	
Cools et al. (2007b)	Controlled laboratory study. (Level of evidence: 3) 45 healthy volunteers (mean age 20.7 ± 1.7 years) To evaluate the effect of 12 exercises on the UT/LT, UT/MT and UT/SA ratios.	***Prone*** Abduction: 90° abduction with external rotation. Horizontal abduction: 90° flexion, abduction to horizontal position. Horizontal abduction with external rotation: 90° flexion, abduction to horizontal position and external rotation at the end of movement. Extension: 90° of flexion, extension to neutral, no rotation.	*Low UT/LT ratio *Concentric:* horizontal abduction with external rotation, side lying external rotation, side lying forward flexion. *Low UT/MT ratio *Concentric:* side lying external rotation, side lying forward flexion and prone extension. *(Low UT activation measured against a high LT / MT activation).	Methodology well described. Exercises performed in random order. Exercise execution was controlled (3 seconds) and different aspects of muscle function were addressed: concentric shortening, isometric hold and eccentric control. The amount of weight and resistance were based on gender and body weight.

	Exercises performed in three phases: concentric, isometric, eccentric (each three seconds), 5 trials of each exercise, three seconds rest between trials. Exercises were randomised.	***Side lying*** Forward flexion: Gleno-humeral joint flexion to 135°. External rotation: Gleno-humeral joint neutral, elbow 90° flexed, external rotation. ***Sitting*** Rowing: Gleno-humeral joint 90° flexion, pulley, extension with elbows flexed. Scaption with external rotation: elevation 30° into frontal plane. ***Standing*** Flexion: maximal flexion in sagittal plane. High row: 135° flexion, vertical pulley, extension to neutral. Low row (1): 45° flexion, pulley, extension with elbows extended. Low row (2): 45° flexion, pulley, extension with elbows extended.		Good variety of starting positions for performing the exercises. Out of the 12 exercises performed six were in sitting or standing and six in lying prone.

UT: upper fibres of Trapezius, MT: middle fibres of Trapezius, LT: lower fibres of Trapezius.

When the patient is fatigued or the scapula is mal-aligned the upper fibres of Trapezius become significantly overactive and the lower and middle fibres become significantly delayed in activation. This delayed activation of the middle and lower fibres of Trapezius has a direct influence on scapula function. Serratus anterior, together with Trapezius, is responsible for ideal scapular upward rotation, posterior tipping and external rotation.

SERRATUS ANTERIOR

Anatomy of Serratus anterior

Serratus anterior, which forms the medial wall of the axilla, originates from the outer and superior borders from ribs one or two to ribs seven to ten and from the aponeuroses that covers the corresponding intercostal muscles (Agur and Dalley 2009; Kendall et al. 2005; Ekstrom et al. 2004). The two upper muscular digits converge and insert into a triangular area on the ventral surface of the superior angle of the scapula. The next two to three digits spread thinly and insert into the medial (vertebral) border of the scapula. The lower three to six digitations from the fourth to the ninth rib converge and insert into a triangular impression on the ventral surface of the inferior angle of the scapula (Agur and Dalley 2009, Ekstrom et al. 2004). The upper fibres of Serratus anterior (upper four digitations) abduct and protract the scapula. The lower part of Serratus anterior rotates the inferior angle of the scapula laterally and the glenoid cranially (Agur and Dalley 2009, Kendall et al. 2005, Ekstrom et al. 2004). In addition the upper fibres may assist in scapula elevation and the lower fibres in scapular depression (Kendall et al. 2005). Serratus anterior keeps the medial border of the scapula against the thoracic wall (Agur and Dalley 2009).

Function of Serratus anterior

In a prospective single group repeated measures study, the function of the upper and lower parts of Serratus anterior was evaluated (Ekstrom et al. 2004). Nine different muscle tests had been done on twenty nine healthy subjects (aged 22 – 33) to determine if the upper and lower fibres of Serratus anterior have different functions. EMG activity of Serratus anterior was recorded. The upper fibres are those that originate from ribs one to four and the lower fibres originate from the ribs below the fourth rib (Table 2.5).

Table 2.5: Summary of muscle tests to determine the activity of different fibres of Serratus anterior (Ekstrom et al. 2004).

Gleno-humeral position	**Fibres activated**	**Maximum voluntary isometric contraction %**
Flexed to 90° (Push up plus) (body weight is resistance).	Upper fibres	78 ± 24♣
	Lower fibres	72 ± 17
Flexed to 90°, adducted and externally rotated (Resistance applied in the direction of abduction and extension and to the lateral border of the scapula).	Upper fibres	68 ± 21
	Lower fibres	73 ± 26
Flexed to125° and protracted (Resistance in the direction of extension and the lateral border of the scapula).	Upper fibres	62 ± 27
	Lower fibres	69 ± 19
Flexed to125° (Resistance in the direction of extension and the lateral border of the scapula).	Upper fibres	60 ± 22
	Lower fibres	83 ± 17 ($p<0.001$)*
Gleno-humeral joint in 90° of flexion and protraction (Resistance applied through the longitudinal axis of the humerus).	Upper fibres	54 ± 27♣
	Lower fibres	47 ± 29
Abducted 125° in plane of scapula (Resistance applied in direction of adduction).	Upper fibres	65 ± 23
	Lower fibres	81 ± 16 ($p<0.01$)*
Abducted to 90° (Resistance applied in the direction of adduction).	Upper fibres	60 ± 26
	Lower fibres	72 ± 24 ($p<0.01$)*
Horizontal adduction to end range and protraction (Resistance through the longitudinal axis of the arm).	Upper fibres	40 ± 21♣
	Lower fibres	32 ± 18
Horizontal adduction to the end range and protraction (Resistance through the longitudinal axis of the arm).	Upper fibres	39 ± 20♣
	Lower fibres	36 ± 24

* Lower fibres of Serratus anterior significantly more active than upper fibres. ♣ Upper fibres more active than lower fibres (not significant)

The tests where upward rotation of the scapula was primarily resisted showed a significant activation of the lower fibres of Serratus anterior (Table 2.5 marked with*). The four tests where protraction to the end range was the major component of the tests showed that the activation of the upper fibres was more than the activation of the lower fibres although not significantly different (Table 2.5 marked with a ♣). The test mostly prescribed to test the agonistic function of Serratus anterior, prone with the gleno-humeral joint in 90° flexion and scapula protraction, showed better activation of the upper fibres but relatively low activation of the whole muscle (Kendall et al. 2005; Ekstrom et al. 2004). The push up plus showed relatively high activation for the upper and lower fibres. During this push up plus the scapula is protracted in a weight bearing position, during the 'plus' phase where the thorax is actively displaced posterior, the scapula is in a upward rotated position and this might explain the relatively high activation of the upper and lower fibres (Kendal et al. 2005; Ekstrom et al. 2004).

Several studies were conducted (Table 2.6) to determine the activity of Serratus anterior during various exercises (Cools et al. 2007b; Hardwick et al. 2006; Ekstrom et al. 2003; Decker et al. 1999).

From the studies summarised in Table 2.6 one may conclude that Serratus anterior is better activated in exercise above 90° of gleno-humeral elevation. This position above 90° of elevation requires upward rotation of the scapula. Ekstrom et al. (2004) concluded that the lower fibres of Serratus anterior are more activated when the scapula is in upward rotation. The studies in Table 2.5 confirm this observation.

Table 2.6: Summary of studies to determine the activation of Serratus anterior during various types of exercises (Cools et al. 2007b; Hardwick et al. 2006; Ekstrom et al. 2003; Decker et al. 1999) (Page 60-63).

Study	Subjects and aim of study	Exercise	Findings	Critical analysis
Cools et al. (2007b)	Controlled laboratory study. (Level of evidence: 3) 45 healthy subjects (mean age 20.7 ±1.7 years) To determine the activation ratio of Serratus anterior, middle fibres of Trapezius and lower fibres of Trapezius with the upper fibres of Trapezius.	***Prone*** Abduction: 90° horizontal abduction with external rotation. Horizontal abduction: 90° flexion, abduction to horizontal position. Horizontal abduction with external rotation: 90° flexion, abduction to horizontal position and external rotation at the end of range. Extension: 90° of flexion, extension to neutral, neutral rotation. ***Side lying*** Forward flexion: Gleno-humeral joint flexion from 0° to 135° External rotation: Gleno-humeral joint neutral, elbow 90° flexed, external rotation of gleno-humeral joint. ***Sitting*** Rowing: Gleno-humeral joint in 90° flexion, pulley, extension with elbows flexed.	In the category of concentric activation all the exercises activated Serratus and upper fibres of Trapezius equally. In the category of isometric hold Serratus was best activated in the high row exercise In the category of eccentric control forward flexion and scaption with external rotation activated Serratus the best.	Methodology well described. Exercises performed in random order. Exercise execution was controlled (3 seconds) and different aspects of muscle function were addressed – concentric shortening, isometric hold and eccentric control. The amount of weight and resistance were based on gender and body weight. Good variety of starting positions for performing the exercises. Out of the 12 exercises performed six were in sitting or standing and six in lying prone.

		Scaption with external rotation: elevation 30° into frontal plane. ***Standing*** Flexion: maximal flexion in sagittal plane. High row: 135° flexion, vertical pulley, extension to neutral. Low row (1): 45° flexion, pulley, extension with elbows extended. Low row (2): 45° flexion, pulley, extension with elbows extended.		
Hardwick et al. (2006)	Single group repeated measures design. (Level of evidence: 3) 20 healthy subjects aged, 23 – 41 years). To determine if the 'Wall slide' exercise activates Serratus anterior above 90° of gleno-humeral elevation.	Wall slide: Gleno-humeral joint in 90° flexion, elbow flexed and ulnar border against wall. Slide into full gleno-humeral elevation (in scapular plane) and protract scapulae. Push up plus.	At 90° of gleno-humeral elevation the activation of Serratus anterior in all three exercises was similar. In the exercises above 90° the wall slide and elevation in the scapular plane elicited significantly higher ($p<0.0001$) activity in Serratus anterior.	Methodology well described. All exercises performed in standing. The aim of the study was to compare the activation of Serratus anterior in three exercises – therefore the inclusion of healthy subjects is not a limitation.

Ekstrom et al. (2003)	Prospective, single-group repeated measures design. (Level of evidence: 3) 30 healthy subjects, aged 22 – 46 years. To determine which high intensity exercise has the highest EMG activity for Serratus anterior and Trapezius.	Diagonal exercise with gleno-humeral flexion, horizontal flexion and external rotation. Gleno-humeral abduction > 120° in scapular plane. Gleno-humeral abduction < 80° in scapular plane. Unilateral shoulder press. 90° abduction with external rotation of the gleno-humeral joint. Bilateral scapular protraction. 135° gleno-humeral flexion, in line with lower Trapezius fibres. Unilateral shoulder shrug. Unilateral row. Horizontal extension and external rotation.	More activity within Serratus anterior where upward scapular rotation is part of the exercise: the combination of gleno-humeral flexion (90°), horizontal flexion and external rotation and gleno-humeral abduction (> 120°) in scapular plane.	The methodology was well described. Great care was taken to control the speed of the exercises during the EMG recordings. Speed and uncontrolled movements may have a negative effect on the EMG analysis.

Decker et al. (1999)	Experimental design. (Level of evidence: 3) 20 healthy male subjects (age 30.4 ± 5.1 years). To determine which exercise has the highest EMG activity for Serratus anterior.	<u>Push up plus:</u> Prone, push up and full scapula protraction added. <u>Knee push up plus:</u> Same as push up plus, weight on knees and not feet. <u>Press up:</u> Seated, feet off the floor, elbows and trunk flexed hands next to hips. Raised body off chair by extending the elbows. <u>Shoulder extension:</u> Gleno-humeral extension from 0° to the end of extension range against elastic band with elbow flexed. <u>Serratus anterior punch:</u> Gleno-humeral joint in 90° flexion, 45° medial rotation, elbow extended, scapula protraction and retraction. <u>Forward punch:</u> Gleno-humeral joint in 90° flexion, elbow extension. <u>Scaption:</u> Gleno-humeral joint in 45° external rotation, elbow extended. With dumbbell full elevation in scapular plane. <u>Dynamic hug:</u> Gleno-humeral joint in 60° abduction, internal rotation 45° and elbows flexed. Horizontal adduction, elbow extension, full internal rotation and scapular protraction (hug).	Exercises with scapular rotation and protraction elicited highest EMG scores for Serratus anterior: dynamic hug, Serratus anterior punch, knee push up plus and push up plus.	Only males were included in the study. Participation in sport or any overhead activity was not mentioned. Exercise execution was well controlled and standardised for all the participants.

Trapezius and Serratus anterior force couple

Trapezius middle and lower fibres as well as Serratus anterior are the muscles responsible to position the scapula during gleno-humeral movement. The most upward rotation of the scapula occurs during the mid-range of gleno-humeral elevation (80° - 140°) (Ekstrom et al. 2003). From the literature reviewed it is evident that Trapezius (middle and lower fibres) as well as Serratus is most active in the ranges above 90° of gleno-humeral flexion / abduction contributing to the dynamic stability of the scapula (Cools et al. 2007b; Hardwick et al. 2006; Ekstrom et al. 2003; Decker et al. 1999). Trapezius and Serratus anterior are the only two muscles that rotate the scapula upwards. The main function of this force couple is to stabilise the scapula during gleno-humeral movement (Magarey and Jones 2003). This force couple is discussed in the following paragraph.

The movement of the scapula during gleno-humeral flexion and abduction will be discussed in the section about the dynamic positioning of the scapula. The muscle activation and contribution to scapular movement will firstly be explored.

In the initial phase of gleno-humeral elevation (0° - 30° abduction and 0° - 60° flexion) the lower and upper fibres of Trapezius are recruited to ensure a stable scapula (Cools et al. 2003a; Cools et al. 2003b). The axis of rotation of the scapula is near the root of the spine of the scapula (Figure 2.4 [A]). Upper fibres of Trapezius and Serratus anterior are the main upward rotators. The main function of middle and lower fibres of Trapezius is to eccentrically control the movement. From this initial phase of gleno-humeral flexion / abduction to 120° the axis of rotation moves along the spine of the scapula (Figure 2.4 [B]). The muscle contribution to movement change as the lower fibres of Trapezius become more active in the upward rotation together with the upper fibres of Trapezius and Serratus anterior. Effective recruitment of the lower fibres of Trapezius results in posterior tipping of the scapula. This combination of upward rotation and posterior tipping ensures optimum positioning of the glenoid fossa. From 120° to 180° of elevation the lower fibres of Trapezius and Serratus anterior upwardly rotate, posteriorly tip and externally rotate the scapula. The axis of rotation of the scapula is now at the acromioclavicular joint (Figure 2.4 [C and D]). Insufficient activation and control of Trapezius and Serratus anterior result in a downward rotated, anteriorly tipped and internally rotated scapula and this position of the scapula is associated with sub acromial impingement (Struyf et al. 2014; Nijs et al. 2007; Magarey and Jones 2003; Cools et al. 2003a; Cools et al. 2003b; Magarey and Jones 2003; Levangie and Norkin 2001).

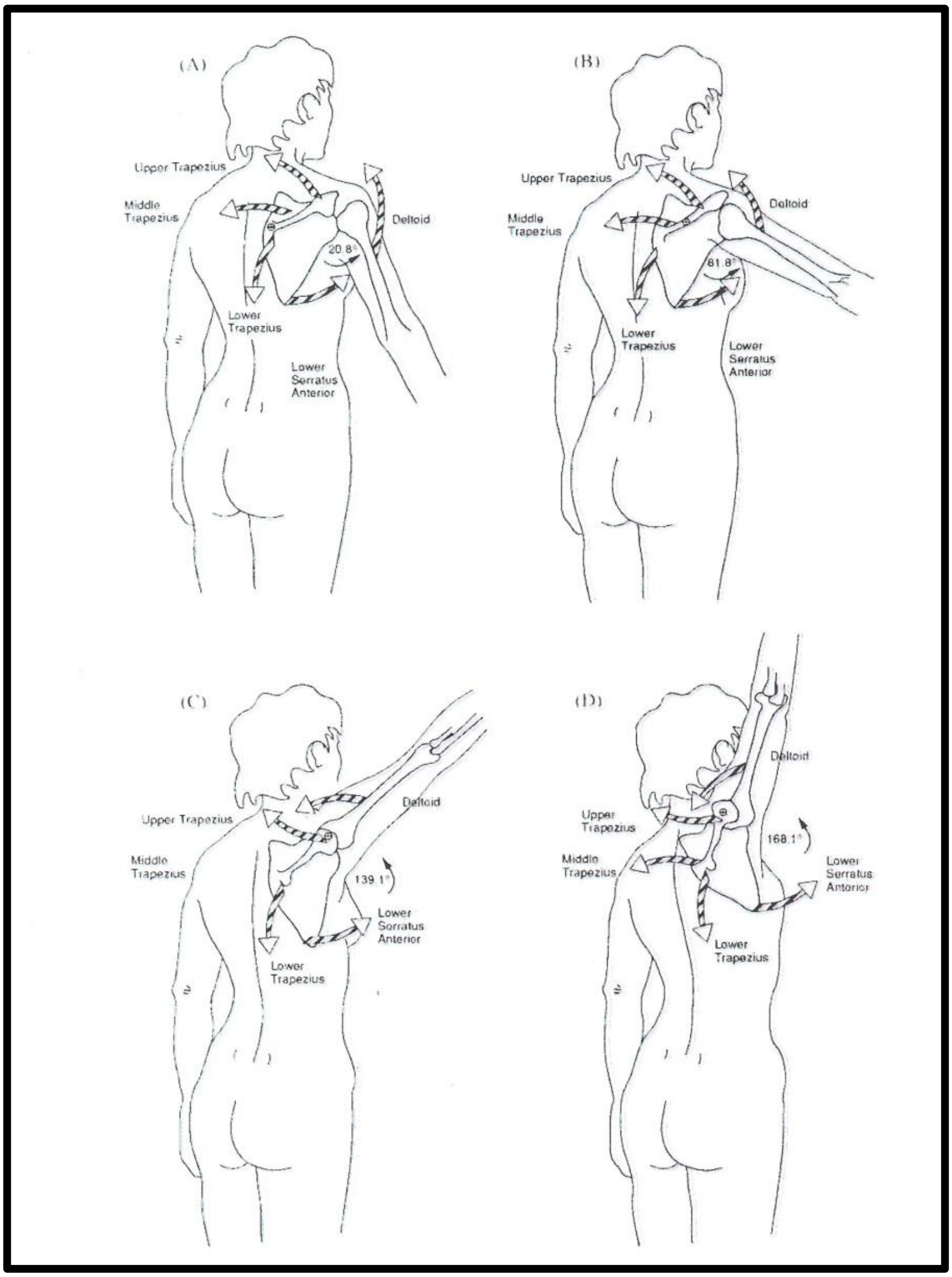


Figure 2.4: Force couples around the scapula (Magarey and Jones 2003).

The anatomy and function of the scapula stabilisers have been reviewed. The involvement and activation of the scapula stabilisers during the freestyle swim stroke are discussed subsequently.

Muscle function during freestyle swim stroke analysis

The freestyle stroke had been biomechanically analysed by Heinlein and colleagues (2010). The stroke is divided into three phases; glide / reach, pull through and recovery (Figure 2.5). During the glide, early pull through and recovery phases the elbow is slightly higher than the shoulder. This implies a position of gleno-humeral abduction.

The recovery phase is much faster than the pull through phase because there is no water resistance to slow down the movement. The pull through phase can be compared to close kinematic chain mechanics; as the hand reaches forward the body is pulled over the hand to propel the body in the water.

Serratus anterior functions at 75% of its maximum strength during the entire swim stroke (Fernandez et al. 2012; Heinlein et al. 2010; Pollard and Fernandez 2004). During the recovery phase Serratus anterior plays an important role to assure upward rotation of the scapula. In the pull through phase, due to the close kinematic mechanics, Serratus anterior assists in protraction of the scapula.

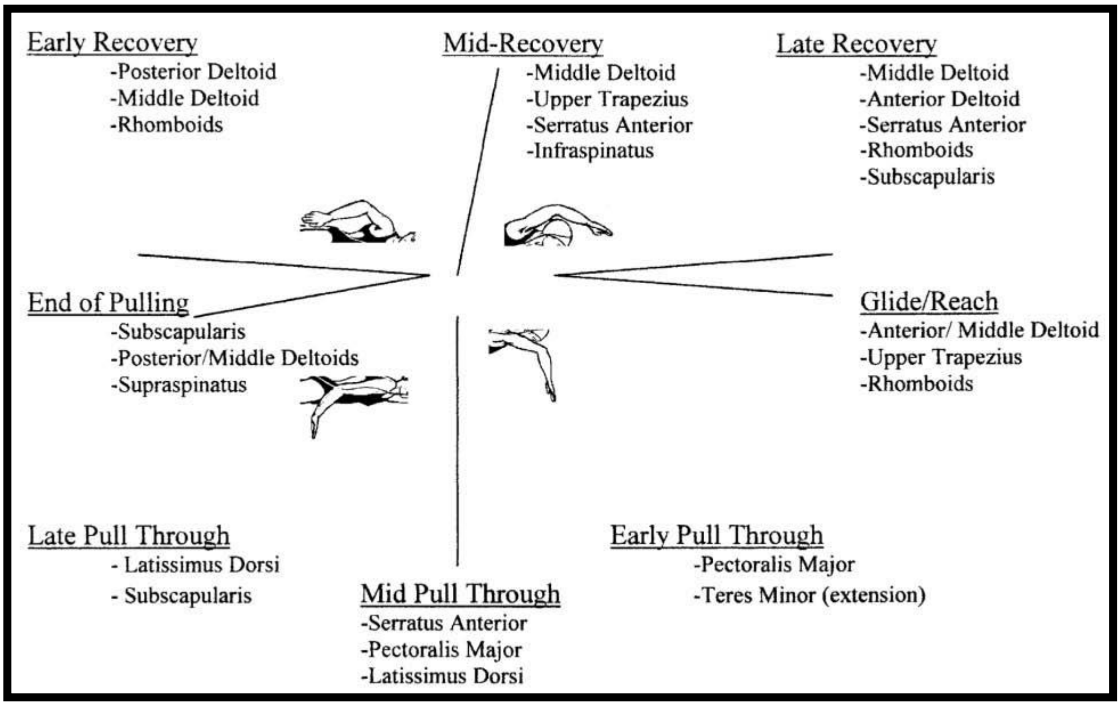


Figure 2.5: Muscle activity of the freestyle stroke based on electromyographic and cinematographic analysis (Heinlein et al. 2010).

Although not mentioned in Figure 2.2 the middle fibres of Trapezius are activated from the recovery to the early pull through phase (Pollard and Fernandez 2004). The gleno-humeral joint is in abduction during these phases and as shown by Cools et al. (2003a) the middle fibres of Trapezius contract to counteract the activation of Deltoid. No activation of the lower fibres of Trapezius is noted.

To summarise the Trapezius and Serratus anterior muscles are responsible to position the scapula during gleno-humeral joint movements. Research showed that activation of Trapezius (lower and middle fibres) is delayed when the athlete is fatigued or has a painful shoulder (Cools et al. 2003a). The upper fibres of Trapezius are active from the beginning range of elevation but the range between 90° to 135° showed the most activation for the middle and lower fibres of Trapezius. The upper fibres of Serratus anterior protract the scapula but the lower fibres assist the scapula in upward rotation. The interaction and simultaneous contraction of Trapezius and Serratus anterior result in a force couple that position the scapula optimally. This ultimate positioning of the scapula, specific to this study, has dual importance. Firstly, when the scapula is stable and well positioned Pectoralis minor has a stable base to contract from origin to insertion, elevating the upper ribs during forceful inspiration. Secondly, a stable well aligned scapula will contribute to optimum control and function of the scapula stabilisers during gleno-humeral movements. The muscles that contribute to scapula stability have been discussed. The ideal position of the scapula, resting as well as dynamic, will further be explored.

The fourth objective of the literature review is to investigate the ideal position of the scapula, resting as well as dynamic. Tests to evaluate the ideal position are reviewed.

RESTING POSITION OF THE SCAPULA

The scapula serves as a stable base for muscle attachments, such as Pectoralis minor. Good alignment of the scapula is needed in a resting as well as dynamic position to ensure a good tension length relationship for muscles attaching to the scapula. This stable base will ensure good force production from muscle originating from and inserting onto the scapula. Mechanically the scapula plays a vital role in the coupled movement between the humerus and the scapula, the so called scapulo humeral rhythm, contributing to shoulder girdle mobility and stability (Kibler et al. 2013; Struyf et al. 2012b; Tate et al. 2012; Bak 2010).

This section of the literature review therefore aims to investigate the relevant information necessary to understand ideal scapular positioning, function and biomechanics in normal function. Methods to evaluate the scapula position are analysed.

Ideal resting position of the scapula

The resting position of the scapula is the position the scapula assume when an individual is standing with normal posture (habitual posture for the specific individual) (Sobush et al. 1996). The ideal resting position of the scapula contributes to ideal gleno-humeral function as well as ideal function of the muscles attached to it, like Pectoralis minor. Scapular positioning must be optimal in relation to the thorax as well as the humerus. In relation to the thorax this ideal position of the scapula will ensure ideal positioning of the muscles that attach to the scapula and that have an effect on humeral movement. In relation to the humerus this ideal position is vital for good positioning of the glenoid. This optimum positioning of the glenoid ensures good stability and mobility of the gleno-humeral joint (Struyf et al. 2012b; Nijs et al. 2007; Levangie and Norkin 2001; Mottram 1997; T'jonck and Lysens 1996).

Methods to describe the resting position of the scapula

Different methods are used to describe the scapula's resting position. The first method to describe the resting scapula position is to compare specific bony landmarks on the scapula with specific thoracic bony marks. Surface palpation of the scapula is a valid method of determining the actual position of the scapula (Lewis et al. 2002). These bony marks include:

- The scapula should be 30° - 40° forward to the frontal plane and 10°- 20° anteriorly tipped from the vertical on the posterior thoracic wall (Struyf et al. 2012b; Nijs et al. 2007; Levangie and Norkin 2001; Mottram 1997; T'jonck and Lysens 1996)
- The medial border of the scapula is parallel to the thoracic spinous processes (Struyf et al. 2012b; Nijs et al. 2007; Levangie and Norkin 2001; Mottram 1997; T'jonck and Lysens 1996)

- The medial border should be flat against the chest wall (Nijs et al. 2007)
- The superior angle is level with the spinous processes of the thoracic vertebrae T2 and T3 (Struyf et al. 2012b; Nijs et al. 2007; Levangie and Norkin 2001; Mottram 1997; T'jonck and Lysens 1996)
- The root of the spine of the scapula is projecting to T3 / T4 (Mottram 1997; Sobush et al. 1996)
- The inferior angle of the scapula is in line with T7 – T9 and is more lateral than the superior angle (Struyf et al. 2012b; Haneline et al. 2008; Nijs et al. 2007; Mottram 1997; Sobush et al. 1996; T'jonck and Lysens 1996)
- The inferior angle should be flat against the chest wall (Nijs et al. 2007)
- The scapula on the dominant side is lower and further away from the spine (Struyf et al. 2012b; Haneline et al. 2008 Nijs et al. 2007; Mottram 1997).

Discrepancy exists on the exact thoracic level that corresponds to the inferior angle of the scapula. Sobush et al. (1996) conducted a study to evaluate the scapula position in healthy females (19 – 21 years) and reported that the inferior angle of the scapula can be as low as the spinous process of T10. In this study only fifteen female subjects had been evaluated (Sobush et al. 2006). Markers were placed on specific bony marks and an x-ray was taken of each subject. The x-rays were evaluated and only two of the fifteen subjects had a scapula with the inferior angle as low as T10. Haneline and his colleagues (2008) did a study to determine which spinal segment most closely corresponds to the level of the inferior angle of the scapula. They evaluated 49 x-rays (25 male and 24 female) taken from subjects standing, feet at ease, arms by side and the back touching a plate. They found that T8 spinous process was in 33% of the subjects the most common spinal segment to correspond to the inferior angle of the scapula. In this study the range of spinal segments varied also from T7 to T10. This wide range (T7 to T10) can be explained by a cadaveric study (Sran et al. 2004). They found that the length of the thoracic spinous processes from T5 to T8 can vary from 2.6 cm to 4.5 cm, explaining the corresponding spinal segment range from T7 to T10.

The second method to describe the resting position of the scapula is to measure distances between the thoracic spine and scapula (Table 2.7).

Host (1995) first described the test to measure the distance between T4 and the medial border of the scapula and gave clinical guidelines on interpreting the results; however this information is based on a single case report. In this study the distance between T4 and the medial border of the scapula was found to be 5.08cm (Host 1995). In a study conducted on 15 female students (aged 19 – 21) it was found that the average distance between the thoracic spine and superior angle of the scapula is 8.76 cm, the distance between the thoracic spine and root of the scapular spine is 8.81 and the distance between the thoracic spine and inferior angle of the scapula is 8.72 cm (Sobush et al. 1996). No statistical difference was found between the dominant and non-dominant side (Sobush et al. 1996). Furthermore, it is argued that a distance of less than five centimetres is indicative of a resting position of the scapula in adduction and a distance of more than six centimetres is indicative of a resting position of the scapula in abduction (Sobush et al. 1996).

In another study conducted on patients complaining of shoulder pain (19 female, 10 male, aged 42 – 70) it has been found that the average distance between the medial border of the scapula and T4 varies between symptomatic (6.15 cm) and asymptomatic (6 cm) subjects (Nijs et al. 2005). The intra- and intertester reliability of this test is good (refer to Table 2.7). The only clinical value of this test is to determine the symmetry between the left and right scapula positions. No consensus on the ideal distance between the thoracic spine and the medial border (Nijs et al. 2005; Sobush et al. 1996; Host 1995) and the inability of this test to differentiate between the symptomatic and asymptomatic side is shown in the study conducted by Nijs et al. (2005).

Table 2.7: Tests to measure the distance between the thoracic spine and scapular medial border (Nijs et al. 2005; Sobush et al. 1996; DiVeta et al. 1990).

Test	Procedure	Aim of test	Intra – class correlation coefficient
Distance between T4 and medial scapular border.	The distance between T4 and medial border of the scapula is measured (Nijs et al. 2005; Host 1995).	To determine if the scapula is in abduction or adduction (Sobush et al. 1996).	Intratester 0.88 - 0.91 (Nijs et al. 2005; Sobush et al. 1996). Intertester 0.5 – 0.91 (Nijs et al. 2005; Sobush et al. 1996).
Scapular distance test.	The distance between angulus acromion and T3 is measured. The distance is normalized by dividing it by the scapular length (margo medialis to angulus acromion) (DiVeta, Walker and Skibinski 1990).	To assess if the resting scapular position is symmetrical.	Intratester 0.85 – 0.94 (DiVeta et al. 1990). Intertester 0.91 – 0.92 (Nijs et al. 2007).
Lennie test.	The distance between the thoracic midline and specific scapula bony marks is measured: (i) thoracic midline to superior angle of the scapula, (ii) thoracic midline to the root of the scapular spine and (iii) thoracic midline to the inferior angle of the scapula.	To determine if the scapula is in elevation or abduction at rest (Sobush et al. 1996)	Intratester 0.84 – 0.96 Intertester 0.76 – 0.94 (Sobush et al. 1996). Validity (Sobush et al. 1996).

The scapular distance test (Superior Kibler test) measured the distance between T3 and the posterior angle of the acromion and this distance is defined as the total scapular distance. This test was adapted by DiVeta et al. (1990) and the total scapular distance (T3 – acromion) was divided by the length of the root of the scapula. This normalization index is used to account for subject size. The intra- and intertester reliability is good but clear diagnostic values are not efficient.

The Lennie test was designed to determine whether the scapulae are in elevation or abduction at rest (Sobush et al. 1996). In this study 15 healthy, physical therapy female students, aged 19 – 21 years had been evaluated. Several bony landmarks were marked on the thorax and scapulae and measurements were taken between the thoracic spinous processes and the superior angle of the scapula, the root of the spine of the scapula and the inferior angle of the scapula. The test showed good inter-and intratester reliability ($p>0.76$) (Sobush et al. 1996). No statistical differences were found between the dominant and the non-dominant scapula's position. Values for all the measuring points were given but clinical interpretation of these values are not available. No interpretation has been provided to values that will indicate an ideal or less ideal position.

The ideal resting scapular position can be evaluated by comparing bony landmarks on the scapula with bony landmarks on the thorax. Several tests exist to measure the distance between the scapula and a fixed thoracic point. The aim of these tests is to determine the resting scapular position and if the scapular positioning is symmetrical or not. Several factors contribute to this ideal positioning of the scapula and these factors include bony or structural changes, ideal muscle length (Pectoralis minor) and nerve function. Correct sequence of activation and recruitment of Trapezius (middle and lower fibres) and Serratus anterior are vital for optimum positioning of the scapula.

The effect of a shortened Pectoralis minor on the scapula (page 32-33) as well as the importance of correct recruitment and activation of Trapezius (middle and lower fibres) and Serratus anterior on scapula function have a been analysed and discussed above.

An overview regarding the resting position of the scapula has been presented. The importance of ideal positioning has been discussed and the factors contributing to this ideal position were addressed. The importance and the role of the dynamic scapula will now be closely examined.

DYNAMIC CONTROL OF THE SCAPULA

Ideal dynamic control of the scapula contributes to ideal movement and congruency of the gleno-humeral joint. Once the scapula is ideally positioned and stable it serves as a base for attachment of muscles that move the gleno-humeral joint (McClure, Greenberg and Kareha 2012; Levangie and Norkin 2001). This ideal positioning of the scapula helps to optimize the length-tension relationship of the shoulder girdle muscles, allowing good quality of gleno-humeral movement. Another advantage of an ideally positioned scapula is that the possibility for impingement of any sub-acromial structure is decreased because the acromion is lifted, allowing full gleno-humeral elevation; an important position for any overhead activity. This synchronized movement between the scapula and gleno-humeral joint is called the scapulohumeral rhythm (Kibler et al. 2013; McClure et al. 2012; Nijs et al. 2007; Michener, McClure and Karduna 2003).

The scapulohumeral rhythm

The ability to do gleno-humeral flexion or abduction is engendered by a combination of movements between the scapulo thoracic, gleno-humeral, acromioclavicular and sternoclavicular joints. The main contributors to gleno-humeral flexion and abduction are the scapulo thoracic and gleno-humeral joints. The advantages of the combination of joint movements are:

- (i) A larger range of motion is possible; this larger range is possible with less compromise on joint stability. If this range of 180° would occur at one joint, the stability of that joint would have been a risk factor.
- (ii) The interaction / relation between the scapula and humerus ensure optimum positioning of the glenoid fossa. This optimum positioning increases joint congruency and simultaneously lessens shear forces on the gleno-humeral joint.

- (iii) A well aligned scapula (throughout the movement) allows muscles acting on the humerus to maintain a good length-tension relationship. The ratio of movement between the humerus and scapula in flexion and abduction is 2:1. The humerus contributes 120° and the scapula 60° to the final 180° of flexion or abduction (McClure et al. 2012; Nijs et al. 2007; Michener et al. 2003; Levangie and Norkin 2001; Mottram 1997).

In Table 2.8 the interaction and biomechanical contribution for gleno-humeral abduction of the joints are summarized.

Table 2.8: Interaction and biomechanical contribution of different joints during gleno-humeral abduction (McClure et al. 2012; Nijs et al. 2007; Michener et al. 2003; Norkin and Levangie 2001; Mottram 1997).

Joint	0° - 30°	30° - 80°	80° - 140°	140° - 180°
Scapulo - thoracic	Seek position of stability – no movement	Upward rotation (very little posterior tipping and external rotation)	Upward rotation, posterior tipping and external rotation	Maintain position of upward rotation, posterior tipping and external rotation
Gleno-humeral	Abduction and lateral rotation	Abduction and lateral rotation	Abduction and lateral rotation	Abduction and lateral rotation
Acromioclavicular	No movement	10° medial rotation	Posterior rotation of the clavicle	Posterior rotation of the clavicle
Sternoclavicular	No movement	Clavicular elevation	Clavicular elevation	Clavicular elevation

The contribution of the scapula during gleno-humeral abduction and flexion is different regarding the degrees of rotation and tipping but the sequence of scapular movement is the same. Scapula upward rotation, posterior tipping and external rotation contribute to gleno-humeral elevation. Scapular upward rotation elevates the acromion and the anterior part of the acromion is further elevated by concurrent scapular posterior tipping (Michener et al. 2003). Upward rotation should be noticeable before 90° of gleno-humeral elevation and between 80° to 140° the scapula should rotate upward, tilt posterior and rotate externally. This position of upward rotation, posterior tipping and external rotation allow space between the acromion and humeral head, preventing sub acromial impingement (McClure et al. 2012; Michener et al. 2003; Levangie and Norkin 2001). During flexion, the scapula protracts, aligning the glenoid fossa posterior to the humeral head, protecting the humerus posteriorly and preventing any posterior dislocation (Levangie and Norkin 2001). This ideal rhythm is the direct result of sufficient activation of the scapula stabilisers and effective length of Pectoralis minor to allow sufficient posterior tipping.

Ideal scapular motion can be altered by several factors. This alteration of scapular motion is termed scapular dyskinesis, which implies the loss of normal scapular control (Kibler et al. 2013). Different factors can contribute to scapular dyskinesis (Table 2.9) (Kibler et al. 2013; Michener et al. 2003).

Table 2.9: Factors causing scapular dyskinesis and the effect on scapular movement (Kibler et al. 2013; McClure et al. 2012; Struyf et al. 2011a; Agur and Dalley 2009; Borstad and Ludewig 2005; Michener et al. 2003; Norkin and Levangie 2001) (Page 75-76).

Factor causing scapular dyskinesis		**Effect on scapular movement**
Bony causes	Thoracic kyphosis.	Scapula in a more abducted internally rotated and anteriorly tipped position. This may lead to adaptive shortening of muscles and ultimately to muscle imbalances.
	Clavicle fractures (mal-union, non-union).	Clavicle contributes to ideal scapulo humeral rhythm – if fractured or shortened it might affect the ideal scapulo humeral rhythm.
Joint causes	Arthrosis of the sternoclavicular or acromioclavicular joints.	Movements at these joints contribute to ideal gleno-humeral movement. If affected it may result in excessive or decreased scapular movement.
	Instability of the acromioclavicular or gleno-humeral joints.	Movements at these joints contribute to ideal gleno-humeral movement. If affected it may result in excessive or decreased scapular movement
Neurological causes	Paralyses of the long thoracic, spinal accessory, thoracodorsal, dorsal scapular and axillary nerves.	These nerves innervate the muscles that attach to the scapula. Function of the muscle will be influenced if nerve is damaged or injured and thereby scapular kinematics may be altered.

Soft tissue causes	Muscle length of Pectoralis minor and Biceps brachii short head.	Both muscles attach to the coracoid and a decrease in length may cause a pull on the coracoid resulting in an anterior tilt and protraction respectively.
	Posterior capsule tightness.	Posterior capsule tightness is associated with excessive scapular protraction and this can contribute to scapular dyskinesis.
Peri scapular muscle activation	Delayed activation of Serratus anterior and Trapezius middle and lower fibres.	Delayed activation of these muscles will result in an unstable scapula in the first 30° - 60° of elevation.
	Lack of concentric muscle strength and eccentric muscle control (Trapezius and Serratus anterior).	Lack of muscle strength can result in decreased upward rotation, posterior tilt and external rotation. Lack of eccentric control may have an influence on the quality of scapular movement.

Evaluation of scapular dyskinesis

Effective evaluation of the dynamic scapula can help to determine the cause of scapular dyskinesis. A clinical examination of scapular movement should be affordable, reliable, valid, easy to perform and responsive to change (Nijs et al. 2007). Several tests exist to evaluate scapular dyskinesis (Table 2.10).

Table 2.10: Tests to evaluate scapular dyskinesis (McClure et al. 2012; Tate et al. 2012; Shadmehr et al. 2010; McClure et al. 2009a; Rabin et al. 2006).

Test	Aim	Reliability and validity
Scapular Reposition Test (McClure et al. 2012)	To evaluate the effect of scapula repositioning (posterior tipping and external rotation) on shoulder pain and muscle strength.	
Lateral Scapular Slide Test (Shadmehr et al. 2010)	To determine scapula symmetry at 0°, 45° and 90° of abduction.	Intrarater reliability 0.87 – 0.96 Interrater reliability 0.63 – 0.86 Asymmetry observed with symptomatic and asymptomatic subjects.
Visual observation	To determine any scapular dyskinesis during gleno-humeral flexion and abduction.	Reliability: Percentage of agreement ranged 75% - 82%, Kappa coefficients from 0.48 – 0.61 (McClure et al. 2009) Validity: Scapular dyskinesis confirmed by three dimensional electromyographic data. (Tate et al. 2012)
Modified Scapular Assistance Test (Rabin et al. 2006)	To assess the contribution of scapular motion (upward rotation and posterior tipping) to shoulder pain.	Kappa coefficient 0.53 (scapular plane) and 0.62 (sagittal plane). Percentage agreement 77% (scapular plane) and 91% (sagittal plane).

The Lateral Scapular Slide Test does not have the capacity to differentiate between symptomatic and asymptomatic subjects as well as symptomatic and asymptomatic sides within a subject (Shadmehr et al. 2010; Nijs et al. 2005; Odom et al. 2001). The threshold for asymmetry is set at 1.5cm. The distance from the inferior angle of the scapula is measured to the spinous process of T7 in 0°, 90° and 120° of abduction. The reliability and validity of this method were tested in various studies (Shadmehr et al. 2010; Nijs et al. 2005; Odom et al. 2001). Despite the incapacity to differentiate between symptomatic and asymptomatic subjects, this test is not an ideal test for scapular movement as all the measurements are done in a static hold position through the range of movement.

Scapular dyskinesis is defined as the inability to maintain a stable scapula against the thoracic wall during movement and to have a smooth and continuous moving scapula during gleno-humeral movement (Kibler et al. 2013). All these aspects of scapular control were evaluated in a study conducted by McClure et al. (2009a) where the scapular movement was evaluated through the range of gleno-humeral flexion and abduction. Overhead athletes (n=142) had been evaluated while performing gleno-humeral flexion and abduction. This evaluation was done in person and every athlete was video-taped for a delayed analysis. The evaluators observed the scapular movement for the following: ideal scapular movement – a stable scapula during the initial 30° - 60° of gleno-humeral movement, then smoothly and continuously rotating upward during elevation and downward during humeral lowering. If scapular dyskinesis had been observed, one of the following should have been present; dysrhythmia or winging of the scapula. Dysrhythmia is defined as premature scapular movement, excessive protraction or elevation of the scapula and non-smooth or shuttering movement during elevation or lowering. Winging is defined as posterior displacement of the medial border or the inferior angle of the scapula during movement. A moderate Interrater reliability was found; for the observers the Kappa coefficient was 0.57 and for the videotaped observed analysis the Kappa coefficient was 0.54. Although the reliability was moderate, this is the only test to evaluate scapular movement during a functional activity.

Testing the validity of this visual observation was the second phase of the study (Tate et al. 2012). The athletes who either had ideal scapular movement or those with obvious scapular dyskinesis underwent a 3-dimentional measurement to confirm insufficient upward rotation, clavicular elevation and clavicular protraction. The athletes classified with ‘ideal scapular movement’ also had ideal scapular upward rotation, clavicular elevation and protraction during the flexion and abduction when measured by the electromyographic device. The athletes classified with obvious dyskinesis had significant insufficiency of upward rotation ($p<0.001$), clavicular elevation ($p<0.001$) and clavicular protraction ($p<0.04$). This data indicates that the visual observation method is valid and clinically significant.

The Lateral Scapular Slide Test and the visual observation test evaluate the scapular movement pattern. The following two tests evaluate the effect of scapular control on shoulder pain and muscle strength and are collectively called the symptom alteration tests. The Scapular Assistance Test (SAT) and the Scapular Reposition Test (SRT) are done with manual guidance of the scapula into upward rotation and posterior tipping.

The SRT was first described as the Scapular Retraction Test (McClure et al. 2012). The subject did gleno-humeral flexion and the medial border of the scapular had been held manually against the thoracic wall while the patient actively retracted the scapula. The test is positive if the subject experience a decrease in shoulder pain or an increase in muscle strength. When tested clinically no subject had a decrease in pain but all had an increase in muscle strength (McClure et al. 2012). The test was modified; the scapula was manually posteriorly tipped and externally rotated. When clinically tested 46/98 subjects experienced a decrease in pain and 46% experienced substantial increase in muscle strength. The decrease in pain or increase in muscle strength when manual assistance was given is indicative of inadequate scapular muscle control.

During the SAT test the scapula is manually rotated upward and the effect is measured on pain perception. Rabin and colleagues (2006) modified the test by adding the posterior tilt component. Forty six patients were evaluated in a test-retest reliability study (Rabin et al. 2006). The test is positive when the patient indicates a decrease of shoulder pain during gleno-humeral movement. All the patients were diagnosed with a shoulder disorder. The patient did gleno-humeral flexion in the sagittal plane and rated the pain. The scapula was manually positioned and guided through the movement and the patient rerated the pain. This procedure was also done in the scapular plane. The Kappa coefficient for the SAT in the scapular plane was 0.51 and in the sagittal plane

0.54. The researcher stated that the hand placing on the scapula during gleno-humeral movement in the sagittal plane had been easier to follow through than in the scapular plane, which may indicate the difference in the reliability outcome.

Scapular movement and positioning during gleno-humeral movement are two crucial components for effective and optimum shoulder function (Kibler et al. 2013). Several factors contribute to this ideal scapular movement. Studies and research to address these factors have been discussed earlier in the literature review. In the studies muscle strength and activation of scapular muscles were evaluated (De Mey et al. 2012; Oyama et al. 2010; Cools et al. 2007a; Cools et al 2007b; Cools et al. 2003a; Cools et al. 2003b; Cools et al. 2002). Dynamic scapular position was evaluated but studies on the effect of treatment on scapular position after invention are not comprehensive enough (Struyf et al. 2014; Worsley et al. 2013; Struyf et al. 2009; Nijs et al. 2007). Studies had been done on muscle activation on scapular control but the discussions and results are focused on the scapular muscle activation (Kibler et al. 2008), the patients' ability to learn the exercises and scapular positioning (Mottram, Woledge and Morrissey 2007), the difference between athletes with and without shoulder pain (Struyf et al. 2011b) and the differences between children and adults (Struyf et al. 2011c). Two studies were conducted to determine the effect of motor control retraining exercises on the scapula (Worsley et al. 2013; Roy et al. 2009).

Interventions to address the scapula position

Two studies (Table 2.11) were conducted with the aim to determine the effect of motor control and retraining of the scapula stabilisers on scapula stabiliser function and scapula kinematics (Worsley et al. 2013; Roy et al. 2009).

The results of both studies demonstrated the value of an exercises program based on motor learning principles. Although the exercises used by Worsley et al. (2013) were not clearly described, they emphasised the importance of scapula positioning and control during active gleno-humeral movement. In both studies, exercises were only progressed when the participants were able to control the scapula during the specific movement (Worsley et al. 2013; Roy et al. 2009). The importance of feedback during the exercises was also emphasised in both studies. Exercises were only progressed once the subject had proper control of the scapula during gleno-humeral movement (Roy et al. 2009). Progression was seen as an increase in the range of motion during the active gleno-humeral movement, an increase in repetitions, an increase in the speed of the exercise and lastly external resistance (Roy et al. 2009). Quality of gleno-humeral movement (correct plane of movement and ideal range of movement) were used as indicators to progress the exercises (Roy et al. 2009). Both studies were conducted on participants diagnosed with shoulder impingement. No study could be found where a motor learning based intervention was evaluated on the scapula stabilisers or scapular position of swimmers on any other athletes.

Table 2.11: Studies conducted to determine the effect of motor control and scapula stabiliser retraining exercises on the scapula position (Worsley et al. 2013; Roy et al. 2009) (Page 82-83).

Authors and aim of study	Type of study	Intervention	Results / outcome	Critical analysis
Worsley et al. (2013) To quantify the clinical, neurophysiological and biomechanical effects of a scapular motor control retraining program for young individuals with impingement signs.	Pre and post-test design. (Level of evidence: 3) Intervention group n=16 (shoulder impingement), control group n=16 (healthy).	1. Motor control exercises to correct alignment and coordination: (i) controlling the scapular position at rest and during active gleno-humeral movements (ii) muscle specific exercises to retrain Trapezius and Serratus anterior. Emphasis on slow controlled exercises for two minutes or 10-15 repetitions. 2. Manual therapy techniques to manage symptoms (trigger point release). Exercises were performed at home twice / day for ten weeks. Five follow up appointments were done during the intervention to assure exercises were performed correctly.	EMG results: activation of Serratus anterior and lower Trapezius increased significantly ($p<0.05$) in intervention group from baseline to ten weeks. Control of Serratus anterior and lower fibres of Trapezius increased significantly ($p<0.05$) during lowering of the arm. Scapula kinematics: posterior tipping as well as upward rotation increased significantly ($p<0.05$) in the intervention group from baseline to ten weeks.	The inclusion and exclusion criteria are well described. Demographic data of both groups correlate well. In both groups the right arm was tested (intervention group right arm was painful arm) and control group (right arm was dominant arm). **Limitations:** It is not clear whether the control group did the exercises as well. Only the intervention group is evaluated at baseline and after ten weeks.

Roy et al. (2009) To evaluate the effect of shoulder control and strengthening exercises on shoulder function in persons with shoulder impingement.	Single-subject study design. (Level of evidence: 3) n=8 (diagnosed by orthopaedic surgeon).	Three phases: Phase one: Two weeks – baseline evaluation was done and subjects followed a home exercise program of isometric exercises in abduction and lateral rotation against the wall. Phase two: Four weeks, 12 supervised exercise sessions, to promote scapular kinematics and to strengthen scapulothoracic and scapulohumeral muscles. Subjects were evaluated at the end of every week. Phase three: Three weeks, home program was specific for every subject based on the scapula control and muscle strength the subject gained in phase two.	Shoulder Pain And Disability Index (SPADI) scores increase significantly ($p<0.05$) SPADI (n=7) showed significant increase. Isometric peak torque test showed significant increase in abduction (n=3) and in flexion (n=4). Scapular kinematics showed (n=7) significant increase in posterior tipping. Scapular kinematics was measured with a Optotrak Probing System (Northern Digital Inc., Waterloo, Ontario, Canada)	The exercises used in the study are not clearly described; it is only stated as 'specific exercises' or 'motor control exercises'. Inclusion and exclusion criteria well described. The motor learning principles that were followed are clearly described. Procedure followed to determine progression is clearly described. **Limitations:** Small sample size (n=8). Age of participants is unknown. Although the results are stated as significant, the p value of significance is not given.

CONCLUSION

The time that a swimmer's face is out of the water allowing him/her to inhale is limited to 0.3 – 0.5 seconds. This time limitation forces a swimmer to depend on the accessory breathing muscles (especially Pectoralis minor) for adequate ventilation. This results in an apical breathing pattern and loss of lateral costal thoracic expansion.

The causes that contribute to the loss of lateral costal expansion in swimmers are twofold; firstly, they mainly rely on accessory inspiration muscles for adequate ventilation increasing the apical anterior posterior diameter; secondly, they use the Oblique externus muscle to exhale forcefully. Oblique externus originates from the lower ribs and this daily overuse may result in less lateral costal expansion. Sufficient lateral costal expansion optimises the length-tension relationship of the Diaphragm and results in optimum contraction of the Diaphragm.

Studies that were identified and that focused on the strengthening of inspiratory and expiratory muscles had no effect on the performance of swimmers. Swim training had the same effect on ventilatory muscle training as breathing exercises on dry land. The frequency of breathing is an aspect of swimmers' breathing pattern that has proven to have an effect on performance. Less frequent breathing during a 25 meter sprint resulted in a better completion time over the 25 meter. This advantage of reduced breathing forces the swimmer to rely even more on accessory breathing muscles.

No existing studies which focus on lateral costal breathing dissociation exercises in swimmers, on dry land or in the pool were identified.

Many swimmers have a distinct rounded shoulder posture and a shortened Pectoralis minor is often associated with this rounded shoulder posture. A shortened Pectoralis minor had been identified as a risk factor causing shoulder pain in swimmers. A shortened Pectoralis minor pulls the scapula in an anteriorly tipped position and this anteriorly tipped position has a negative effect on scapula function.

Several methods exist to evaluate the length of Pectoralis minor. The test where the distance between the posterior acromion and plinth or wall is measured reflected a good inter-observer reliability coefficient (ICC = 0.88). The internal consistency scored 0.88 on the Cronbach α coefficient however; the test could not differentiate between subjects with shoulder pain and subjects without shoulder pain. Although an ideal distance of 2.6 cm is used as an essential criterion, this test does not account for the diversity in bone structure and body build of different swimmers.

On the other hand, the PMI was developed and this test does account for the diverse bone structure and body build of swimmers. This measurement from origin to insertion was evaluated with a measurement tape and compared to an electromagnetic motion capture system and a digital calliper. The interclass correlation coefficient between the three measurement techniques varied from 0.82 to 0.87 indicating that the less expensive, manual measurement with a calliper can be used in clinical practice with accuracy. Although the PMI does account for bone differences in bone structure and body build, a golden standard is absent.

Several studies were conducted to evaluate the effect of different stretch positions on Pectoralis minor. The most effective position is with the gleno-humeral joint in 90°abduction and 90° lateral rotation. According to the literature the study which utilised the principle of reciprocal inhibition, presented a statistical change ($p<0.05$) in Pectoralis minor length.

A stable scapula contributes to optimum upper quadrant function. It serves as a stable base for muscles to contract from (Pectoralis minor), it orientates the glenoid for optimum gleno-humeral function and if ideally aligned it contributes to ideal ranges of motion that is needed by swimmers. Scapular stability is dependent on optimum functioning of the scapula stabilisers. Trapezius (middle and lower fibres) and Serratus anterior stabilise the scapula and ensures sufficient upward rotation as needed through gleno-humeral abduction and flexion.

The middle fibres of Trapezius are most active between 90°-120° of abduction. Therefore, the exercises to retrain and strengthen the middle fibres of Trapezius should be done with the gleno-humeral joint in 90° of abduction. Another component to add to effective strengthening of the middle fibres is lateral rotation of the gleno-humeral joint. With the gleno-humeral joint in lateral rotation the lateral rotators

(Infraspinatus and Teres minor) pull the scapula lateral activating contraction of the middle fibres of Trapezius.

The lower fibres of Trapezius are best activated in 120° of scaption. This position aligns the lower fibres of the muscle and better activation is noted. Serratus anterior is divided into upper and lower fibres. The upper fibres are most active during protraction activities and the lower fibres are most active during upward scapula rotation which is most evident from 80°-140° of abduction. Scapular upward rotation is one of the most important components during scapula movements. It is therefore needed to start Serratus anterior activation and strengthening in a position above 80° of abduction to activate the lower fibres of Serratus anterior that control upward rotation. Interventions based on motor learning principles of controlling the scapula position while performing exercises, visual and kinaesthetic feedback during exercises and control of the speed of exercises showed to be effective. The effectiveness is evident in an increase of shoulder function, improved muscle function quality and optimum scapula positioning.

Consistency in evaluation techniques to evaluate the scapula in a resting or dynamic position is ineffective. The resting position is best described by matching anatomical markers on the scapula and thorax. This technique allows evaluating the position of the scapula on the thorax as well as the influence of muscle function on the scapula. Specific measurements between bony markers on the scapula and the thorax lack clinical significance and are patient specific.

Visual observation for scapula dyskinesis is found to be valid and reliable. The benefit of this form of evaluation is that the movement control of the scapula can be evaluated throughout the full range of gleno-humeral flexion or abduction.

From the literature reviewed no study could be found which reflected evidence that the effect of lateral costal breathing dissociation exercises and scapula muscle retraining on the scapula had been measured. In the light of this summary one may argue that lateral costal breathing exercises may contribute to the multidirectional expansion of the thorax. With lateral costal expansion of the thorax the zone of opposition of the Diaphragm is favoured and may result in better ventilation. The biomechanical advantage of an increase in thoracic dissociation may be seen in a more ideal positioned scapula. The ideal resting position of the scapula as well as the dynamic scapula control may contribute to better activation of the scapula stabilisers. Contracting from a stable scapula, Pectoralis minor can fulfil its role as accessory breathing muscle. Furthermore the posteriorly tipped, upwardly rotated scapula will counteract the position of anterior tipping that result in adaptive shortening of Pectoralis minor. Against this background the research question was postulated as described in Chapter 1. The methodology of this study is described in Chapter 3.

CHAPTER 3

METHODOLOGY

INTRODUCTION

Swimmers have to use the accessory breathing muscles for adequate ventilation (Lomax and McConnell 2003). Pectoralis minor, an accessory breathing muscle, has a tendency to adaptively shorten in swimmers due to the overuse of gleno-humeral flexion and medial rotation (Cools et al. 2013; Bak 2010; Lomax and McConnell 2003). Overuse of the accessory breathing muscles may lead to an apical breathing pattern which loads Pectoralis minor even more due to insufficiency of lateral costal expansion. A shortened Pectoralis minor was identified as a risk factor that contributes to malalignment of the scapula (Tate et al. 2012; Bak 2010; Borstad 2006).

With a shortened Pectoralis minor the scapula is in an anteriorly tipped position. In this anteriorly tipped position the scapula stabilisers are in a lengthened position and their ability to control the resting as well as dynamic scapular position is affected (Kibler et al. 2013; McClure 2012; Tate et al. 2012).

This chapter aims to discuss the methodology used in this study. The methods chosen are based on the literature reviewed in Chapter 2. The length of Pectoralis minor and thoracic expansion was measured. The force vital capacity of each swimmer had been tested. The agonistic function of Trapezius middle and lower fibres as well as Serratus anterior was evaluated. The resting as well as dynamic positioning of the scapula had been evaluated.

STUDY DESIGN

A comparative parallel group longitudinal single blind design was used in this study. Two similar available groups of swimmers were included in the study; the effect of the intervention was evaluated on both groups and a comparison had been executed compared over time (Brink 2006). The swimmers identified for this study are members of the TuksSwim Club. TuksSwim Club swimmers are coached by four different coaches. The swimmers of coach A and C were in the intervention group and the swimmers of coach B and D were in the control group. An outline of the study design is presented in Figure 3.1.

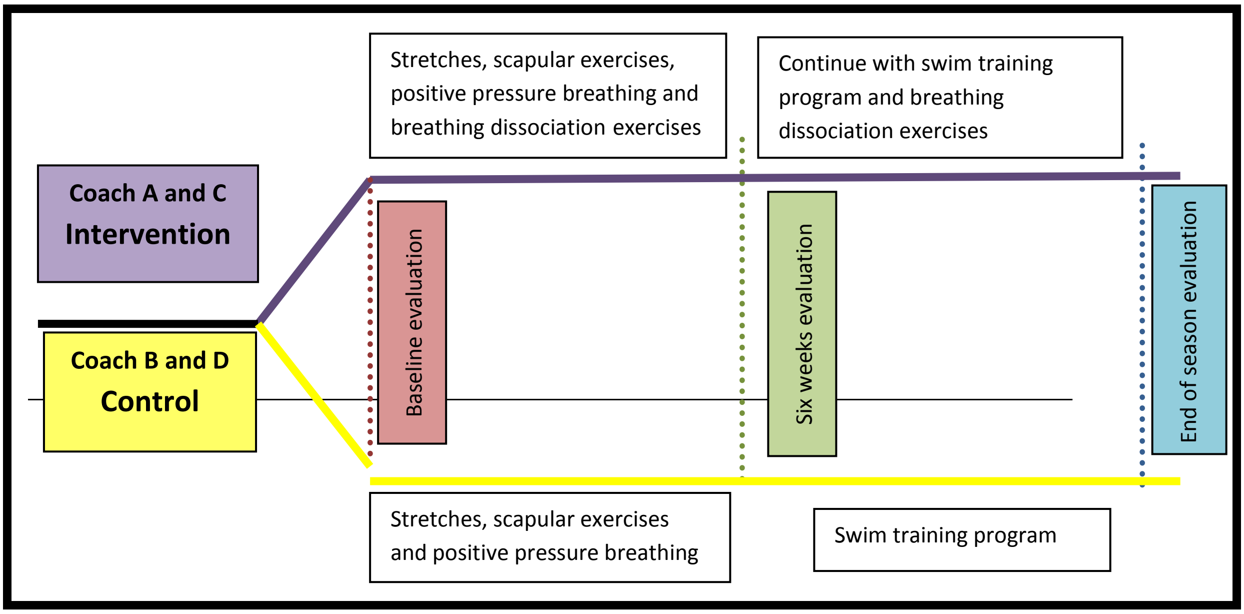


Figure 3.1: Schematic presentation of the study design.

STUDY SETTING

The study was conducted at TuksSwim Club, TuksAquatics Complex, South Street, University of Pretoria, Gauteng, South Africa.

STUDY POPULATION AND SAMPLING

Study population

The target population of this study was swimmers from level two up to senior national level (SwimSA accredited) of TuksSwim Club. TuksSwim Club had been incorporated because it is the largest swim club in South Africa. No other club nationally could be found to match the number of members of the TuksSwim Club. The accreditation system used by SwimSA to rank swimmers according to performance is different to those used by other countries. This difference in the accreditation systems made it impossible to match the swimmers of TuksSwim Club to any other swim club internationally. The swimmers of TuksSwim Club were included because they have similar training hours and -programmes, and they are dedicated to improve their rankings. A non-probability sampling population was used in this study, which, according to Brink (2006), is described as sampling where subjects are chosen from a specific population by non-random methods. The swimmers were divided into an intervention and control group based on the coaching group they are allocated to.

Sampling method

A sample of convenience was used, as the swimmers that are members at TuksSwim Club are all accredited swimmers (level two up to senior national level) at the national body of Swim SA. A meeting was held with the swimmers where they were informed about the study (Annexure 2). To ensure blindness they were told that the study had been evaluating two different types of breathing exercises together with stretches and strengthening exercises. Those who were interested completed a personal information form (Annexure 3). Swimmers had been contacted via text messages and an evaluation time was booked. This evaluation was scheduled in alignment with their normal training sessions. A day before the evaluation commenced, every participating swimmer had been reminded via text message about the evaluation. On the form they completed they also indicated the coach whom they were training with. The swimmers of coach A and C were in the intervention group and the swimmers of coach B and D were in the control group. Each swimmer received a number after completing the personal information form and this number was used on all data capturing forms to ensure blindness of all the research assistants.

Inclusion criteria

Swimmers were included if they were ranked according to the SwimSA accreditation system. Swimmers had to be at least level two up to senior national level, aged between 13 and 23 and engaged in swim training for at least 6 hours per week.

Exclusion criteria

Swimmers had been excluded:

(i) if they complained of any respiratory infection at the time of all the evaluations, because any respiratory infection would have had an effect on the spirometery tests (Koegelenberg et al. 2012);

(ii) if they had any previous fractures of the humerus and / or shoulder girdle, and have not undergone rehabilitation for it. These previous injuries could have had an effect on the shoulder girdle function and biomechanics (Levangie and Norkin 2001) and

(iii) if they participated in any other overhead sport. The technique used for the other sport (such as tennis) and the overhead activity would have contributed to the over activity of M Pectoralis minor (Jobe and Pink 1993).

Sample size

Thirty six swimmers per group had a 90% power to detect an increase of 0.4 in PMI from baseline to six weeks, for the intervention group compared to the control group. A difference of one standard deviation was regarded as a clinically relevant change and a standard deviation for change from baseline of 0.567 (√2x0.4) was assumed (Cools et al. 2010). Sample size calculation was based on a two-sample t-test at the one-sided 0.05 level of significance.

DATA COLLECTION

Research team

The main researcher, not blinded, was responsible for all the administrative work. This researcher was responsible for the implementation of the intervention, during the intervention period.

Research assistant A and B, qualified physiotherapists, were responsible for the baseline and post-test evaluation of Pectoralis minor length (A), resting scapula position (A), dynamic scapula control (A) and muscle function (B). Both these research assistants had been blinded to the intervention and control groups. Research assistant C, a qualified physiotherapist, was responsible to perform the spirometry test and the measurement of the thoracic expansion. This research assistant had also been blinded to the intervention and control groups.

Measurement tools

The following table (Table 3.1) lists the measurement instruments which were utilized by the research assistants for the purposes of this study. Studies to confirm reliability and validity are listed in the table.

Table 3.1: Validity and reliability of measurement tools (Interclass correlation coefficients – (ICC)).

Measurement tool	Aim of instrument	Studies to confirm reliability and validity
Vernier calliper® (300mm) INSIZE CO., LTD	To measure the length of Pectoralis minor from the origin to the insertion.	ICC 0.94 (Borstad 2008; Lewis and Valentine 2007).
Measurement tape	To measure lateral costal thoracic expansion during inspiration.	Reliability ICC 0.99 (Bockenhauer et al. 2007)
Spirometer MIR Spirobank *II* (Via del Maggiolino, Rome, Italy)	To evaluate lung function and specifically FVC in this study.	The highest correlation was for FEV(1) (r(2) = 0.949) and the lowest for the maximum expiratory flow at 25% of FVC (MEF(25) (r(2) = 0.864) (Koegelenberg et al. 2012).
Evaluation of manual muscle strength	To evaluate the muscle's ability to perform the agonistic function effectively.	Validity ($p<0.001$) and reliability of 0.90 (Spearman's rank correlation) were confirmed by Rider et al. (2010).
Evaluation of the resting scapula through skin surface palpation	To evaluate the resting position of the scapula on the thoracic wall.	Validity ($p<0.005$) was confirmed by Lewis et al. (2002) with a reliability of ICC 0.88 by T'jonck and Lysens (1996).
Visual evaluation of dynamic scapular position	To evaluate the position of the scapula during gleno-humeral flexion	Validity ($p<0.001$) was confirmed by McClure et al. (2009a) with a reliability of a Kappa of 0.85 (McClure et al. 2009b).

Lewis and Valentine (2007) state that interclass correlation coefficients above 0.75 are indicative of good reliability and those below 0.75 should be considered as moderate to poor. All the instruments that were used in this study were above 0.75.

Measurement procedures

Process of evaluation

The evaluation instruments and procedures mentioned in Table 3.1 had been done by research assistants A, B and C. The baseline evaluation was done from 12 September 2012 to 8 October 2012. A six week intervention period followed (8

October 2012 to 16 November 2012). The evaluation after the intervention period was done from 19 November 2012 to 26 November 2012. The final evaluation was done 20 to 22 March 2013 and 9 to 11 April 2013. Please refer to Annexure 4 for details regarding the evaluation process. All the data was captured on a data collection form (Annexure 5). The baseline evaluation took three and a half weeks because these three weeks also served as the recruitment period. The intervention period started on 8 October 2012 for the intervention group as well as the control group. The final evaluation had been split into two sessions of three days each. This had been done in order to accommodate swimmers between the university holiday and national trials.

Evaluation

During the evaluation both male and female participants had been dressed in suitable swim suites, throughout the duration of all procedures. The evaluation was done in a well lit room next to the swimming pool. Each swimmer received a specific number and this number was used on all the data capturing forms. Before any evaluation had been done, the specific bony and landmarks were marked by research assistant A (coracoid, spinal levels and scapula) and research assistant C (intercostal space and xifisternum) with a non-permanent, washable skin pencil.

The following was evaluated in no specific order: resting and dynamic scapular position, the function of Trapezius middle and lower fibres as well as the function of Serratus anterior, thoracic expansion, force vital capacity and the length of Pectoralis minor. After the evaluation had been done the swimmer swam 200m freestyle. The instruction given to the swimmer was: ‘Swim the first 100m as a warm up and the second 100m as fast as you can’. After this 200m free style the resting and dynamic scapula position had been evaluated again. Although swimmers have different strokes for their main event, freestyle was chosen because 70% of swim training is done by means of the free style stroke (Heinlein et al. 2010).

The different evaluation techniques will be outlined hereunder.

Measurement of Pectoralis minor length

Muscle imbalance is one of the main contributors to postural malalignment and pain. Pectoralis minor has the tendency to shorten and to contribute to a malaligned scapula (Struyf et al. 2012a; Lewis and Valentine 2007; Borstad 2006). It is for this reason that the measurement of Pectoralis minor was included in this study.

Figure 3.2: Pectoralis minor length measurement (Cools et al. 2010).

The swimmer was positioned in supine, with the second cervical vertebra (C2) in line with the gleno-humeral joint, assuring neutral alignment of the cervical spine. The elbows were flexed with the hands resting on the abdomen, to prevent any influence of Biceps brachii on the position of the coracoid process (Lewis and Valentine 2007). Two anatomical landmarks had been determined (ICC 0.96) and marked with a skin pencil, representing the length of Pectoralis minor: the medial inferior angle of the coracoid process and a landmark just lateral to the sternocostal junction of the inferior aspect of the fourth rib (Borstad 2008). A Vernier calliper® (Cools et al. 2010) was used to measure the distance between the two bony landmarks. The Vernier calliper® was used to measure the true distance between the bony landmarks to eliminate the influence of any muscle bulk. The distance was documented in centimetres. Pectoralis minor length was measured and documented by research assistant A. A normalization index had been applied to allow for muscle length and body build variety. The Pectoralis minor index was calculated by dividing the resting muscle length by the subject's height and multiply it by 100 (muscle length / swimmers height x 100) (Cools et al. 2010; Borstad 2008).

Evaluation of thoracic expansion

Figure 3.3: Evaluation of thoracic expansion (Bockenhauer et al. 2007).

The measurement of thoracic expansion was divided into upper thoracic and lower thoracic expansion. During inspiration the ribcage diameter increases in an anteroposterior, transverse and vertical diameter. The anteroposterior increase is seen in the upper thorax and the vertical and transverse increase is seen in the lower thorax (Pryor and Prasad 2008). To measure the increase in anteroposterior, transverse and vertical diameters the following anatomical markers were used (Bockenhauer et al. 2007):

- *Upper thorax*: fifth thoracic spinous process and the third intercostal space at the mid clavicular line
- *Lower thorax*: tenth thoracic spinous process and the xiphoid process

The swimmers stood with their arms relaxed by their side. The tape was placed around the thorax, comfortable but not tightly, thus the contour of the soft tissue remained unchanged. The tape had been kept flat against the swimmer's skin with the hand positioned in such a way that the zero (0) on the tape was visible. The swimmer was instructed to inhale to maximum capacity followed by a maximum exhalation. Research assistant C crossed her hands, allowing ten centimetres of tape to overlap and then the swimmer had been instructed to breathe in as deep as possible. During the action of breathing in, the researcher allowed the tape to 'glide' and at end inspiration the researcher took the reading. This procedure had been repeated three times for the upper and lower thoracic expansion and the mean measurement was applied (Bockenhauer et al. 2007).

Evaluation of force vital capacity

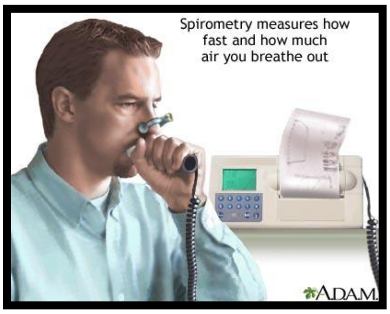


Figure 3.4: Spirometry test (Koegelenberg et al. 2012).

Force vital capacity, is defined as 'the maximum volume of gas exhaled from a position of maximal inspiration by means of a rapid, maximally forced expiratory effort, expressed in litres' (Koegelenberg et al. 2012). The swimmer was sitting upright on a firm chair with the chin slightly elevated and the cervical spine in slight extension. A nose clip was used and the swimmer was instructed to maintain this position throughout the procedure. The swimmer had been instructed not to bite on to the mouthpiece, to seal the lips tightly around the mouthpiece and to keep the tongue from obstructing the mouthpiece. The swimmer was further instructed to inhale slowly, exhale quickly to the maximum for six seconds and inhale to the swimmer's maximum capacity again. The procedure had been demonstrated to the swimmers by research assistant C and while the test was being conducted the research assistant encouraged the swimmer. Furthermore, feedback to the swimmer had been provided by the researcher in order to ensure good cooperation. During the test the swimmer was reminded of key points such as 'breathe in as deep as possible', 'blow out as hard and quickly as possible' and 'don't stop until I tell you to stop'. The measurement was repeated three times and the best reading had been recorded for testing purposes. The spirometer was calibrated with a three litre syringe. A sterilized turbine was used for each subject. Research assistant C was blinded.

Evaluation of muscle function

The evaluation of muscle function encompassed a combination of muscle tests. This combination was chosen because the agonistic function of the muscle was evaluated against gravity according to the Oxford grading principle (Kendall 2002). The ability of the muscle to contract through the available range, to hold the inner range position without any other muscle substitution and the ability to breathe relaxingly while contracting the muscle was also tested as explained by Mottram and Comerford (2001). This combination of agonistic action and the muscle's ability to contract without substitutions gave a better indication of the quality of the muscle contraction and function (Cuthbert and Goodheart 2007; Magarey and Jones 2003).

Muscle function had been evaluated by research assistant B. Muscle function was documented on a table. The different characteristics of muscle function that were evaluated have been listed in the table below (Table 3.2). If a swimmer underperformed according to one of the characteristics, it was an indication that the swimmer requires specific rehabilitation to address that specific component. If a swimmer reflected inability to activate the muscle without substitution, the swimmer started with rehabilitation in category one, which addressed the motor control component of muscle function. If the swimmer reflected inability to actively contract or to eccentrically control the muscle contraction, the swimmer would start with the rehabilitation in category two, which addressed the muscle's ability to control movement. If a swimmer had all the characteristics of muscle function, the swimmer would start with rehabilitation in category three, which are exercises to address muscle strength and endurance. If the passive range of motion had not been equal to ideal range, the test would still have been performed and muscle control in the available range would have been evaluated, however the defective range would have been recorded as such (Magarey and Jones 2003).

Middle fibres of Trapezius muscle function test

(Struyf et al. 2012b; Oyama et al. 2010; Comerford and Mottram 2001a)

Figure 3.5: Muscle function test of Trapezius middle fibres.

The swimmer was positioned prone with the gleno-humeral joint in 90° of abduction, elbows flexed and thumbs pointing forward (gleno-humeral lateral rotation). If the scapula was not in the ideal plane (15° - 30° from the frontal plane into the sagittal plane), a towel had been placed under the shoulder girdle to ensure ideal alignment for the scapula. Research assistant B, who was blinded, tested the passive range of scapula retraction by placing one hand under the gleno-humeral joint and the other hand on the scapula and by passively moving the scapula into adduction. The swimmer was instructed to actively do scapular retraction and ideally the active range should have been equal to the passive range. The swimmer had been guided through the test movement to get familiarized with the test. After the assisted movement the swimmer was allowed to practise the test movement once before the test commenced. For the test the swimmer performed this action twice, doing scapular retraction through the full range of motion and holding the inner range of contraction for fifteen seconds. Research assistant B observed for the following possible compensatory movements:

- Scapular elevation or retraction or over activity of Levator scapulae or Rhomboid major and minor (movement of the inferior angle or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Gleno-humeral horizontal abduction or over activity of the posterior Deltoid (gleno-humeral instead of scapular movement)

- Gleno-humeral adduction and
- Thoracic extension.

The function of the muscle had been scored on the following table.

Table 3.2: Evaluation of the muscle function of Trapezius middle fibres (Cuthbert and Goodheart 2007; Magarey and Jones 2003; Comerford and Mottram 2001).

Test of muscle function for Trapezius middle fibres		
Quality of muscle contraction	**✓ = yes ✗ = no**	
	L	**R**
The active range of muscle contraction equals the passive range scapula retraction.		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles.		
Smooth eccentric control.		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk.		
The swimmer can hold this inner range position for fifteen seconds (two repetitions).		
The swimmer can perform the test without fatigue.		
The swimmer can perform the test with relaxed breathing.		

Lower fibres of Trapezius muscle function test

(Struyf et al. 2012b; Comerford and Mottram 2001)

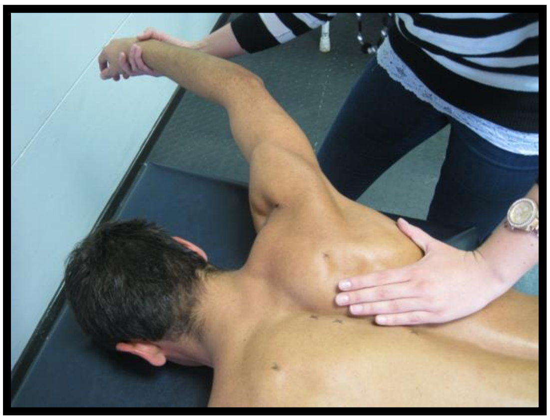


Figure 3.6: Muscle function test of Trapezius lower fibres.

The swimmer was positioned prone with the gleno-humeral joint in 120° of abduction, elbows extended and in the available range of lateral rotation (Figure 3.6). If the scapula had not been in the ideal plane (15° - 30° from the frontal plane into the sagittal plane), the researcher would have placed a rolled face towel under the shoulder girdle to obtain ideal alignment for the scapula. Research assistant B tested the passive range of scapula adduction (ideal range is two – four centimetre of adduction of the superior medial border of the scapula to the thoracic spine). The swimmer was instructed to take the weight of his / her arm and to lift the arm with a scapular movement (adduction and posterior tilt). Ideally the active range should be equal to the passive range. The swimmer was guided through the test movement to familiarize him / her with the test. After completion of the assisted movement the swimmer was allowed to practice the test movement once before the test commenced. For the purposes of the test the swimmer performed this action twice, doing scapular retraction through the full range of motion and holding the inner range of contraction for fifteen seconds. Research assistant B observed for the following possible compensatory movements:

- Scapular elevation or over activity of Levator scapula (movement of the inferior angle medially or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Gleno-humeral flexion (gleno-humeral movement instead of scapular movement);
- Gleno-humeral adduction and
- Thoracic extension or rotation.

The function of the muscle had been recorded on the following table.

Table 3.3: Evaluation of the muscle function of Trapezius lower fibres (Cuthbert and Goodheart 2007; Magarey and Jones 2003; Comerford and Mottram 2001).

Test of muscle function for Trapezius lower fibres		
Quality of muscle contraction	**✓ = yes** **✗ = no**	
	L	**R**
The active range of muscle contraction equals the passive range scapula upward rotation and retraction.		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles.		
The swimmer can smoothly control the eccentric return.		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk.		
The swimmer can hold this inner range position for fifteen seconds (two repetitions).		
The swimmer can perform the test without fatigue.		
The swimmer can perform the test with relaxed breathing.		

Serratus anterior muscle function test

(Ekstrom et al. 2004; Comerford and Mottram 2001)

Figure 3.7: Muscle function test of Serratus anterior.

This push up plus position was chosen to evaluate the function of Serratus anterior because it was shown that in this position the scapula protracts and upwardly rotates (Table 2.5) (Ekstrom et al. 2004). Both these functions of Serratus anterior are needed in the swim action (Heinlein et al. 2010). The swimmer had been positioned in four point kneeling with the knees under the hips and the hands under the shoulders, in order to assure good spinal alignment. The swimmer was instructed to protract the scapulae around the chest wall by 'making the shoulder blades wide'. The inferior angle of the scapula should protract around to the posterior axillary line. The swimmer had further been instructed to take full weight over the hands and to shift the weight unto the left hand, lifting the right hand from the plinth. The active contraction should meet the passive range of protraction and upward rotation. The swimmer was guided through the test movement to familiarize him / her with the test. After the assisted movement the swimmer was allowed to practise the test movement once before the test commenced. For the purposes of the test the swimmer performed this action twice, doing scapular protraction through the full range of motion and holding the inner range of contraction for fifteen seconds. Research assistant B observed for the following possible compensatory movements:

- Thoracic flexion;
- Scapular winging (the medial border of the scapula not in contact with the thoracic wall);
- Scapular tipping (the inferior angle of the scapula not in contact with the thoracic wall);
- Scapular elevation (movement of the inferior angle or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Scapular depression (movement of the inferior angle or superior-medial corner inferiorly) and
- Thoracic rotation.

The function of the muscle had been recorded on the following table.

Table 3.4: Evaluation of the muscle function of Serratus anterior (Cuthbert and Goodheart 2007; Magarey and Jones 2003; Comerford and Mottram 2001).

Test of muscle function for Serratus anterior		
Quality of muscle contraction	**✓ = yes** **✗ = no**	
	L	**R**
The active muscle contraction range equals the passive range of scapula protraction.		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles.		
The swimmer can smoothly control the eccentric return.		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk.		
The swimmer can hold this inner range position for fifteen seconds (two repetitions).		
The swimmer can perform the test without fatigue.		
The swimmer can perform the test with relaxed breathing.		

Evaluation of the resting scapula position

Ideal scapular positioning contributes to upper limb function. Scapular positioning should be ideal in relation to the thorax and the humerus (Nijs et al. 2007). Although there is no documented evidence of consensus about the optimum resting position of the scapula, several guidelines exist to determine the resting position of the scapula. The ideal resting position of the scapula had been discussed in the literature review. The landmarks used during the evaluation are based on these guidelines (Struyf et al. 2012b; Haneline et al. 2008; Nijs et al. 2007; Sobush et al. 1996; Levangie and Norkin 2001; Mottram 1997; T'jonck and Lysens 1996).

The relation of the following anatomical landmarks was evaluated (Figure 3.8):

Figure 3.8: Scapula landmarks to evaluate the resting scapular position.

- The spinous processes of various thoracic vertebrae: second (T2), third (T3), fourth (T4), seventh (T7) and eighth (T8);
- The superior angle of the scapula;
- The root of the spine of the scapula;
- The acromial angle (most lateral dorsal point of the scapula);
- The inferior angle of the scapula and
- The coracoid process.

The swimmers stood with their feet hip width apart and parallel to assure a uniformed starting position. They were instructed to stand at ease (Lewis et al. 2002). Research assistant A had been positioned two and a half meters behind the swimmer while they were evaluating the resting scapular position (McClure et al. 2009a). The resting position of the scapula was evaluated as stipulated in Table 3.7. The scapula landmark (left column) should correlate to the ideal resting position (middle column). If the specific landmark did correlate to the ideal position, it had been indicated with a ✓ in the right column. If the landmark did not correlate to the ideal position, an x was used.

After evaluation of the scapula's resting position had been completed, the following border prominences were also evaluated visually:

- Inferior angle prominence (scapular tipping);
- Medial border winging, more than two-thirds of the medial border is away from the thoracic wall (scapular winging) and

- Inferior medial border winging, only the inferior third of the medial border is away from the thoracic wall (pseudo winging).

This information (angle and border prominence) provided an indication of the ability of the scapula stabilizers to position the scapula in a resting position (McClure et al. 2009a).

Table 3.5: Evaluation form to document the resting position of the scapula (Struyf et al. 2012b; Hanneline et al. 2008; Nijs et al. 2007; Levangie and Norkin 2001; Mottram 1997; Soblush et al. 1996; T'jonk and Lysens 1996).

Scapula landmark	**Ideal position**	**✓ = yes, x = no**	
		L	**R**
Root of scapula spine	Level to T3 projecting to T4		
Inferior angle	Below T7		
	Against thoracic wall		
Inferior angle relation to superior angle	Inferior angle should be lateral to superior angle		
Medial border position	Parallel to spine		
Acromion position	Left and right level / same height		
	Higher than superior border of the scapula		
Position of the spine of the scapula	Angled upwards		
Coracoid process position	Same height		
Clavicle position	Same height		
	Incline upwards		
Medial scapula border	Whole border against thoracic wall		
	Inferior third of border against thoracic wall		

Evaluation of the dynamic scapular control

Scapular control during upper limb movement is one of the most important factors to ensure optimum gleno-humeral range of motion and function (Struyf et al. 2012b; Nijs et al. 2007; Kibler 2003). This ability to position the scapula dynamically helps to distribute forces effectively from the trunk to the upper limb (Kibler et al. 2013) and to ensure a stable base for those muscles which are attached to the scapula (Kibler

2003; Kibler 1998; Mottram 1997). Ideal control of the scapula during gleno-humeral movements also helps to prevent impingement of the subacromial structures (Kibler et al. 2013).

Several methods exist to measure the control of the scapula during movement, although logistics around setting it up in the clinical context are usually costly and difficult. In a study done by McClure and his colleagues (2009a and b) they found the visual observation of the scapula during movement reliable and valid (refer to Table 3.1, measuring tools).

Figure 3.9: Evaluation of the dynamic scapular control.

The swimmer had been instructed to stand at ease with weights in both hands. The weight the swimmer was holding in his/her hands was calculated according to the swimmer's weight: 50 kg or less used a 1kg weight per hand, 50 – 60kg used a 2kg weight per hand, 60 – 70kg used a 3kg weight per hand, 70 – 80kg used a 4 kg weight per hand and above 80kg used a 5kg weight per hand (McClure et al. 2009a). The test began with arms by the side, elbows extended and gleno-humeral joints in neutral rotation (thumbs facing forward). The researcher was positioned two and a half meters behind the swimmer to observe the scapular movement (McClure et al. 2009a). The swimmers were instructed to lift the gleno-humeral joints through the full range of flexion (as this is the gleno-humeral joint movement that is part of all four strokes) for four counts and to lower the hands back to the starting position for four counts. They repeated this movement five times. The swimmer practised each movement twice without the weights. The dynamic position of the scapula had been evaluated twice, once before the 200m free style swim and once directly after the 200m free style swim.

Research assistant A documented whether the scapular movement was ideal or whether scapular dyskinesis (abnormal movement) existed. Scapular dyskinesis was documented as: dysrhythmia, winging or tipping (McClure et al. 2009a).

The findings of the dynamic scapula were documented in the table below (Table 3.6). Depending on the movement demonstrated by the swimmer, a tick was made in the applicable row.

Table 3.6: Evaluation form to document the dynamic scapula position.

Scapula dynamic position (pre 200m free style)										
Reps	1		2		3		4		5	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
Ideal scapulohumeral movement										
Dysrhythmia										
Winging										
Tipping										
Scapula dynamic position (post 200m free style)										
Reps	1		2		3		4		5	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
Ideal scapulohumeral movement										
Dysrhythmia										
Winging										
Tipping										

Variables

The independent variables were used to influence the outcome of the dependent variable. In this study the independent variables consisted of stretches for Pectoralis minor, rehabilitative and strengthening exercises for Trapezius (middle and lower fibres) and Serratus anterior as well as breathing dissociation exercises. The dependent variable in this study was the resting and dynamic position of the scapula.

Follow – up procedure

Text messages have been employed for both the intervention and control groups for communication regarding evaluation dates and times. A text message was sent to the swimmer 24 hours before the evaluation to confirm the appointment. Text messages were also used to remind the swimmers to do their breathing exercises.

ETHICAL CONSIDERATIONS

Only swimmers who gave written informed consent were involved in this study (Annexure 2). Swimmers younger than 18 have only been included in the study once their parents / guardians gave written consent to participate in the procedures needed for this study (Annexure 6). Swimmers were informed that they have the right to withdraw from the study at any point in time, without having to fear any negative consequences as a result of their decision to withdraw. Swimmers' anonymity was ensured. All information gathered from the subjects was kept confidential and documents had been stored in a safe, fire and water proof place. The information was only used for research purposes. Swimmers have the right to access all research and information pertaining to them personally at any time during or after the study (Annexure 7).

The requirements of the Faculty of Health Sciences Research and Ethics Committee of the University of Pretoria had strictly been adhered to during the entire research process. The study only commenced once approval from the Faculty of Health Sciences Research and Ethics Committee had been obtained (6 September 2012), ethics approval number 163/2012 (Annexure 8). The study is also registered at the Department of Health, trial registration number DOH-27-0913-4521.

The person who modelled for the photos inserted to illustrate the scapula evaluation as well as rehabilitative and strengthening exercises, gave informed consent (Annexure 9).

Feedback to the swimmers

After every evaluation (baseline, six weeks and at the end of the season) each swimmer received individual feedback (Annexure10). Feedback consisted of information regarding the evaluation as well as how to progress or adapt with the exercises. This feedback had been presented in table format in order to share specific instances of progression or regression with the swimmer. The aim of every exercise was explained on the form.

After completion of the final evaluation, feedback was given to all the coaches and to all members of the dry land training team.

PILOT STUDY

A pilot study was conducted on 5 September 2012. The evaluation process and intervention were tested on four student volunteers, aged 19 to 23. The information was documented on the evaluation forms. The documentation of the research assistants correlated well and no discrepancies in the interpretation of the data capturing forms had been observed. The only change made after completion of the pilot study was headings on the data capturing form in order to create more clarity about pre swim and post swim evaluation.

The validity and reliability of the instruments that were utilized is well documented. Refer to Table 3.1 for details regarding the instruments.

THE INTERVENTION

The intervention took place at the swim club of the University of Pretoria. Exercises and stretches had been performed under the researcher's supervision. Daily sessions were scheduled for six weeks, in alignment with the swimmers' regular training and strengthening sessions (8 October 2012 – 16 November 2012). In consultation with the coaches and dry land training team it was decided that swimmers had to attend two of these sessions. Two sessions fitted into their Monday to Thursday training schedule. The six week period which included two supervised session per week, was comparable to current recommendations (De Mey et al. 2012; Tate et al. 2010). Fridays and Saturdays swimmers focused on cardiovascular fitness and competitions**.** A group of eight second year physiotherapy students had been trained to assist the researcher at every session to ensure that the stretches as well as exercises were performed correctly and without any compensatory movements. Both groups did stretches and retraining and strengthening of the scapular muscles. The breathing exercises differed for the two groups (Table 3.7).

Table 3.7: Exercises for the intervention and control groups.

Group	Stretches and exercises	Breathing exercises
Intervention	Stretched Pectoralis minor Retrained and strengthened Serratus anterior, Trapezius middle and lower fibres.	Breathing dissociation exercises. Exhaled into positive pressure system, inhaled against pressure of elastic band around thorax at T10 and xifisternum level.
Control	Stretched Pectoralis minor Retrained and strengthened Serratus anterior, Trapezius middle and lower fibres.	Exhaled into positive pressure system.

The stretching of Pectoralis minor aimed to increase flexibility of this muscle. The aim of the scapular muscle exercises were to address muscle function; the ability of the muscle to activate in the correct sequence as well as agonistic strengthening. The exercises had been divided into three categories. In the first category the exercise aimed to address correct activation and sequence of activation (motor control) of the Trapezius middle and lower fibres, as well as Serratus anterior muscles. In the second category concentric strength and eccentric control were addressed. The third category aimed at agonistic strengthening and endurance of the specific muscle. The breathing dissociation exercises (intervention group) aimed to facilitate lateral costal breathing.

Pectoralis minor muscle stretches

The stretch for Pectoralis minor utilized in this study is based on the principle of reciprocal inhibition (Lynch et al. 2010).

Figure 3.10: Position of Pectoralis minor stretches (Cools et al. 2010).

The swimmer had been lying with a towel roll underneath the spine, thick enough to keep the shoulder girdle from the surface. The towel was aligned with the swimmer's spine. The swimmer began by flattening the lumbar curve against the towel and flexing the gleno-humeral joints and elbows to 90° above the thorax, with the fore arms and palms touching (Lynch et al. 2010; Tate et al. 2010; Borstad and Ludewig 2005). The swimmer then did horizontal abduction, keeping the angle between the humerus and the thorax and keeping the forearm parallel to the surface. The position was carefully monitored and if the swimmer dropped the gleno-humeral joint into flexion or compensated with an elevated or protracted shoulder girdle the position was corrected. The swimmers were then instructed to hold the stretch. The stretch was held for thirty seconds and repeated five times (Cools et al. 2010).

Breathing exercises

In this study, lateral costal breathing was facilitated in the intervention group during dry land training and twice a day in their own time. The aim was not to change the swimmer's breathing technique but to facilitate lateral costal expansion.

The aim of the lateral costal breathing pattern was to enhance the swimmer's ability to cope with the high load of breathing for adequate ventilation, and lessen the demand on Pectoralis minor as accessory breathing muscle. The ideal sequence of a lateral costal breathing pattern in the phasic phase of the diaphragm contraction ensures optimum use of diaphragm during the breathing pattern and this may result in effective fulfilment of the function of the diaphragm (Magarey and Jones 2003).

This part of the intervention had been divided in two sections: section one was the usage of breathing against a positive pressure and section two was the training of lateral costal breathing exercises (dissociation of breathing exercises). The intervention group did both exercises whereas the control group only did the breathing against a positive pressure.

Breathing against positive pressure

(Intervention and control group)

A 500 ml plastic bottle had been filled with water to a mark of ten centimetres. A 42 centimetre plastic tube of one centimetre in diameter was inserted into the bottle. The instruction to the control group was to inhale for six counts and then to exhale blowing bubbles in the water, five times twice daily. The emphasis of this exercise was to exhale for four counts. The ten centimetres represent the depth at which their faces are in the water when they swim (Sehlin et al. 2007).

Breathing against positive pressure and breathing dissociation exercise

(*Intervention* group)

Each swimmer received an elastic band. The circumference of each swimmer's thorax was measured at the xifisternum and tenth thoracic vertebra. This measurement had been taken, five centimetres were deducted and the elastic band was sewn together with a two centimetre overlap. This elastic band was placed over the 10^{th} thoracic vertebrae and the xifisternum. The swimmer was instructed to inhale for six counts against the resistance of the elastic band, keeping the shoulder girdle relaxed and opened. This inhalation was followed by expiration for four counts into the plastic bottle. While blowing into the bottle, the resistance should be kept for two of the four counts against the elastic band (Comerford and Mottram 2012). The counts aimed to break the short inspiration – expiration pattern that swimmers have. This exercise had been done five times twice daily. The intervention group wore this elastic band during the muscle retraining and stretching as well. They were constantly reminded to breathe against the elastic band and to relax the shoulder girdle enhancing a lateral costal breathing pattern.

Retraining of the scapular stabilisers

The following aspects of muscle strengthening were addressed: (i) retraining of correct muscle recruitment pattern (motor control), (ii) concentric inner range hold strengthening and eccentric control as well as (iii) strengthening with load and endurance of the muscle's agonistic function. Depending on the muscle function tests results, swimmers started with scapular muscle retraining and strengthening in one of the following categories.

In the first category the focus of the exercises was the correct activation of the specific muscle as well as correct sequence of activation (motor control). This tonic, low threshold muscle activation aimed to increase the biomechanical muscle stiffness of the scapula stabilisers to control the ideal positioning of the scapula. Scapula stability is dependent on the correct recruitment of the local stabilisers (muscle stiffness) in anticipation of any shoulder girdle movement and / or upper limb movement (Cuthbert and Goodheart 2007; Magarey and Jones 2003; Comerford and Mottram 2001a; Comerford and Mottram 2001b).

The second category of exercises addressed the ability of the specific muscle to contract concentrically through the full range of movement, the ability to hold this inner range and the ability to eccentrically control the range. Trapezius middle and lower fibres as well as Serratus anterior are muscles with a stability role through gleno-humeral range of movement (Struyf et al. 2012a; Struyf et al. 2012b; Cools et al. 2006; Hardwick et al. 2006). These muscles are required to have the ability to: (i) concentrically shorten through the available joint range, in other words the muscle must have the ability to move the joint through the same range as the joint can be moved passively, (ii) isometrically hold the inner range position to sustain postural alignment or support trunk or limb load and (iii) eccentrically control the available range and specific rotational control in all functional movements (Cuthbert and Goodheart 2007; Magarey and Jones 2003; Comerford and Mottram 2001b).

The third category of exercises addressed the strengthening and endurance of the specific muscle in the ideal agonistic function. The exercises chosen for concentric and eccentric strengthening and endurance of Trapezius middle and lower fibres had been based on a study conducted by De Mey et al. (2012); Arlotta et al. (2011); Oyama et al. (2010) and Cools et al. (2007).

Rehabilitation of the Trapezius middle fibres will first be discussed hereunder, then the rehabilitation of Trapezius lower will follow and finally a discussion of the rehabilitation of Serratus anterior will be presented.

Retraining and strengthening of Trapezius middle fibres

The agonistic function of Trapezius middle fibres is retraction / adduction of the scapula (Agur and Dalley 2009, Kendall et al. 2005). The middle fibres of Trapezius contribute mainly to scapular stability during gleno-humeral abduction above 90° and lateral rotation of the gleno-humeral joint, resisting the protraction pull on the scapula, caused by the lateral rotators Teres minor and Infraspinatus (Cools et al. 2007a; Cools et al. 2003a; Cools et al. 2002). The mean normalised electromyographic activity for the exercises used to strengthen Trapezius middle fibres are summarised in Table 3.8. The intervention group wore their elastic bands and they were instructed to breathe against the elastic band throughout the exercise, to facilitate lateral costal breathing. The control group was instructed to breathe throughout the exercise.

Table 3.8: Mean normalised electromyographic activity of different exercises for Trapezius middle fibres (Cools et al. 2007b).

Exercise	Concentric phase	Isometric phase	Eccentric phase
Horizontal abduction with external rotation	54.22	78.18	26.39
Forward flexion in side lying	40.29	35.35	41.18
Side lying external rotation	27.32	18.23	18.43
Prone extension	20.00	30.09	15.24

Values expressed as percentage of maximal voluntary contraction.

Category one **(**retraining motor control) (Lynch et al. 2010; Cools et al. 2007a)

The purpose of the exercises in this category was to retrain and recruit the middle fibres of the Trapezius muscle. The position against the wall gave 'support' and tactile feedback to the swimmer, allowing the swimmer to focus on the muscle contraction.

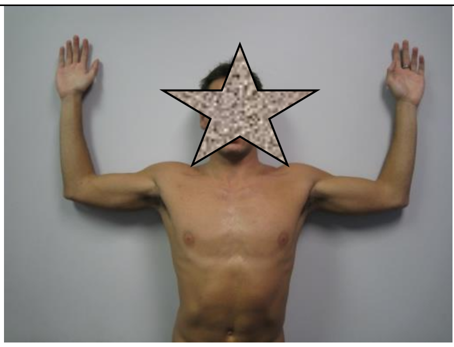
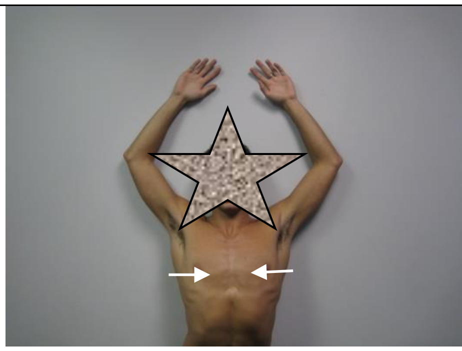
Starting position	End position
	

Figure 3.11: Exercise to retrain motor control of Trapezius middle fibres.

The swimmer stood against a wall, with the feet three to five centimetres away from the wall. With the spine in ideal alignment (anterior superior iliac spine left and right on same horizontal line and anterior superior iliac spine and posterior superior iliac spine in line in the sagittal plane), the gleno-humeral joints in 90° abduction and 90° external rotation the swimmer did scapular retraction. In this position of retraction the swimmer did gleno-humeral abduction within the available range. If any scapular elevation or loss of external rotation occurred, the swimmer stopped at that point. The swimmer held this inner range position for ten seconds and repeated the exercise ten times. Once the swimmers could do the exercise without any compensation and once they could hold the position for ten seconds during ten repetitions they progressed to the exercise describe in category two.

Category two (retraining concentric hold and eccentric control) (De Mey et al. 2012; Lynch et al. 2010; Oyama et al. 2010; Cools et al. 2007a).

This exercise aimed at retraining the concentric hold, isometric strengthening in the inner range of muscle action and eccentric control. This exercise reflected the best activation of isometric hold for Trapezius middle fibres (refer to Table 3.8).

Starting position	**End position**
	

Figure 3.12: Exercise to retrain concentric hold and eccentric control of Trapezius middle fibres: horizontal abduction with external rotation.

The swimmer was positioned prone with the gleno-humeral joint in 90° of abduction, elbows flexed and thumbs pointing forward. If the scapula had not been in the neutral position, the researcher would have placed a rolled face towel under the shoulder girdle to obtain ideal alignment for the scapula. The swimmer was instructed to actively do scapular retraction and ideally the active range of retraction should be equal to the passive range of retraction. The swimmer held this inner range position for ten seconds and then returned to the starting position in four counts. This count of four aimed to retrain eccentric control of the muscle. The researcher observed for the following possible compensatory movements:

- Scapular elevation or over activity of Levator scapulae or Rhomboid muscles (movement of the inferior angle or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi muscle (movement of the acromion inferiorly);
- Gleno-humeral horizontal abduction or over activity of the posterior fibres of the Deltoid muscle (gleno-humeral instead of scapular movement);
- Gleno-humeral adduction and
- Thoracic extension.

Once the swimmer could do this exercise ten times as prescribed, the test for Trapezius middle fibres were conducted again and if the swimmer passed the test he / she continued with the exercises prescribed in category three.

Category three (strengthening and endurance) (De Mey et al. 2012; Cools et al. 2007b).

The amount of weight that was held by the swimmer was determined by the athlete's body weight and gender (Cools et al. 2007b). The exercises were not done in a specific order. The aim of the exercises in category three was to strengthen the middle fibres of the Trapezius muscle (refer to Table 3.8)

<u>Exercise 1</u>

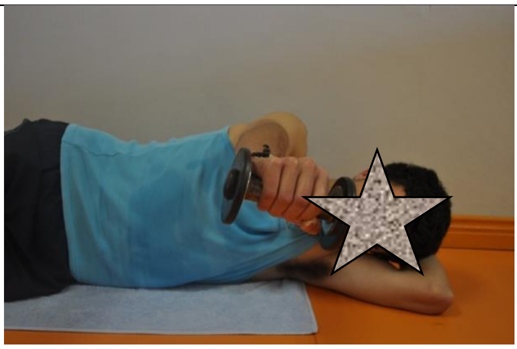
Starting position	**End position**
	

Figure 3.13: Exercise one to strengthen Trapezius middle fibres: forward flexion in side lying.

In side lying with the scapula, spine and gleno-humeral joints in neutral, the swimmer performed gleno-humeral flexion from 90° to 135° of flexion (the humerus stays parallel to the surface) (15 repetitions x 3). The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following compensatory movements had been observed:

- Scapula protraction;
- Scapula elevation and
- If the humerus did not stay parallel to the surface and the gleno-humeral joint dropped into horizontal adduction.

<u>Exercise 2</u>

Starting position	**End position**
	

Figure 3.14: Exercise two to strengthen Trapezius middle fibres: side lying external rotation.

In side lying with the scapula, spine and gleno-humeral joint in neutral position, a face towel was folded and placed between the humerus and the trunk. With the elbow flexed to 90°, the swimmer performed gleno-humeral lateral rotation (15 repetitions x 3). The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following compensatory movements had been observed:

- Thoracic rotation and
- Gleno-humeral abduction (humerus moving away from the towel).

Exercise 3

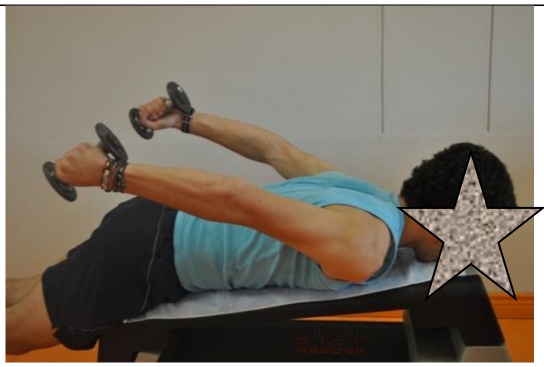
Starting position	End position
	

Figure 3.15: Exercise three to strengthen Trapezius middle fibres: prone extension.

In prone, arms by side and no gleno-humeral rotation (palms facing towards the body and the thumbs down to the floor), elbows extended and the scapula and spine in neutral position. The swimmer performed gleno-humeral extension. The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following compensatory movements had been observed:

- Elbow flexion and extension;
- Thoracic flexion and
- Protraction of the scapula.

Retraining and strengthening of Trapezius lower fibres

Ideal function of the lower fibres of Trapezius contributes to optimum resting and dynamic function of the scapula. The lower fibres are the only fibres of Trapezius that are active during the first 60° of gleno-humeral abduction, indicating their role in scapula stability with initial gleno-humeral movement (Mottram 1997). The lower fibres upwardly rotate the scapula (Arlotta et al. 2011, Agur and Dalley 2009, Kendall et al. 2005). During gleno-humeral elevation upward rotation, posterior tipping and external rotation of the scapula occur. Lower fibres of Trapezius (in conjunction with the upper fibres of Trapezius and Serratus anterior) are responsible for this ideal positioning of the scapula during gleno-humeral elevation (Cools et al. 2007a). The mean normalised electromyographic activity for the exercises used to strengthen Trapezius lower fibres are summarised in Table 3.9. The intervention group wore their elastic bands and they were instructed to breathe against the elastic band throughout the exercise, to facilitate lateral costal breathing. The control group was instructed to breathe throughout the exercise.

Category one (retraining motor control) (Struyf et al. 2012a; Lynch et al. 2010)

The aim of the exercise in this category was to retrain and recruit the lower fibres of Trapezius. In the prone position with the gleno-humeral joint in 120° of abduction Trapezius lower fibres are well recruited (Struyf et al. 2012a; Lynch et al. 2010; Oyama et al. 2010; Cools et al. 2007a).

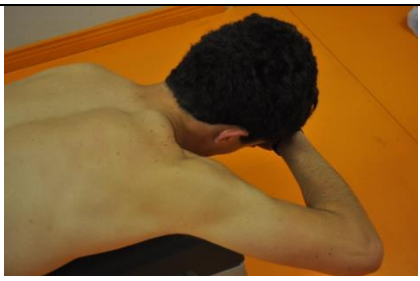
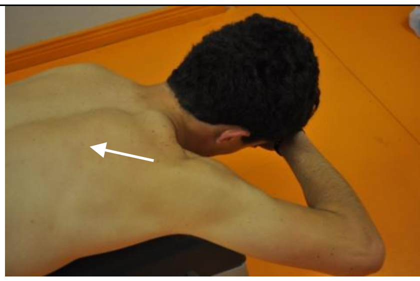
Starting position	**End position**
	

Figure 3.16: Exercise to retrain motor control of Trapezius lower fibres.

The swimmer was positioned prone with the gleno-humeral joint in 120° of abduction and the elbows flexed. If the scapula was not in the ideal plane (15° - 30° from the frontal plane into the sagittal plane), the researcher would have placed a rolled face towel under the shoulder girdle to obtain ideal alignment for the scapula. The upper arm and elbow was placed on a folded towel to unload Trapezius lower fibres. The swimmer had been instructed to take weight of the arm without lifting the arm from the towel. The swimmer held this inner range position for ten seconds and repeated the exercise ten times. Once a swimmer could do the exercise without any compensation and held the position for ten seconds during ten repetitions he progressed to the exercise described for category two.

The researcher observed for the following possible compensatory movements:

- Scapular elevation or over activity of Levator scapulae (movement of the inferior angle medially or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Gleno-humeral extension or over activity of Deltoid (gleno-humeral instead of scapular movement) and
- Thoracic extension or rotation.

Category two (retraining concentric hold and eccentric control) (Struyf et al. 2012a, Lynch et al. 2010, Oyama et al. 2010)

The aim of this category was to retrain the agonistic function of the muscle. The scapular plane elevation exercise reflected activation of the lower fibres of Trapezius from early in the range of gleno-humeral elevation with an increase in muscle activation as the range of elevation become more. Peak activation of Trapezius lower fibres had been observed from 120° of elevation (Hardwick et al. 2006).

Starting position	**End position**

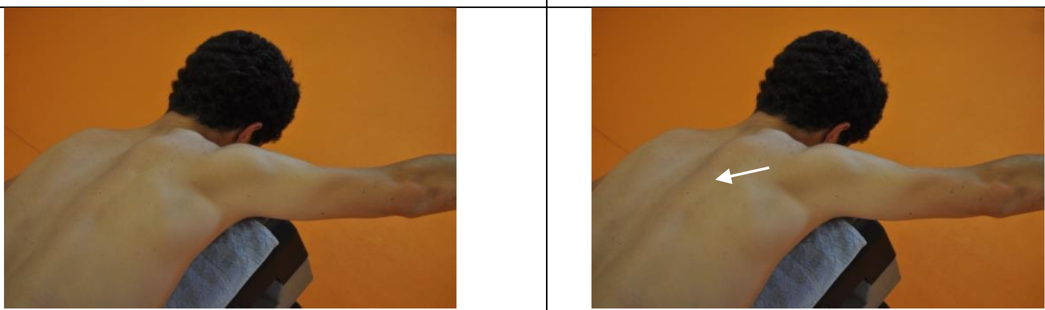


Figure 3.17: Exercise to retrain concentric hold and eccentric control of Trapezius lower fibres.

The swimmer was positioned prone with the gleno-humeral joint in 120° of abduction, elbows extended and thumbs pointing to the roof. If the scapula was not in the ideal plane (15° - 30° from the frontal plane into the sagittal plane), the researcher would have placed a rolled face towel under the shoulder girdle to obtain ideal alignment for the scapula. The swimmer was instructed to take the weight of his arm and lift the arm with a scapular movement (adduction) and ideally the active range should be equal to the passive range (ideal range is to lift the arm three to five centimetre). The researcher observed for the following possible compensatory movements:

- Scapular elevation or over activity of Levator scapulae (movement of the inferior angle medially or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Gleno-humeral extension or over activity of Deltoid (gleno-humeral instead of scapular movement) and
- Thoracic extension or rotation.

Once the swimmer could do this exercise ten times as prescribed, the test for Trapezius lower fibres was conducted again and if the swimmer passed the test he continued with the exercises prescribed in category three.

Category three (strengthening and endurance) (De Mey et al. 2012; Oyama et al. 2010; Cools et al. 2007b)

Table 3.9: Mean normalised electromyographic activity of different exercises for Trapezius lower fibres (Cools et al. 2007b).

Exercise	**Concentric phase**	**Isometric phase**	**Eccentric phase**
Forward flexion in side lying	58.22	63.72	47.99
Side lying external rotation	65.27	51.13	33.97
Horizontal abduction with external rotation	58.22	63.72	47.99

Values expressed as percentage of maximal voluntary contraction.

The amount of weight that will be used by the swimmer will be determined by the athlete's body weight and gender (Cools et al. 2007b).

Exercise 1

Starting position	**End position**
	

Figure 3.18: Exercise one to strengthen Trapezius lower fibres: forward flexion in side lying.

In side lying with the scapula, spine and gleno-humeral joint in neutral, the swimmer performed gleno-humeral flexion from 90° to 135° (the humerus stays parallel to the surface) (15 repetitions x 3). The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following compensatory movements had been noticed:

- Scapula protraction;
- Scapula elevation and
- If the humerus did not stay parallel to the surface and the gleno-humeral joint dropped into horizontal adduction.

Exercise 2

Starting position	**End position**
	

Figure 3.19: Exercise two to strengthen Trapezius lower fibres: side lying external rotation.

In side lying with the scapula, spine and gleno-humeral joint in neutral, a face towel was folded and placed between the humerus and the trunk. With the elbow flexed to 90°, the swimmer will perform gleno-humeral lateral rotation (15 repetitions x 3). The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following compensatory movements had been observed:

- Thoracic rotation and
- Gleno-humeral abduction (humerus moving away from the towel).

Exercise 3

Starting position	**End position**
	

Figure 3.20: Exercise three to strengthen Trapezius lower fibres: prone abduction external rotation.

The swimmer was positioned prone with the spine and scapula in neutral position. The gleno-humeral joints were in 90° flexion. The swimmer performed gleno-humeral abduction to the horizontal position with gleno-humeral external rotation added at the end of the horizontal abduction movement. The movement into the exercise and back to the starting position was controlled; the swimmer counted to four to execute the movement and four counts to return to the staring position. The swimmer was stopped if the following trick movements had been observed:

- Thoracic extension and
- Elbow flexion and extension.

Retraining and strengthening of Serratus anterior

Ideal function of Serratus anterior is a crucial component in ideal positioning of the scapula, resting as well as dynamic. Serratus anterior upwardly rotates, posteriorly tips and protacts the scapula and prevents winging of the medial border of the scapula (Agur and Dalley 2009; Kendall et al. 2005; Ekstrom et al. 2004). The wall slide exercise, category one (Figure 21), had been proven to activate and strengthen Serratus anterior above 90° of humeral elevation ($p<0.0001$) (Hardwick et al. 2006). The amount of Serratus anterior activation increased as the amount of humeral elevation increased with the wall slide exercise (Table 3.10) (Hardwick et al. 2006). Although the scapular plane gleno-humeral elevation had even better activation of Serratus anterior, the wall slide was chosen for category one. The aim of category one was to retrain muscle recruitment and with the wall slide the swimmer had the 'support' of the wall for the upper limbs. While being supported, the swimmer could focus on the scapular position during the exercise. Minimal activation of Lattisimus dorsi occurred during the range of elevation with the wall slide exercise. The intervention group wore their elastic bands and they were instructed to breathe against the elastic band throughout the exercise, to facilitate lateral costal breathing. The control group was instructed to breathe throughout the exercise.

Table 3.10: Serratus anterior activation during different exercises (Hardwick et al. 2006).

Range of gleno-humeral elevation	Wall slide	Push up plus	Scapular plane gleno-humeral elevation
90°	0.498 V (0.469)	0.398 V (0.338)	0.499 V (0.293)
120°	0.745 V (0.779)	No activation	0.716 V (0.512)
140°	0.840 V (0.728)	No activation	1.009 V (0.826)

Category one (retraining motor control) (Hardwick et al. 2006).

Starting position	**End position**
	

Figure 3.21: Exercise to retrain motor control of Serratus anterior.

The swimmer had been positioned one step away from a smooth wall, with the dominant foot against the wall and the non-dominant foot shoulder width behind the dominant foot. The swimmer flexed both gleno-humeral joints and elbows to 90° and the fore arm midway between supination and pronation, with the ulnar border against the wall. In this starting position the swimmer was reminded not to shrug the shoulders. While sliding the fore arms up against the wall in a V shape, the swimmer transferred the weight to the front dominant leg. The swimmer was encouraged to *'bring the shoulder blades out and around the chest as you slide'* and to maintain the distance between the ears and the shoulders (no scapular elevation). The end of range of elevation was held for 10 seconds. The swimmer was stopped if the following compensatory movements had been observed:

- Winging of the scapulae and
- Elevation of the scapulae.

The swimmer continued to the next category, if he could do ten repetitions of this exercise without any compensatory movements.

Category two (retraining concentric hold and eccentric control) (Struyf et al. 2012; Ekstrom et al. 2004).

In the push up plus, scapular protraction (the agonistic function of Serratus anterior) was done in a weightbearing position. The push up plus exercise showed good activation of Serratus anterior (0.398 V, Table 3.10).

Starting position	**End position**
	

Figure 3.22: Exercise to retrain concentric hold and eccentric control of Serratus anterior.

The swimmer was positioned in four point kneeling with the knees under the hips and the hands under the shoulders. The swimmer had been instructed to protract the scapulae around the chest wall by 'making the shoulder blades wide'. The swimmer was also instructed to keep the distance between the ear and the shoulder (not to shrug the shoulders). The inferior angle of the scapula should protract around to the posterior axillary line. The swimmer was instructed to take full weight over the hands and shifted the weight unto the left hand, lifting the right hand from the floor. The medial border of the scapula (at the spine of the scapula) should be eight to ten centimetres from the thoracic spine and in contact with the thorax. The swimmer held this inner range position for ten seconds and returned to the starting position in four counts (eccentric control). The exercise was repeated ten times. The swimmer was stopped if any of the following compensatory movements had been observed:

- Thoracic flexion;
- Scapular winging (the medial border of the scapula not in contact with the thoracic wall);

- Scapular tipping (the inferior angle of the scapula not in contact with the thoracic wall);
- Scapular elevation or over activity of the Levator scapulae (movement of the inferior angle or superior-medial corner superiorly);
- Scapular downward rotation or over activity of Lattisimus dorsi (movement of the acromion inferiorly);
- Scapular depression (movement of the inferior angle or superior-medial corner inferiorly) and
- Thoracic rotation.

Once the swimmer could do this exercise ten times as prescribed, the test for Serratus anterior was conducted again and if the swimmer passed the test he/she continued with the exercises prescribed in category three.

Category three (strengthening and endurance)

The exercises done in category three were not done in a specific order. The exercises included were aimed at strengthening of Serratus anterior through the full range of gleno-humeral elevation as needed by swimmers. The push up plus (exercise one) showed good activation of Serratus anterior at 90° of elevation. The scapular plane gleno-humeral elevation exercise showed even better activation from 90° - 140° (Table 3.10). Thus including these exercises, Serratus anterior were strengthened throughout the range of gleno-humeral elevation (Cools et al. 2007b; Hardwick et al. 2006).

<u>Exercise 1</u> (Hardwick et al. 2006; Ekstrom et al. 2004).

Push up plus

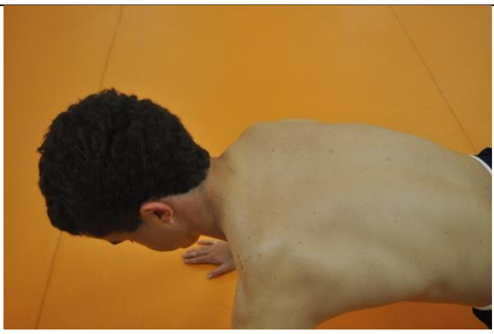


Figure 3.23: Exercise one strengthen Serratus anterior: push up plus.

The exercise was performed in the classical push up position (prone with the legs together and bearing weight on the elbows and fore arms). The scapula should be in neutral position (no scapula elevation). The swimmer had been instructed to first sag with the thorax into the shoulder girdle (scapula retraction) and then to move from this position into the full scapula protraction position. The swimmer held this protracted position for ten seconds and returned to the starting position on four counts (Hardwick et al. 2006). The swimmer was stopped if one of the following compensatory movements occurred:

- Lumbar flexion;
- Thoracic flexion and
- Scapular elevation.

Exercise 2 (Cools et al. 2007b; Hardwick et al. 2006)

Starting position	**End position**
	

Figure 3.24: Exercise to strengthen Serratus anterior: scapular plane gleno-humeral elevation.

The swimmer had been seated with hips and knees at 90° flexion. The spine and scapula were aligned in neutral. The swimmer performed gleno-humeral flexion in the scapular plane to full range of elevation. The elbows had to be extended and the thumbs were facing forward. The swimmer returned to the starting position on four counts (Cools et al. 2007b). The swimmer was stopped if one of the following compensatory movements were observed:

- Thoracic extension;
- Lumbar extension and
- Uncontrolled movement with momentum.

DATA MANAGEMENT AND ANALYSIS

Statistical considerations

The study sets out to determine whether following a postural improvement exercise programme, the relapse of the PMI (Pectoralis minor index) for the non-breathing dissociation group is greater than that of the breathing dissociation exercise group.

Data analysis

Data from the intervention was captured on an excel spread sheet and analysed as described. Data summary employed descriptive statistics including mean and standard deviation for continuous data (PMI, FVC and thoracic expansion) and frequency, percentage and 95% confidence intervals for categorical data (muscle function, resting and dynamic scapula position) by treatment group over time.

Treatment groups were assessed with respect to the observed longitudinal data making use of linear mixed model analysis. Treatment groups were also compared with respect to change from baseline to six weeks and baseline to five months in PMI, FVC and thoracic expansion utilizing analysis of covariance (ANCOVA) with covariates baseline reading. Baseline refers to the onset of the intervention.

Groups were compared with respect to change from baseline to six weeks and five months respectively for categorical parameters, muscle function and scapula position (resting and dynamic) using Fisher's exact test. Within group analysis to assess the change from baseline to six weeks and five months respectively, for categorical parameters muscle function and scapula position (resting and dynamic) employed McNemar's test for symmetry.

For the event, change from baseline to six weeks and five months respectively, the odds ratio for intervention relative to control was determined along with its 95% confidence interval.

Testing was done at the 0.05 level of significance.

SUMMARY

Chapter 3 describes the study design and research methodology which have been incorporated into this study. The swimmers included in this study were part of a six week supervised training programme to retrain scapular stabilisers and stretch Pectoralis minor. The intervention group did additional breathing exercises to facilitate lateral costal breathing.

After six weeks the swimmers had been re-evaluated and each swimmer received individual feedback. The swimmers' exercises were adjusted according to the results as documented after six weeks. The final evaluation took place after five months.

A detailed account of the analysis of the data and the discussion of the results gathered during the intervention period is presented in Chapter 4.

CHAPTER 4

RESULTS

INTRODUCTION

The aim of the study was to determine if lateral costal breathing exercises in conjunction with scapular retraining had a short term and long term effect on the scapular position of swimmers. The results obtained at baseline, six weeks and five months are presented by means of tables, graphs and histograms.

A flow diagram of the study is presented in Figure 4.1.

The results are presented in the following order: demographic data, Pectoralis minor length, thoracic expansion and force vital capacity. This will be followed by the muscle function of Serratus anterior, Trapezius middle fibres and Trapezius lower fibres. Lastly the resting position of the scapula and the dynamic scapula position will be presented.

Results were calculated between groups as well as within groups.

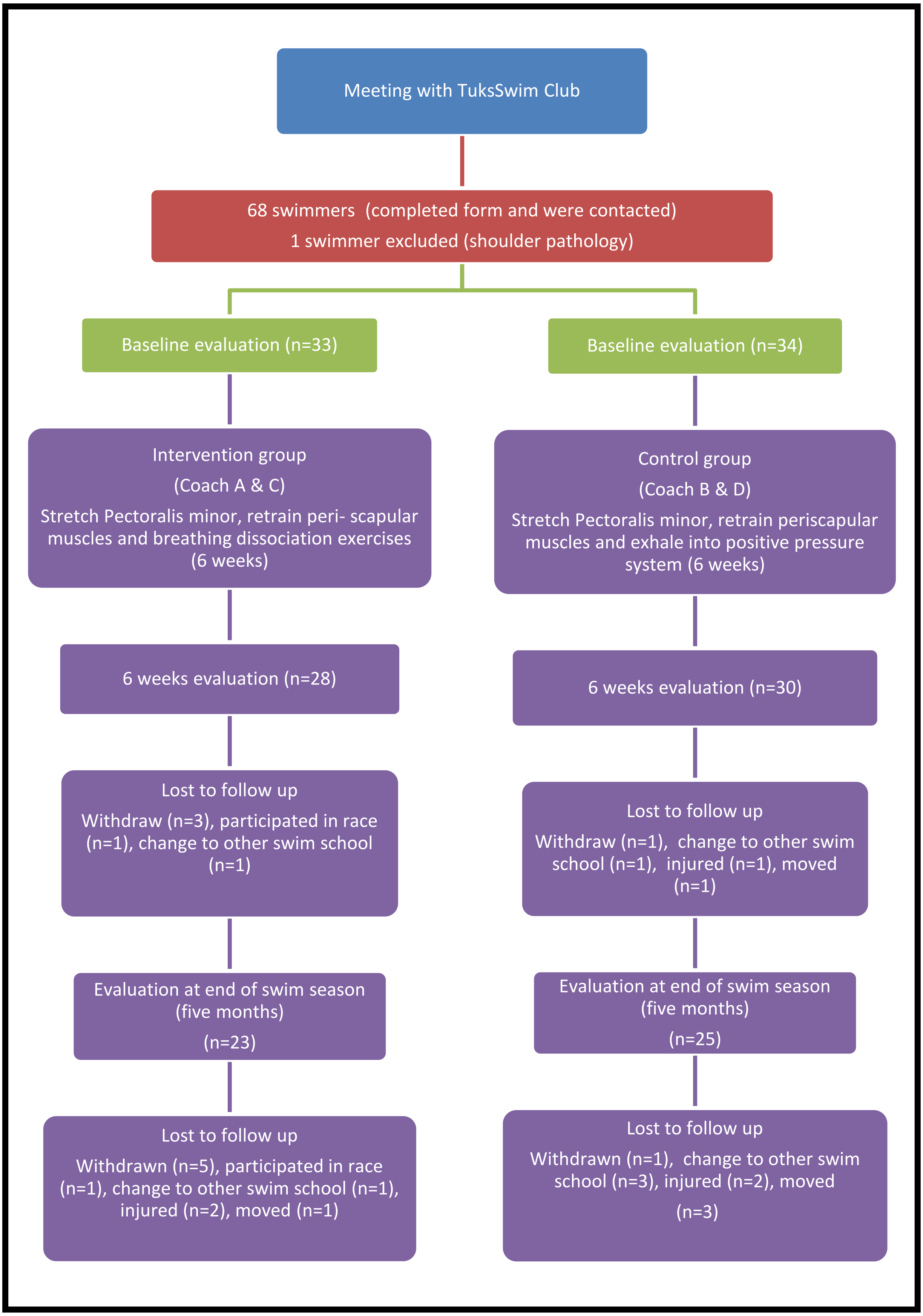


Figure 4.1: Flow diagram of the study.

Table 4.1: Summary of the demographic data of the swimmers.

Demographic data	Intervention (n=33)	Control (n=34)
Age (Mean)	16.73 years	16.05 years
Height (Mean)	176.46 m	173.78 m
Level of participation (Frequency %)		
Level 2	9 (27%)	3 (8%)
Level 3	9 (27%)	19 (55%)
Senior national level	15 (45%)	12 (35%)
Preferred stroke style (Frequency %)		
Free style	10 (30%)	4 (11%)
Back stroke	1 (3%)	4 (11%)
Breast stroke	4 (12%)	9 (26%)
Butterfly	8 (24%)	6 (17)
Medley	2 (6%)	4 (11%)
Free style & butterfly	2 (6%)	6 (17)
Free style & back stroke	2 (6%)	1 (2%)
Free style & breast stroke	1 (3%)	0
Back stroke & butterfly	2 (6%)	0
Breast stroke & butterfly	1 (3%)	0
Distance (Frequency %)		
Sprint	12 (36%)	14 (41%)
Mid distance	14 (42%)	11 (32%)
Distance	2 (6%)	4 (11%)
Sprint / mid distance	3 (9%)	2 (5%)
Mid distance / Distance	2 (6%)	3 (8%)

PECTORALIS MINOR LENGTH

Study groups (intervention and comparison) were compared in a linear mixed – model analysis using random effects maximum likelihood regression with time as panel variable. With respect to PMI (Table 4.2) the two groups did not differ significantly (p=0.811) on the left and neither on the right (p = 0.999). In particular, the effect size (Intervention – Control) adjusted for time was 0.044 (left) with 95% confidence interval (-0.314; 0.402) and <0.001 (right) with 95% confidence interval (-0.353; 0.352). Furthermore, the overall effect size at six weeks post intervention versus pre intervention was 0.514 (p=0.010) and at five months post intervention versus pre intervention was 0.532 (p=0.011) for the left side. On the right side overall the effect size for 6 weeks post intervention versus pre intervention was 0.611 (p=0.001) and for five months post intervention versus pre intervention was 0.632 (p=0.001).

Thus although the groups did not differ significantly, the overall improvement over time was significant. No significant interaction had been detected, for the left (Figure 4.2) and the right (Figure 4.3) side and modelling did not include interaction. In the control group, although not significant, deterioration from six weeks post intervention to five months post intervention was observed (left and right side) but not so in the intervention group. Groups were also compared over the intervention period of six weeks. Groups did not differ significantly with respect to change from baseline to six weeks adjusted for baseline (left: p=0.933 with effect size 0.004; right p=0.508 with effect size 0.211; ANCOVA).

Table 4.2: Data summary for Pectoralis minor index over time.

Left side				
Group	**Baseline**	**6 weeks**	**5 months**	**Shift in PMI**
Intervention (N)	32	28	23	
Mean (SD)	9.31 (0.87)	9.80 (0.87)	9.97 (0.74)	0.66
Control (N)	34	29	25	
Mean (SD)	9.32 (0.89)	9.83 (0.76)	9.75 (2.27)	0.43
Right side				
Group	**Baseline**	**6 weeks**	**5 months**	**Shift in PMI**
Intervention (N)	32	28	23	
Mean (SD)	9.19 (0.75)	9.71 (0.77)	9.85 (0.66)	0.66
Control	34	29	25	
Mean (SD)	9.12 (0.73)	9.83 (0.66)	9.76 (2.13)	0.64

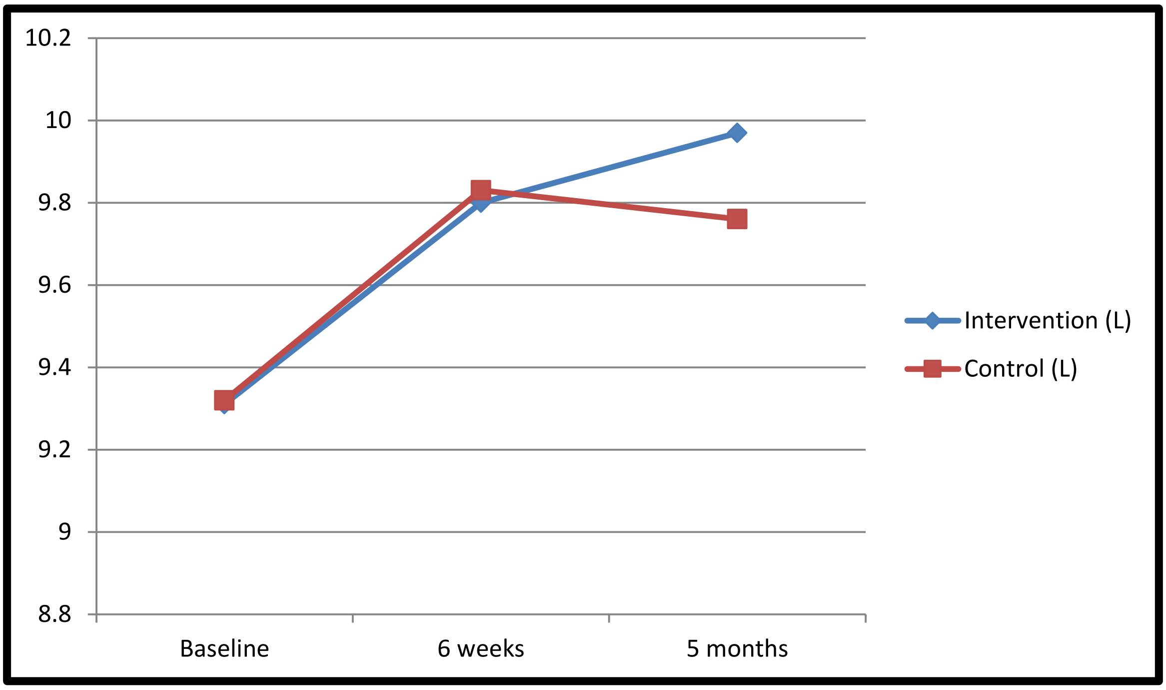


Figure 4.2: Graphic display of left mean PMI over time by group.

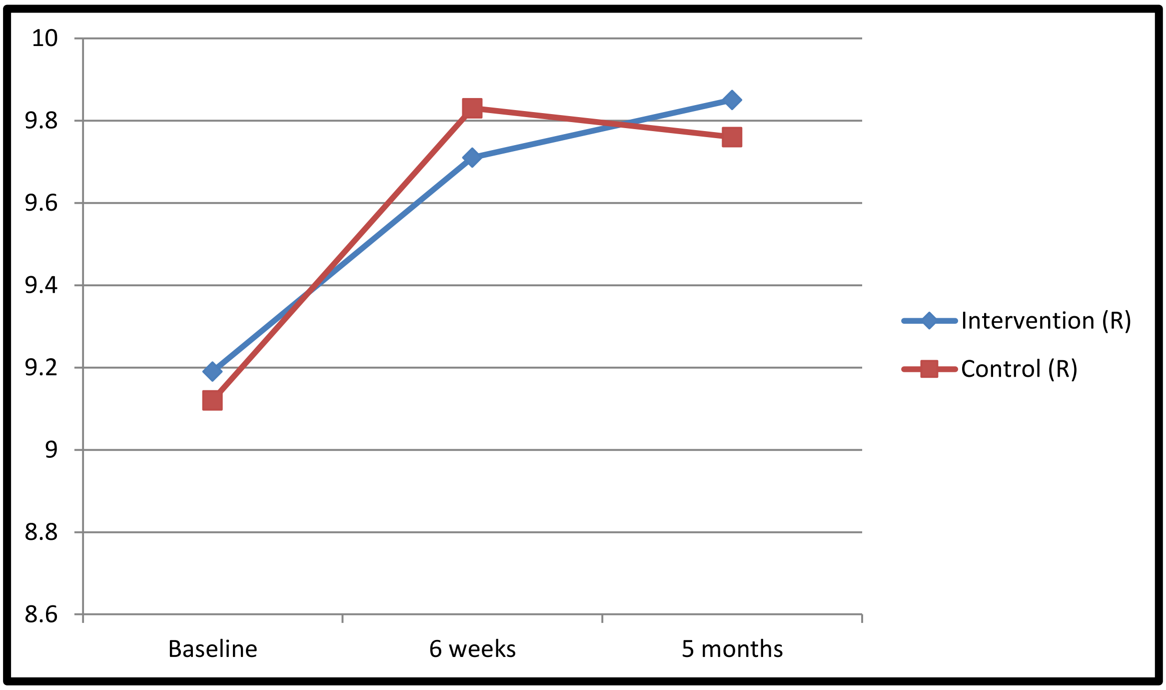


Figure 4.3: Graphic display of right mean PMI over time by group.

Thoracic expansion

The observed data for thoracic expansion, as discussed below, supports the PMI findings. With respect to thoracic expansion (Table 4.3) the two groups did not differ significantly (p=0.381) for upper thoracic expansion or lower thoracic expansion (p =

0.447). In particular, the effect size (Intervention – Control) adjusted for time was 0.252 (upper thoracic) with 95% confidence interval (-0.312; 0.815) and 0.270 (lower thoracic) with 95% confidence interval (-0.426; 0.967). Furthermore, overall the effect size for six weeks post intervention versus pre intervention was -0.412 (p=0.070) and for five months post intervention versus pre intervention was -0.336 (p=0.617) for upper thoracic expansion. For lower thoracic expansion the overall effect size for six weeks post intervention versus pre intervention was -0.319 (p=0.226) and for five months post intervention versus pre intervention was 0.390 (p=0.167).

No interaction was detected, for upper or lower expansion, although in the intervention group upper thoracic expansion decreased from 4.72 cm to 4.39 cm and lower thoracic expansion increased from 5.67 cm to 6.20 cm. In the control group upper and lower thoracic expansion decreased over time.

Groups were also compared over the intervention period of six weeks. Groups did not differ significantly with respect to change from baseline to six weeks adjusted for baseline (upper expansion: p=0.481 with effect size 1.171; upper expansion: p=0.154 with effect size 8.254; ANCOVA).

Table 4.3: Data summary for upper and lower thoracic expansion over time (measured in centimetre).

Upper thoracic expansion			
Group	**Baseline**	**6 weeks**	**5 months**
Intervention (N)	32	28	23
Mean (SD)	4.724 (1.319)	4.267 (1.144)	4.399 (1.261)
Control (N)	34	29	25
Mean (SD)	4.472 (1.064)	4.370 (1.019)	4.273 (1.328)
Lower thoracic expansion			
Group	**Baseline**	**6 weeks**	**5 months**
Intervention (N)	32	28	23
Mean (SD)	5.671 (1.518)	5.353 (1.402)	6.2 (1.491)
Control (N)	34	29	25
Mean (SD)	5.401 (1.373)	5.135 (1.389)	5.292 (1.719)

FORCE VITAL CAPACITY

The FVC results did not differ significantly over time (p=0.590) between the intervention and control group. The change in FVC, for both groups, from baseline to six weeks (p=0.338) and to five months (p=0.213) did not change significantly. In particular, the effect size (Intervention – Control) adjusted for time was 0.17 with 95% confidence interval (-0.45; 0.80). Furthermore, overall the effect size at six weeks post intervention versus baseline was 0.106 (p=0.338) and at five months post intervention versus baseline was -0.15 (p=0.213). No interaction was detected for FVC.

Groups were also compared over the intervention period of six weeks. Groups did not differ significantly with respect to change from baseline to six weeks adjusted for baseline (p=0.394 with effect size 56.110; ANCOVA).

Table 4:4: Data summary for FVC over time.

Force vital capacity						
Group	**Intervention**			**Control**		
	Baseline	**6 weeks**	**5 months**	**Baseline**	**6 weeks**	**5 months**
FVC Mean (SD)	5.49 (1.26)	5.58 (1.26)	5.44 (1.94)	5.28 (1.19)	5.40 (1.12)	5.43 (1.30)
FVC predicted (%) mean (SD)	122.76 (15.34)	123.88 (15.14)	117.92 (22.82)	123.82 (12.34)	126.56 (13.16)	122.20 (17.56)

MUSCLE FUNCTION

Muscle function of the two groups of swimmers was compared with a two sided Fischer exact test. The two groups of swimmers (intervention and control) were compared with respect to muscle function of Serratus anterior and Trapezius middle and lower fibres. The specific characteristics of muscle function that were measured included the muscle's ability to actively meet the ideal range of movement, the ability to concentrically hold the muscle contraction, the ability to hold the inner range isometrically, the eccentric control of the muscle and the ability to perform the muscle contraction without any substitutions and with relaxed breathing.

In Table 4.5 the results of the different characteristics of Serratus anterior function are summarised. In the columns the intervention and control groups were compared with respect to each outcome at baseline, six weeks and five months using Fisher's exact test. The p value for the left and right sides has been provided. The rows represent the value given for the quality of the specific outcome; 0 = the swimmer could perform the outcome with good quality, 1 = the swimmer could perform the outcome but quality is lacking (e.g. the swimmer could perform the muscle contraction, but after lack of control to keep the muscle contraction), 2 = the swimmer could not perform the outcome and quality is not satisfactory. For every specific outcome the number of swimmers per category (0, 1, 2) has been provided as well as the percentage.

The fact that there are no significant differences at baseline with respect to the muscle function outcomes (Table 4.5, 4.9, 4.12) the resting (Table 4.15) as well as the dynamic scapula position (Table 4.22), confirms that although the intervention and control groups were selected based on the coach they trained with, both groups were equal at baseline.

No significant differences were observed between the intervention and control groups for any of the specific characteristics of Serratus anterior muscle function (Table 4.5) from baseline to six weeks and from baseline to five months.

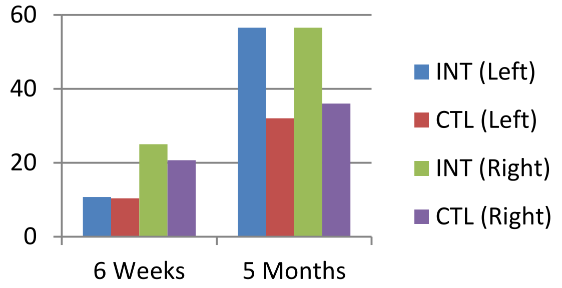
Table 4.5: Summary of the two sided Fischer exact results of the different characteristics of Serratus anterior function from baseline to six weeks and baseline to five months (Page 139-140).

Out - come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
The active range equals the passive range of muscle contraction																		
0	1/33 3.03%	1/33 3.03%	0	1/34 2.94%			4/28 14.29%	8/28 28.57%	4/29 13.79%	7/29 24.14%			17/23 73.91%	17/23 73.91%	18/25 72%	17/25 68%		
1	2/33 6.06%	5/33 15.15%	6/34 17.65%	3/34 8.82%	0.259	0.734	20/28 71.43%	16/28 57.14%	17/29 58.62%	16/29 55.17%	0.495	0.874	3/23 13.04%	3/23 13.04%	2/25 8%	3/25 12%	0.806	0.900
2	30/33 90.91%	27/33 81.82%	28/34 82.35%	30/34 88.24%			4/28 14.29%	4/28 14.29%	8/29 27.59%	6/29 20.69%			3/23 13.04%	3/23 13.04%	5/25 20%	5/25 20%		
Concentric hold 3seconds (without substitution)																		
0	1/33 3.03%	1/33 3.03%	0	0			3/28 10.71%	7/28 25%	3/29 10.34%	6/29 20.69%			13/23 56.52%	13/23 56.52%	8/25 32%	9/25 36%		
1	2/33 6.06%	5/33 15.15%	6/34 17.65%	3/34 8.82%	0.259	0.362	20/28 71.43%	16/28 57.14%	18/29 62.07%	17/29 58.62%	0.782	1.000	1/23 4.39%	2/23 8.70%	4/25 16%	3/25 12%	0.163	0.420
2	30/33 90.91%	27/33 81.82%	28/34 82.35%	31/34 91.18%			5/28 17.86%	5/28 17.86%	8/29 27.59%	6/29 20.69%			9/23 39.13%	8/23 34.78%	13/25 52%	13/25 52%		
Eccentric control																		
0	1/33 3.03%	2/33 6.06%	0	0			4/28 14.29%	7/28 25%	3/29 10.34%	6/29 20.69%			5/23 21.74%	5/23 21.74%	6/25 24%	5/25 20%		
1	1/33 3.03%	1/33 3.03%	5/34 14.71%	2/34 5.88%	0.197	0.515	15/28 53.57%	12/28 42.86%	17/29 58.62%	16/29 55.17%	0.932	0.695	0	1/23 4.35%	2/25 8%	2/25 8%	0.577	1.000
2	31/33 93.94%	30/33 90.91%	29/34 85.29%	32/34 94.12%			9/28 32.14%	9/28 32.14%	9/29 31.03%	7/29 24.14%			18/23 78.26%	17/23 73.19%	17/25 68%	18/25 72%		
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk																		
0	0	0	0	0			0	1/28 3.57%	1/29 3.45%	1/29 3.45%			14/23 60.87%	14/23 60.87%	17/25 68%	16/25 64%		
1	0	1/33 3.03%	2/34 5.88%	2/34 5.88%	0.493	1.000	10/28 35.71%	12/28 42.86%	12/29 41.38%	14/29 48.28%	0.687	0.893	0	0	1/25 4%	2/25 8%	0.543	0.536
2	33/33 100%	32/33 96.97%	32/34 94.12%	32/34 94.12%			18/28 64.29%	15/28 53.57%	16/29 55.17%	14/29 48.28%			9/23 39.13%	9/23 39.13%	7/25 28%	7/25 28%		

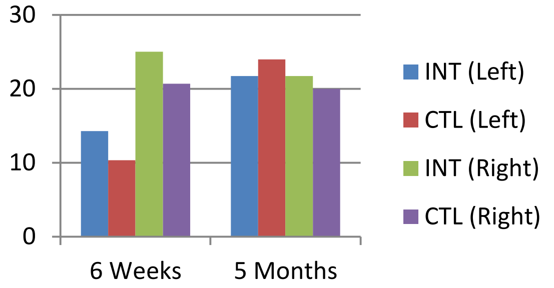
Swimmer can hold inner range position for 15 seconds (2 repetitions)																		
0	0	0	0	0			0	1/28 3.57%	1/29 3.45%	1/29 3.45%			4/23 17.39%	5/23 21.74%	6/25 24%	5/25 20%		
1	0	1/33 3.03%	1/34 2.94%	1/34 2.94%	1.000	1.000	9/28 32.14%	10/28 35.71%	13/29 44.83%	15/29 51.72%	0.344	0.581	4/23 17.39%	4/23 17.39%	3/25 12%	4/25 16%	0.839	1.000
2	33/33 100%	32/33 96.97%	33/34 97.06%	33/34 97.06%			19/28 67.86%	17/28 60.71%	15/29 51.72%	13/29 44.83%			15/23 65.22%	14/23 60.87%	16/25 64%	16/25 64%		
Swimmer can perform test without fatigue																		
0	0	0	0	0	1.000	0.614	0	1/28 3.57%	1/29 3.45%	1/29 3.45%	1.000	0.892	4/23 17.39%	5/23 21.74%	6/25 24%	5/25 20%	0.892	1.000
1	1/33 3.03%	2/33 6.06%	1/34 2.94%	1/34 2.94%			10/28 35.71%	11/28 39.29%	11/29 37.93%	13/29 44.83%			2/23 8.70%	1/23 4.35%	2/25 8%	2/25 8%		
2	32/33 96.97%	31/33 93.94%	33/34 97.06%	33/34 97.06%			18/28 64.29%	16/28 57.14%	17/29 58.62%	15/29 51.72%			17/23 73.91%	17/23 73.91%	17/25 68%	18/25 72%		
Swimmer can perform test with relaxed breathing																		
0	0	1/33 3.03%	0	0			0	1/28 3.57%	1/29 3.45%	1/29 3.45%			4/23 17.39%	5/23 21.74%	6/25 24%	5/25 20%		
1	0	0	2/34 5.88%	2/34 5.88%	0.493	0.493	10/28 35.71%	11/28 39.29%	11/29 37.93%	13/29 44.83%	1.000	0.892	2/23 8.70%	1/23 4.35%	2/25 8%	2/25 8%	0.892	1.000
2	33/33 100%	32/33 96.67%	32/34 94.12%	32/34 94.12%			18/28 64.29%	16/28 57.14%	17/29 58.62%	15/29 51.72%			17/23 73.91%	17/23 73.91%	17/25 68%	18/25 72%		

Serratus anterior (percentage of specific characteristic performed successfully)

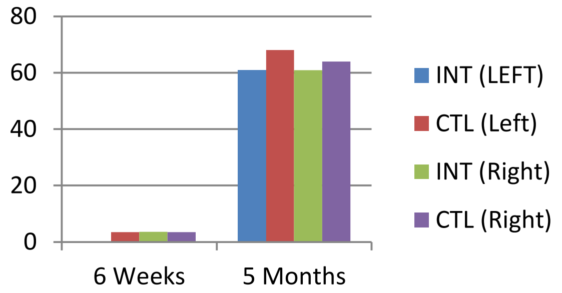
Concentric hold (3 seconds) without substitution



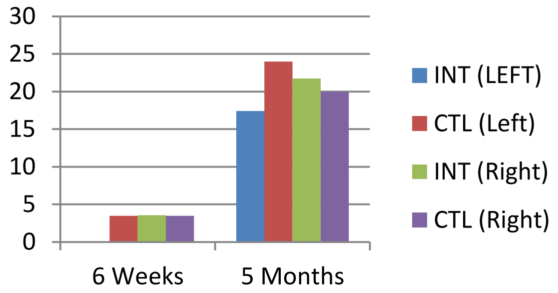
Eccentric control



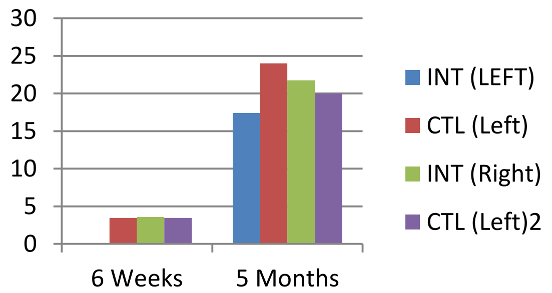
Perform test without fixation of shoulder girdle / trunk



Inner range hold (15 seconds)



Perform test without fatigue



Perform test with relaxed breathing

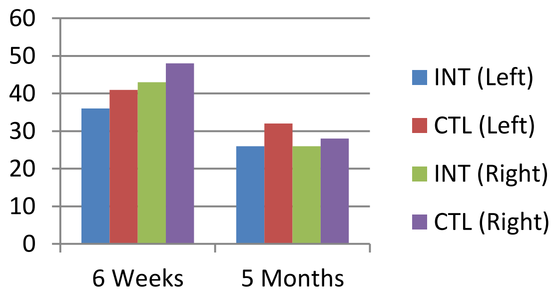


Figure 4.4: Between group comparisons with respect to Serratus anterior muscle function characteristics at six weeks and five months. (INT: intervention, CTL: control).

In Figure 4.3 data regarding the characteristic of the muscle contraction is graphically presented. The values displayed are the percentages of swimmers who could perform the specific characteristic successfully. Both groups showed deterioration from six weeks to five months in the characteristic of the muscle contraction. Although no statistical difference was observed between the two groups (Table 4.5) a clinical relevant improvement to contract Serratus anterior concentrically in the intervention group is noticeable at five months. The McNemar test for symmetry was conducted to determine if there were any changes over time within a specific group (intervention or control). The numerical value of 0, 1, and 2 was given as explained earlier.

In Table 4.6 the 3x3 table as used in the McNemar test for symmetry is explained. The rows present data at baseline and columns present data at six weeks. The information in Table 4.6 is data obtained after statistical analysis. Swimmers presented in the diagonal cells represent the swimmers who showed no change during the intervention period, in this case 8/28. Two swimmers (1/28) deteriorate (from 0 at baseline to 2 at six weeks) and 19/28 improved (from 2 at baseline to 1 at six weeks OR 1 at baseline to 0 at six weeks). The p value of <0.0009 is dependent on the distribution of swimmers (19/28 improved versus 1/28 deteriorate) in the 3x3 table.

Table 4.6: Example in the use of McNemar's test for symmetry to assess the change from baseline to six weeks with respect to muscle function categories (0;1;2)

Eccentric control of muscle without any substitution (Intervention group, right side, N = 28)					
		Data at six weeks			
Data at baseline		0	1	2	Total
	0	0	0	1	1 (3.57%)
	1	1	0	0	1 (3.57%)
	2	6	12	8	26 (92.86%)
	Total	7 (25%)	12 (42.86%)	9 (32.14%)	28 (100%)

At baseline only one (3.57%) swimmer could eccentrically control the contraction (0) with good quality, one (3.57%) had eccentric control but quality was lacking (1) and 26 (92.86%) swimmers could not control the contraction eccentrically (2).

After six weeks seven (25%) swimmers could eccentrically control the contraction with good quality (0), 12 (42.86%) swimmers had eccentric control but quality was not satisfactory (1) and nine (32.14%) swimmers could not control the contraction eccentrically (2).

Table 4.7: Summary of the McNemar test results for the different characteristics of Serratus anterior function from baseline to six weeks.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	5/28	0/28	23/28	0.0000
	Right	5/28	1/28	22/28	0.0002
Control	Left	12/29	0/29	17/29	0.0007
	Right	5/29	1/29	23/29	0.0001
Concentric hold 3seconds (without substitution)					
Intervention	Left	5/28	0/28	23/28	0.0000
	Right	5/28	1/28	22/28	0.0002
Control	Left	12/29	0/29	17/29	0.0007
	Right	6/29	0/29	23/29	0.0000
Eccentric control					
Intervention	Left	9/28	0/28	19/28	0.0003
	Right*	8/28	1/28	19/28	0.0009
Control	Left	13/29	0/29	16/29	0.0011
	Right	7/29	0/29	22/29	0.0001
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	18/28	0/28	10/28	0.0016
	Right	14/28	1/28	13/28	0.0058
Control	Left	18/29	0/29	11/29	0.0041
	Right	16/29	0/29	13/29	0.0015
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	19/28	0/28	9/28	0.0027
	Right	16/28	1/28	11/28	0.0153
Control	Left	16/29	0/29	13/29	0.0015
	Right	14/29	0/29	15/29	0.0006
Swimmer can perform test without fatigue					
Intervention	Left	17/28	1/28	10/28	0.0067
	Right	14/28	2/28	12/28	0.0269
Control	Left	18/29	0/29	11/29	0.0041
	Right	16/29	0/29	13/29	0.0015
Swimmer can perform test with relaxed breathing					
Intervention	Left	18/28	0/28	10/28	0.0016
	Right	15/28	1/28	12/28	0.0041
Control	Left	19/29	0/29	10/29	0.0067
	Right	17/25	0/29	12/29	0.0025

* Data explained in Table 4.6

Table 4.8: Summary of the McNemar test results for the different characteristics of Serratus anterior function from baseline to five months.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	3/23	0/23	20/23	0.0002
	Right	3/23	0/23	20/23	0.0002
Control	Left	4/25	1/25	20/25	0.0004
	Right	7/25	0/25	18/25	0.0004
Concentric hold 3seconds (without substitution)					
Intervention	Left	9/23	0/23	14/23	0.0029
	Right	8/23	0/23	15/23	0.0018
Control	Left	13/25	1/25	11/25	0.0293
	Right	13/25	0/25	12/25	0.0074
Eccentric control					
Intervention	Left	18/23	0/23	5/23	0.0821
	Right	16/23	1/23	6/23	0.2839
Control	Left	18/25	0/25	7/25	0.0719
	Right	18/25	1/25	6/25	0.0821
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	9/23	0/23	14/23	0.0002
	Right	9/23	0/23	14/23	0.0009
Control	Left	7/25	0/25	18/25	0.0004
	Right	8/25	0/25	17/25	0.0007
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	15/23	0/23	8/23	0.0183
	Right	13/23	1/23	9/23	0.0334
Control	Left	17/25	0/25	8/25	0.0183
	Right	17/25	0/25	8/25	0.0183
Swimmer can perform test without fatigue					
Intervention	Left	17/23	0/23	6/23	0.1116
	Right	16/23	1/23	6/23	0.1718
Control	Left	18/25	0/25	7/25	0.0302
	Right	19/25	0/25	6/25	0.0498
Swimmer can perform test with relaxed breathing					
Intervention	Left	17/23	0/23	6/23	0.0498
	Right	16/23	1/23	6/23	0.1599
Control	Left	18/25	0/25	7/25	0.0719
	Right	18/25	1/25	6/25	0.0821

Within the intervention and control group the change over time (baseline to six weeks as well as base line to five months) for the characteristics of Serratus anterior function was remarkable. The ability to control the contraction eccentrically did not change significantly within any of the two groups over five months. Although improvement between groups was not statistically significant (Table 4.5) for the change within groups, the change within the control group was indicative of better improvement. The change within the intervention group on the left side reflected statistical significance, but the right side (intervention) and both sides of the control group did not show any significant change over five months.

The results of the characteristics of the function of Trapezius middle fibres will be presented hereunder. In Table 4.9 the results of the two sided Fischer exact test for the function of middle fibres of Trapezius has been summarised. No significant change was observed between the two groups over time for any characteristic of the muscle function. In Figure 4.4 specific muscle function characteristics have been presented graphically. The deterioration from six weeks to five months, as with Serratus anterior, has been obvious once again, however to a lesser extent.

Table 4.9: Summary of the two sided Fischer exact results of the different characteristics of the middle fibres of Trapezius function from baseline to six weeks and baseline to five months (Page 146-147).

Out-come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
The active range equals the passive range of muscle contraction																		
0	3/33 9.09%	3/33 9.09%	0	0			11/28 39.29%	14/28 50%	8/29 27.59%	7/29 24.14%			19/23 82.61%	20/23 86.96%	18/25 72%	18/25 72%		
1	4/33 12.12%	5/33 15.15%	1/34 2.94%	2/34 5.88%	0.067	0.063	9/28 32.14%	4/28 14.29%	11/29 37.93%	12/29 43.33%	0.673	0.041	0	0	2/25 8%	2/25 8%	0.631	0.471
2	26/33 78.79%	25/33 75.76%	33/34 97.06%	32/34 94.12%			8/28 28.57%	10/28 35.71%	10/29 34.48%	10/29 34.48%			4/23 17.39%	3/23 13.04%	5/25 20%	5/25 20%		
Concentric hold 3seconds (without substitution)																		
0	2/33 6.06%	2/33 6.06%	0	0			10/28 35.71%	14/28 50%	8/29 27.59%	8/29 27.59%			9/23 39.13	10/23 43.48%	9/25 36%	9/25 36%		
1	5/33 15.15%	5/33 15.15%	3/34 8.82%	2/34 5.88%	0.251	0.138	10/28 35.71%	4/28 14.29%	10/29 34.48%	10/29 34.48%	0.714	0.129	3/23 13.04%	2/23 8.70%	5/25 20%	5/25 20%	0.859	0.624
2	26/33 78.79%	26/33 78.79%	31/34 91.18%	32/34 94.12%			8/28 28.57%	10/28 35.71%	11/29 37.93%	11/29 37.93%			11/23 47.83%	11/23 47.83%	11/25 44%	11/25 44%		
Eccentric control																		
0	2/33 6.06%	2/33 6.06%	0	0			15/28 53.57%	16/28 57.14%	13/29 44.83%	13/29 44.83%			7/23 30.43%	7/23 30.43%	5/25 20%	5/25 20%		
1	2/33 6.06%	2/33 6.06%	1/34 2.94%	1/34 2.94%	0.325	0.325	1/28 3.57%	0	3/29 10.34%	3/29 10.34%	0.663	0.313	1/23 4.35%	1/23 4.35%	4/25 16%	4/25 16%	0.421	0.421
2	29/33 87.88%	29/33 87.88%	33/34 97.06%	33/34 97.06%			12/28 42.86%	12/28 42.86%	13/29 44.83%	13/29 44.83%			15/23 65.22%	15/23 65.22%	16/25 64%	16/25 64%		
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk																		
0	0	0	1/34 2.94%	0			6/28 21.43%	4/28 14.29%	6/29 20.69%	5/29 17.24%			13/23 56.52%	13/23 56.52%	14/25 56%	14/25 56%		
1	2/33 6.06%	2/33 6.06%	0	2/34 5.88%	0.614	1.000	4/28 14.29%	5/28 17.86%	7/29 24.44%	8/29 29.59%	0.662	0.697	1/23 4.35%	1/23 4.35%	2/25 8%	2/25 8%	1.000	1.000
2	31/33 93.94%	31/33 93.94%	33/34 97.06%	32/34			18/28 64.29%	19/28 67.86%	16/29 55.17%	16/29 55.17%			9/23 39.13%	9/23 39.13%	9/25 36%	9/25 36%		

Swimmer can hold inner range position for 15 seconds (2 repetitions)																		
0	1/33 3.03%	1/33 3.03%	0	0	0.239	0.239	5/28 17.86%	4/28 14.29%	5/29 17.24%	4/29 13.79%	0.523	0.375	8/23 34.78%	9/23 39.13%	8/25 32%	9/25 36%	1.000	0.792
1	1/33 3.03%	1/33 3.03%	0	0			4/28 14.29%	4/28 14.29%	8/29 27.59%	9/29 31.03%			4/23 17.39%	4/23 17.39%	5/25 20%	3/25 12%		
2	31/33 93.94%	31/33 93.94%	34/34 100%	34/34 100%			19/28 67.86%	20/28 71.43%	16/29 55.17%	16/29 55.17%			11/23 47.83%	10/23 43.48%	12/25 48%	13/25 52%		
Swimmer can perform test without fatigue																		
0	2/33 6.06%	2/33 6.06%	0	0	0.239	0.239	5/28 17.86%	4/28 14.29%	5/29 17.24%	4/29 13.79%	0.357	0.236	6/23 26.09%	6/23 26.09%	7/25 28%	7/25 28%	0.737	1.000
1	0	0	0	0			4/28 14.29%	4/28 14.29%	8/29 27.59%	9/29 31.03%			1/23 4.35%	1/23 4.35%	3/25 12%	2/25 8%		
2	31/33 93.94%	31/33 93.94%	34/34 100%	34/34 100%			19/28 67.86%	20/28 71.43%	16/29 55.17%	16/29 55.17%			16/23 69.57%	16/23 69.57%	15/25 60%	16/26 64%		
Swimmer can perform test with relaxed breathing																		
0	2/33 6.06%		0		0.114		14/28 50%	13/28 46.43%	11/29 37.93%	11/29 37.93%	0.507	0.761	7/23 30.43%	7/23 30.43%	5/25 20%	5/25 20%	0.301	0.301
1	1/33 3.03%		0				0	1/28 3.57%	1/29 3.45%	2/29 6.90%			0	0	3/25 12%	3/25 12%		
2	30/33 90.91%		34/34 100%				14/28 50%	14/28 50%	17/29 58.62%	16/29 55.17%			16/23 69.57%	16/23 69.57%	17/25 68%	17/25 68%		

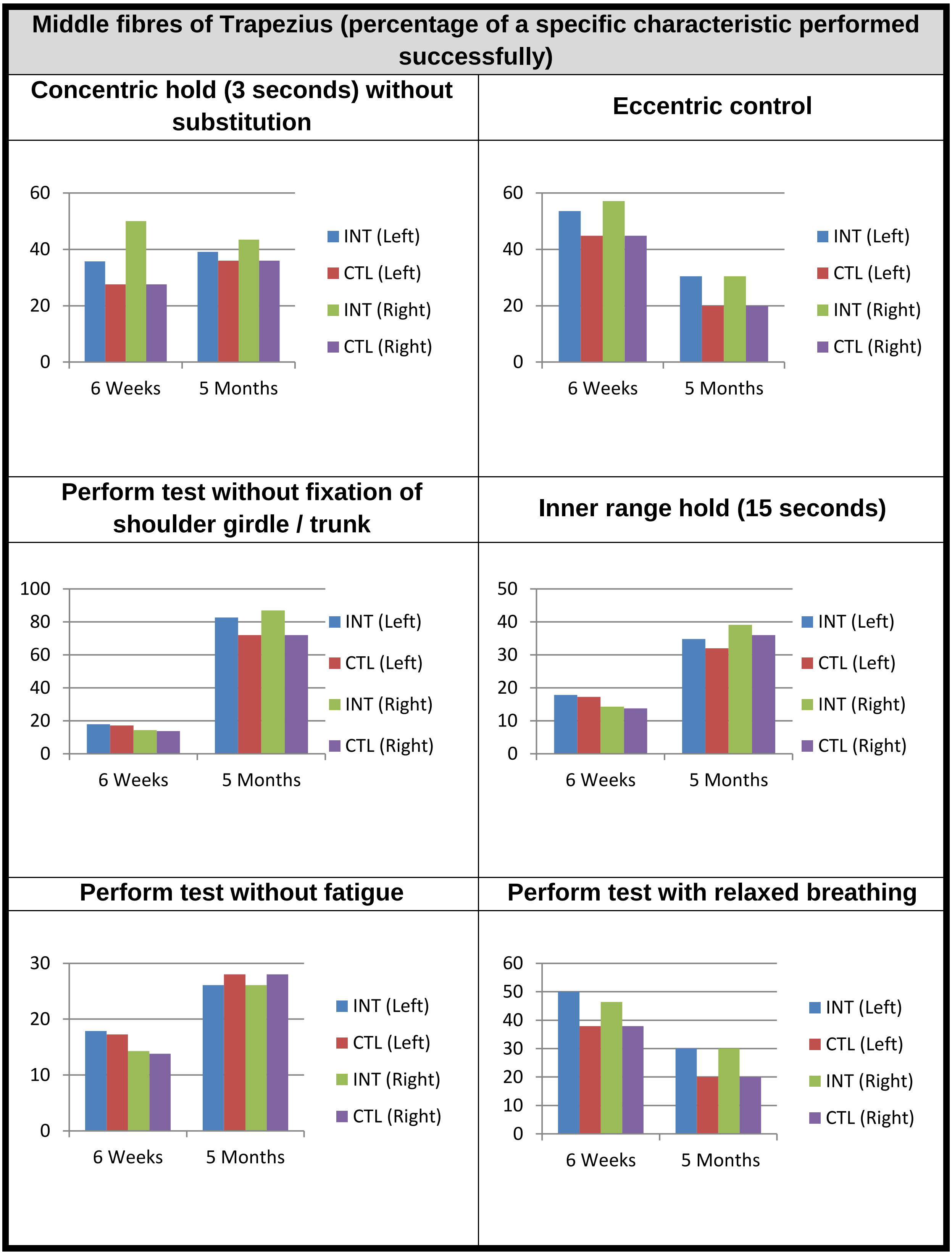


Figure 4.5: Between group comparisons with respect to middle fibres of Trapezius muscle function characteristics at six weeks and five months.

Although improvement between groups was not significant (Table 4.9) the intervention group showed better improvement in all aspects of the characteristic of function for the middle fibres of Trapezius from baseline to six weeks. The same trend is noticeable at five months except for the ability to perform the test without fatigue. The within group muscle function results for the middle fibres of Trapezius (Table 4.10) shows significant changes for both groups from baseline to six weeks.

Table 4.10: Summary of the McNemar test results for the different characteristics of the middle fibres of Trapezius function from baseline to six weeks.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	11/28	1/28	16/28	0.0025
	Right	9/28	4/28	15/28	0.017
Control	Left	9/29	1/29	19/29	0.0003
	Right	10/29	1/29	19/29	0.0010
Concentric hold 3seconds (without substitution)					
Intervention	Left	12/28	0/28	16/28	0.0011
	Right	8/28	4/28	16/28	0.0074
Control	Left	11/29	1/29	17/29	0.0024
	Right	10/29	1/29	18/29	0.0015
Eccentric control					
Intervention	Left	11/28	2/28	15/28	0.0036
	Right	11/28	2/28	15/28	0.0013
Control	Left	12/29	1/29	16/29	0.0009
	Right	12/29	1/29	16/29	0.0009
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	20/28	0/28	8/28	0.0183
	Right	19/28	1/28	8/28	0.0550
Control	Left	16/29	1/29	12/29	0.0046
	Right	16/29	1/29	12/29	0.0087
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	19/28	1/28	8/28	0.0550
	Right	18/28	2/28	8/28	0.1663
Control	Left	16/29	0/29	13/29	0.0015
	Right	16/29	0/29	13/29	0.0015
Swimmer can perform test without fatigue					
Intervention	Left	19/28	1/28	8/28	0.0550
	Right	18/28	2/28	8/28	0.0970
Control	Left	16/29	0/29	13/29	0.0015
	Right	16/29	0/29	13/29	0.0015
Swimmer can perform test with relaxed breathing					
Intervention	Left	14/28	1/28	13/28	0.0013
	Right	14/28	1/28	13/28	0.0058
Control	Left	17/29	0/29	12/29	0.0025
	Right	15/29	1/29	13/29	0.0035

From baseline to five months (Table 4.11) the control group reflected remarkable change for all the characteristics. However, the intervention group showed significant change for some of the outcomes but for the concentric hold, eccentric control, performing the test without fatigue and performing the test with relaxed breathing the change within the intervention group had not been significant.

Table 4.11: Summary of the McNemar test results for the different characteristics of the middle fibres of Trapezius function from baseline to five months.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	6/23	1/23	16/23	0.0007
	Right	5/23	1/23	17/23	0.0004
Control	Left	5/25	0/25	20/25	0.0002
	Right	5/25	0/25	20/25	0.0002
Concentric hold 3seconds (without substitution)					
Intervention	Left	10/23	2/23	11/23	0.0869
	Right	10/23	2/23	11/23	0.075
Control	Left	12/25	0/25	13/25	0.0046
	Right	11/25	0/25	14/25	0.0029
Eccentric control					
Intervention	Left	12/23	3/23	8/23	0.2494
	Right	12/23	3/23	8/23	0.2494
Control	Left	17/25	0/25	8/25	0.0183
	Right	17/25	0/25	8/25	0.0183
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	9/23	1/23	13/23	0.0058
	Right	8/23	1/23	14/23	0.0046
Control	Left	10/25	0/25	15/25	0.0006
	Right	9/25	0/25	16/26	0.0011
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	11/23	2/23	11/23	0.0186
	Right	9/23	2/23	12/23	0.0117
Control	Left	12/25	0/25	13/25	0.0015
	Right	13/25	0/25	12/25	0.0025
Swimmer can perform test without fatigue					
Intervention	Left	14/23	2/23	7/23	0.2231
	Right	14/23	2/23	7/23	0.2231
Control	Left	15/25	0/25	10/25	0.0067
	Right	16/25	0/25	9/25	0.0111
Swimmer can perform test with relaxed breathing					
Intervention	Left	14/23	2/23	7/23	0.0956
	Right	14/23	2/23	7/23	0.0956
Control	Left	17/25	0/25	8/25	0.0183
	Right	18/25	0/25	7/25	0.0302

The results of the characteristics of the function of Trapezius lower fibres have been presented hereunder. The two sided Fischer exact test results for the lower fibres of

Trapezius are summarized in Table 4.12. No significant change over time between the two groups was observed. In Figure 4.5 the percentage of the specific characteristics of Trapezius lower fibre functions that were done with good quality have been presented graphically. Different to Serratus anterior and the middle fibres of Trapezius, the function of the lower fibres of Trapezius showed an improvement from six weeks to five months for both groups.

Table 4.12: Summary of the two sided Fischer exact results of the different characteristics of muscle function for the lower fibres of Trapezius from baseline to six weeks and baseline to five months (Page 152-153).

Out-come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
The active range equals the passive range of muscle contraction																		
0	0	0	0	0			2/28 7.14%	2/28 7.14%	3/29 10.34%	3/29 10.34%			20/23 86.96%	20/23 86.96%	19/25 76%	19/25 76%		
1	2/33 6.06%	1/33 3.03%	1/34 2.94%	2/34 5.88%	0.614	1.000	6/28 21.43%	5/28 17.86%	4/29 13.79%	4/29 13.79%	0.748	1.000	0/23	0/23	3/25 12%	3/25 12%	0.380	0.380
2	31/33 93.94%	32/33 96.97%	33/34 97.06%	32/34 94.12%			20/28 71.43%	21/28 75%	22/29 75.86%	22/29 75.86%			3/23 13.04%	3/23 13.04%	3/25 12%	3/25 12%		
Concentric hold 3seconds (without substitution)																		
0	0	0	0	0			0	0	2/29 6.90%	1/29 3.45%			9/23 39.13%	10/23 43.48%	9/25 36%	10/25 40%		
1	1/33 3.03%	0	1/34 2.94	2/34 5.88%	1.000	0.493	7/28 25%	6/28 21.43%	4/29 13.79%	5/29 17.24%	0.293	1.000	8/23 34.78%	7/23 30.34%	6/25 24%	5/25 20%	0.551	0.539
2	32/33 96.97%	33/33 100%	33/34 97.06%	32/34 94.12%			21/28 75%	22/28 78.57%	23/29 79.31%	23/29 79.31%			6/23 26.09%	3/23 26.09%	10/25 40%	10/25 40%		
Eccentric control																		
0	0	0	0	0			0	1/28 3.57%	2/29 6.90%	1/29 3.45%			3/23 13.04%	3/23 13.04%	4/25 16%	5/25 20%		
1	0	0	0	1/34 2.94%		1.000	6/28 21.43%	4/28 14.29%	3/29 10.34%	4/29 13.79%	0.258	1.000	3/23 13.04%	3/23 13.04%	2/25 8%	2/25 8%	0.897	0.806
2	33/33 100%	33/33 100%	34/34 100%	33/34 97.06%			22/28 78.57%	23/28 82.14%	24/29 82.76%	24/29 82.76%			17/23 73.91%	17/23 73.91%	19/25 76%	18/25 72%		
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk																		
0	0	0	0	0			0	0	1/29 3.45%	1/29 3.45%			12/23 52.17%	13/29 56.52%	16/25 64%	16/25 64%		
1	0	0	0	0			2/28 7.14%	5/28 17.86%	3/29 10.34%	2/29 6.90%	1.000	0.334	2/23 8.70%	1/23 4.35%	0	0	0.384	0.659
2	33/33 100%	33/33 100%	34/34 100%	34/34 100%			26/28 92.86%	23/28 82.14%	25/29 86.21%	26/29 89.66%			9/23 39.13%	9/23 39.13%	9/25 36%	9/25 36%		

Swimmer can hold inner range position for 15 seconds (2 repetitions)																		
0	0	0	0	0			0	0	1/29 3.45%	1/29 3.45%			3/23 13.04%	4/23 17.39%	4/25 16%	6/25 24%		
1	0	0	0	0			2/28 7.14%	5/28 17.86%	3/29 10.34%	2/29 6.90%	1.000	0.334	10/23 43.48%	9/23 39.13%	6/25 24%	4/25 16%	0.383	0.223
2	33/33 100%	33/33 100%	34/34 100%	34/34 100%			26/28 92.86%	23/28 82.14%	25/29 86.21%	26/29 89.66%			10/23 43.48%	10/23 43.48%	15/25 60%	15/25 60%		
Swimmer can perform test without fatigue																		
0	0	0	0	0			0	0	1/29 3.45%	1/29 3.45%			3/23 13.04%	3/23 13.04%	2/25 8%	4/25 16%		
1	0	0	0	0			2/28 7.14%	5/28 17.86%	3/29 10.34%	2/29 6.90%	1.000	0.246	4/23 17.39%	4/23 17.39%	3/25 12%	2/25 8%	0.703	0.652
2	33/33 100%	33/33 100%	34/34 100%	34/34 100%			26/28 92.86%	23/28 82.14%	25/29 86.21%	26/29 89.66%			16/23 69.57%	16/23 69.57%	20/25 80%	19/25 76%		
Swimmer can perform test with relaxed breathing																		
0	0	0	0	0			0	1/28 3.57%	1/29 3.45%	1/29 3.45%			6/23 26.09%	6/23 26.09%	3/25 12%	5/25 20%		
1	0	0	0	0			2/28 7.14%	5/28 17.86%	3/29 10.34%	2/29 6.90%	1.000	0.619	1/23 4.35%	1/23 4.35%	3/25 12%	2/25 8%	0.347	0.896
2	33/33 100%	33/33 100%	34/34 100%	34/34 100%			26/28 92.86%	22/28 78.57%	25/29 86.21%	26/29 89.66%			16/23 69.57%	16/23 69.57%	19/25 76%	18/25 72%		

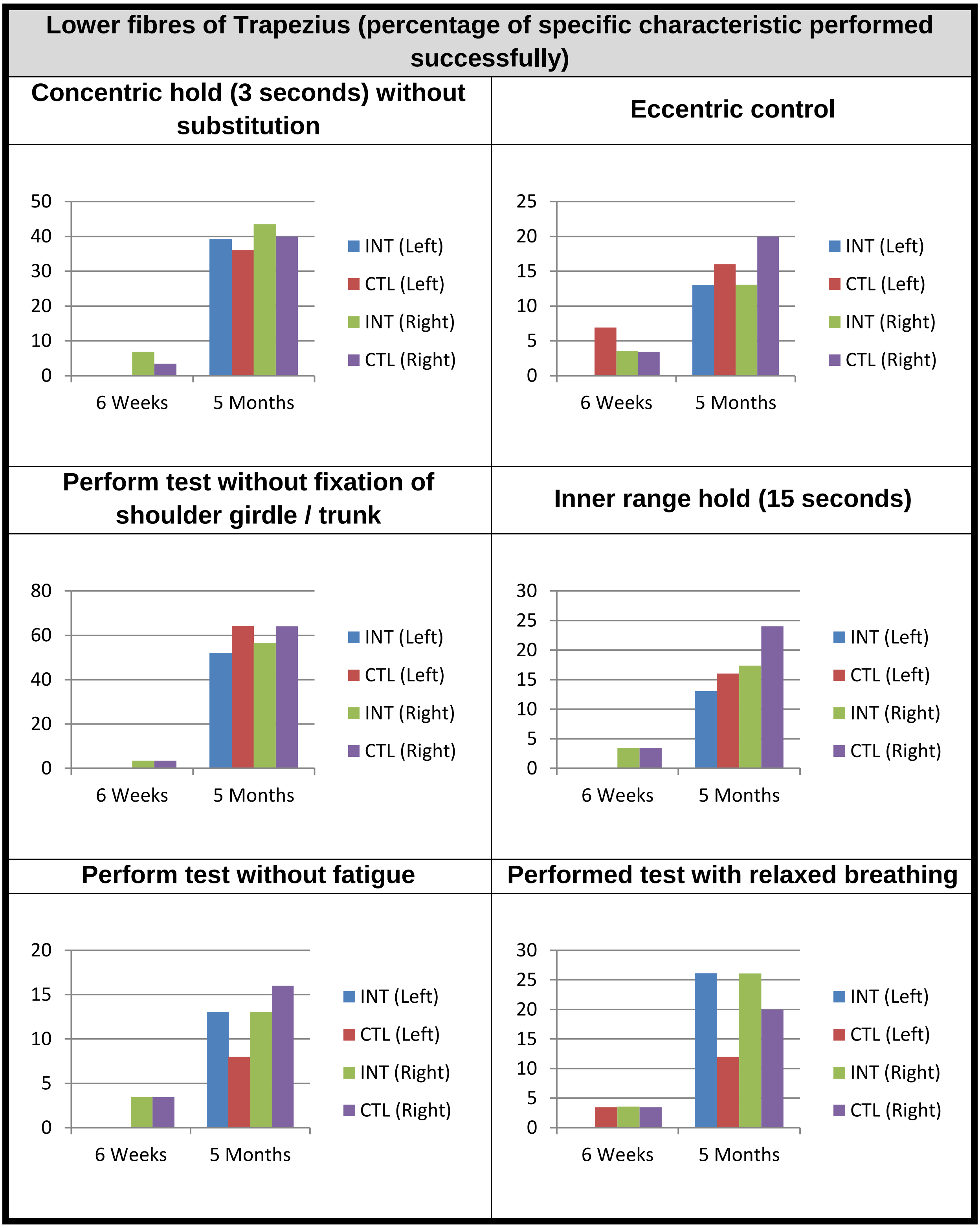


Figure 4.6: Between group comparisons with respect to lower fibres of Trapezius muscle function characteristics at six weeks and five months.

In the McNemar test for symmetry (Table 4.13) the results for the lower fibres of Trapezius have been different to that of Serratus anterior and the middle fibres of

Trapezius. Both groups reflected significant changes within the group over six weeks for Serratus anterior and middle fibres of Trapezius function. Within the intervention group the ability to concentrically contract the lower fibres of Trapezius showed a remarkable change from baseline to six weeks (left and right side). The other characteristics of muscle function (except the eccentric control) showed a significant change only on the right side. Eccentrically, only the left side showed significant change. No significant change had been observed over six weeks for any characteristic of function of lower fibres of Trapezius within the control group.

Table 4.13: Summary of the McNemar test results for the different characteristics of the lower fibres of Trapezius function from baseline to six weeks.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	20/28	1/28	7/28	0.0970
	Right	22/28	0/28	6/28	0.0498
Control	Left	21/29	1/29	7/29	0.0970
	Right	20/29	2/29	7/29	0.1599
Concentric hold 3seconds (without substitution)					
Intervention	Left	20/28	1/28	7/28	0.0339
	Right	22/28	0/28	6/28	0.0143
Control	Left	22/29	1/29	6/29	0.1496
	Right	21/29	2/29	6/29	0.3189
Eccentric control					
Intervention	Left	22/28	0/28	6/28	0.0143
	Right	23/28	0/28	5/28	0.0821
Control	Left	24/29	0/29	5/29	0.0821
	Right	23/29	0/29	5/29	0.2466
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	26/28	0/28	2/28	0.1573
	Right	23/28	0/28	5/28	0.0253
Control	Left	25/29	0/29	4/29	0.1353
	Right	26/29	0/29	3/29	0.2231
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	26/28	0/28	2/28	0.1573
	Right	23/28	0/28	5/28	0.0253
Control	Left	25/29	0/29	4/29	0.1353
	Right	26/29	0/29	3/29	0.2231
Swimmer can perform test without fatigue					
Intervention	Left	26/28	0/28	2/28	0.1573
	Right	23/28	0/28	5/28	0.0253
Control	Left	25/29	0/25	4/25	0.1353
	Right	26/29	0/29	3/29	0.2231
Swimmer can perform test with relaxed breathing					
Intervention	Left	26/28	0/28	2/28	0.1573
	Right	22/28	0/28	6/28	0.0498
Control	Left	25/29	0/29	4/29	0.1353
	Right	26/29	0/29	3/29	0.2231

From baseline to five months (Table 4.14) the significant change was more noticeable within both groups. The ability to perform the muscle function test without fatigue and with relaxed breathing for the lower fibres of Trapezius was only significant in the intervention group (p=0.0302).

Table 4.14: Summary of the McNemar test results for the different characteristics of the lower fibres of Trapezius function from baseline to five months.

Group	Side	Status quo	Deteriorate	Improve	P value
The active range equals the passive range of muscle contraction					
Intervention	Left	3/23	0/23	22/23	0.0000
	Right	3/23	0/23	22/23	0.0000
Control	Left	3/25	0/25	22/25	0.0001
	Right	3/25	0/25	22/25	0.0001
Concentric hold 3seconds (without substitution)					
Intervention	Left	6/23	0/23	17/23	0.0007
	Right	6/23	0/23	17/23	0.0002
Control	Left	10/25	0/25	15/25	0.0018
	Right	10/25	0/25	15/25	0.0018
Eccentric control					
Intervention	Left	17/23	0/23	6/23	0.0498
	Right	17/23	0/23	6/23	0.0498
Control	Left	19/25	0/25	6/25	0.0498
	Right	18/25	0/25	7/25	0.0719
Muscle function test can be performed without proximal fixation of the shoulder girdle / trunk					
Intervention	Left	9/23	0/23	14/23	0.0009
	Right	9/23	0/23	14/23	0.0009
Control	Left	9/25	0/25	16/25	0.0001
	Right	9/25	0/25	16/25	0.0001
Swimmer can hold inner range position for 15 seconds (2 repetitions)					
Intervention	Left	10/23	0/23	13/23	0.0015
	Right	10/23	0/23	13/23	0.0015
Control	Left	15/25	0/25	10/25	0.0067
	Right	15/25	0/25	10/25	0.0067
Swimmer can perform test without fatigue					
Intervention	Left	16/23	0/23	7/23	0.0302
	Right	16/23	0/23	7/23	0.0302
Control	Left	20/25	0/25	5/25	0.0821
	Right	19/25	0/25	6/25	0.0498
Swimmer can perform test with relaxed breathing					
Intervention	Left	16/23	0/23	7/23	0.0302
	Right	16/23	0/23	7/23	0.0302
Control	Left	19/25	0/25	6/25	0.0498
	Right	18/25	0/25	7/25	0.0302

RESTING SCAPULA POSITION

A two sided Fischer exact test was used to compare the two independent groups of swimmers, with respect to the resting position of the scapula. The results have been presented in Table 4.15. The rows represent the specific marker that was used to determine the resting position of the scapula. The value given for a specific marker was either 0 / 1, where 0 = 'good', the specific marker that was evaluated was correct and 1 = 'bad', the specific marker was not correct. In the columns the specific markers were compared at baseline, six weeks and five months.

Different markers were used to define the ideal resting position of the scapula. Each of these markers were evaluated before and after a 200m swim and compared over time. Two markers showed marginal significance before swim in the intervention group. The position of the inferior angle against the thoracic wall (p=0.092) and the inferior third of the medial border against the thoracic wall (p=0.057). One marker showed statistical significant change from baseline to six weeks after swim. The marker, inferior third of the medial border against the thorax, in the intervention group on the left side reflected remarkable change from baseline to six weeks (p=0.035) after the 200m swim. One other marker, the position of the inferior angle against the thoracic wall, showed marginal significance in the intervention group (p=0.056). No statistical differences were observed for the control group from baseline to six weeks. No significant changes were observed for either group from baseline to five months.

One marker out of thirteen showed statistical significant change over time (Table 4.16) and therefore the odds ratio for all the markers had been calculated. The odds ratio in this study had been incorporated to measure the odds of change on the markers of the resting scapula due to a lateral costal breathing pattern.

The odds ratio results as presented in (Table 4.17) indicated that the improvement in the intervention group regarding the position of the inferior angle of the scapula against the thoracic wall was 2.29 fold better than that of the control group on the left side pre swim. On the right side the improvement was 1.8 fold better than the control group. Post swim the intervention group also demonstrated a better improvement regarding the position of the inferior angle of the scapula against the thoracic wall, than the control group.

The marker used to describe the inferior medial border of the scapula indicated an even better improvement in the intervention group. Before swim the intervention group showed 5.4 fold improvement on the left side and 2.25 fold improvement on the right side. Post swim the left side of the intervention group showed 4.3 fold improvement on the left side and 2.0 fold on the right side.

Table 4.15: Summary of the two sided Fischer exact test results of the resting scapula position (pre swim) from baseline to six weeks and baseline to five months (Page 159-160).

Resting scapula position (pre swim)																		
Out - come	**Baseline**						**6 weeks**						**5 months**					
	Intervention		**Control**		**P value**		**Intervention**		**Control**		**P value**		**Intervention**		**Control**		**P value**	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
Root of scapular spine: level to T3 projecting to T4																		
0 = good	26/33 78.79%	25/33 75.76%	27/34 79.41%	27/34 79.41%	1.000	0.776	28/28 100%	28/28 100%	26/29 89.66%	26/29 89.66%	0.237	0.237	22/23 95.65%	22/23 95.65%	25/25 100%	25/25 100%	0.479	0.479
1 = bad	7/33 21.21%	8/33 24.24%	7/34 20.59%	7/34 20.59%			0	0	3/29 10.34%	3/29 10.34%			1/23 4.35%	1/23 4.35%	0	0		
Inferior angle of scapula: level to T7																		
0 = good	7/33 21.21%	4/33 12.12%	7/34 20.59%	7/34 20.59%	1.000	0.512	17/28 60.71%	16/28 57.14%	14/29 48.28%	14/29 48.28%	0.429	0.599	14/23 60.87%	14/23 60.87%	13/25 52%	13/25 52%	0.573	0.573
1 = bad	26/33 78.79%	29/33 87.88%	27/34 79.41%	27/34 79.41%			11/28 39.29%	12/28 42.86%	15/29 51.72%	15/29 51.72%			9/23 39.13%	9/23 39.13%	12/25 48%	12/25 48%		
Inferior angle: against thoracic spine																		
0 = good	17/33 51.52%	16/33 48.48	15/34 44.12%	14/34 41.18%	0.628	0.627	22/28 78.57%	21/28 75%	16/29 55.17%	17/29 58.62%	**0.092**	0.263	12/23 52.17%	12/23 52.17%	10/25 40%	9/25 36%	0.563	0.383
1 = bad	16/33 48.49%	17/33 51.52%	19/34 55.88	20/34 58.82%			6/28 21.43%	7/28 25%	13/29 44.83%	12/29 41.38%			11/23 47.83%	11/23 47.83%	15/25 60%	16/25 64%		
Inferior angle of scapula more lateral than superior angle																		
0 = good	17/33 51.52%	15/33 45.45%	15/34 44.12%	15/34 44,12%	0.628	1.000	27/28 96.435	25/28 89.29%	27/29 93.10%	27/29 93.10%	1.000	0.670	23/23 100%	23/23 100%	25/25 100%	25/25 100%	0	0
1 = bad	16/33 48.48%	18/33 54.55%	19/34 55.88%	19/34 55.88%			1/28 3.57%	3/28 10.71%	2/29 6.90%	2/29 6.90%			0	0	0	0		
Medial border of scapula parallel to spine																		
0 = good	28/33 84.85%	22/33 66.67%	21/34 61.76%	15/34 44.12%	0.053	0.087	28/28 100%	26/28 92.86%	28/29 96.55%	28/29 96.55%	1.000	0.611	18/23 78.26%	17/23 73.91%	22/25 88%	22/25 88%	0.454	0.279
1 = bad	5/33 15.15%	11/33 66%	13/34 38.24%	19/34 55.88%			0	2/28 7.14%	1/29 3.45%	1/29 3.45%			5/23 21.74%	6/23 26.09%	3/25 12%	3/25 12%		
Acromion: left and right same level / height																		
0 = good	12/33 36.36%	12/33 36.36%	7/34 20.59%	7/34 20.59%	0.183	0.183	21/28 75%	21/28 75%	21/29 72.41%	21/29 72.41%	1.000	1.000	15/23 65.22%	15/23 65.22%	15/25 60%	15/25 60%	0.772	0.772
1 = bad	21/33 63.64%	21/33 63.64%	27/34 79.41%	27/34 79.41%			7/28 25%	7/28 25%	8/29 27.59%	8/29 27.59%			8/23 34.7%	8/23 34.7%	10/25 40%	10/25 40%		

Acromion higher than superior border of the scapula																		
0 = good	24/32 75%	25/33 75.76%	27/34 79.41	29/34 85.29%	0.772	0.369	25/28 89.29%	26/28 92.86%	27/29 93.10%	26/29 89.66%	0.670	1.000	21/23 91.30%	20/23 86.96%	25/25 100%	25/25 100%	0.224	0.102
1 = bad	8/32 25%	8/33 24.24%	7/34 20.59	5/34 14.71%			3/28 10.71%	2/28 7.14%	2/29 6.90%	3/29 10.34%			2/23 8.70%	3/23 13.04%	0	0		
Spine of scapula angled upwards																		
0 = good	25/33 75.76%	25/33 75.76%	31/34 91.18%	28/34 82.35%	0.109	0.560	28/28 100%	28/28 100%	29/29 100%	29/29 100%	0	0	23/23 100%	23/23 100%	24/25 96%	25/25 100%	1.000	0
1 = bad	8/33 24.24%	8/33 24.24%	3/34 8.82	6/34 17.65%			0	0	0	0			0	0	1/25 4%	0		
Coracoid process same height																		
0 = good	13/33 39.39%	14/33 42.42%	9/34 26.47%	9/34 26.47%	0.305	0.204	20/28 71.43%	20/28 71.43%	17/29 58.62%	17/29 58.62%	0.408	0.408	12/23 52.17%	12/23 52.17%	13/25 52%	13/25 52%	1.000	1.000
1 = bad	20/33 60.61%	19/34 57.58%	25/34 73.53%	25/34 73.53%			8/28 28.57%	8/28 28.57%	12/29 41.38%	12/29 41.38%			11/23 47.83%	11/23 47.83%	12/25 48%	12/25 48%		
Clavicle same height																		
0 = good	19/33 57.58%	19/33 57.58%	15/34 44.12%	15/34 44.12%	0.332	0.332	20/28 71.43%	20/28 71.43%	18/29 62.07%	18/29 62.07%	0.576	0.576	12/23 52.17%	12/23 52.17%	16/25 64%	16/25 64%	0.559	0.559
1 = bad	14/33 42.42%	14/33 42.42%	19/34 55.88%	19/34 55.88%			8/28 28.57%	8/28 28.57%	11/29 37.93%	11/29 37.93%			11/23 47.83%	11/23 47.83%	9/25 36%	9/25 36%		
Clavicle incline upwards																		
0 = good	28/33 84.85%	28/33 84.85%	31/34 91.18%	31/34 91.18%	0.476	0.476	28/28 100%	28/28 100%	29/29 100%	29/29 100%	0	0	21/23 91.30%	21/23 91.30%	25/25 100%	25/25 100%	0.224	0.224
1 = bad	5/33 15.15%	5/33 15.15%	3/34 8.82%	3/34 8.82%			0	0	0	0			2/23 8.70%	2/23 8.70%	0	0		
Whole medial border of scapula against thoracic wall																		
0 = good	16/33 48.48%	17/33 51.52%	18/34 52.94%	17/34 50%	0.809	1.000	28/28 100%	28/28 100%	29/29 100%	29/29 100%	0	0	11/23 47.83%	13/23 56.52%	18/25 72%	18/25 72%	0.140	0.367
1 = bad	17/33 51.52%	16/33 48.48%	16/34 47.06	17/34 50%			0	0	0	0			12/23 52.17%	10/23 43.48%	7/25 28%	7/25 28%		
Inferior third of medial border of scapula against thoracic wall																		
0 = good	16/33 48.48%	17/33 51.52%	16/34 47.06	13/34 38.24%	1.000	0.330	21/28 75%	21/28 75%	14/29 48.28%	17/29 58.62%	**0.057**	0.263	8/23 34.78%	8/23 34.78%	11/25 44%	11/25 44%	0.566	0.566
1 = bad	17/33 51.52%	16/33 48.48%	18/34 52.94%	21/34 61.67%			7/28 25%	7/28 25%	15/29 51.72%	12/29 41.38%			15/23 65.22%	15/23 65.22%	14/25 56%	14/25 56%		

Table 4:16: Summary of the two sided Fischer exact test results of the resting scapula (post swim) from baseline to six weeks and baseline to five months (Page 161-162).

Resting scapula position (post swim)																		
Out - come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Root of scapular spine: level to T3 projecting to T4																		
0 = good	26/33 78.79%	25/33 75.76%	27/34 79.41%	27/34 79.41%	1.000	0.776	28/28 100%	28/28 100%	27/30 90%	27/30 90%	0.238	0.238	22/23 95.65%	22/23 95.65%	26/26 100%	26/26 100%	0.469	0.469
1 = bad	7/33 21.21%	8/33 24.24%	7/34 20.59%	7/34 20.59%			0	0	3/30 10%	3/30 10%			1/23 4.35%	1/23 4.35%	0	0		
Inferior angle of scapula: level to T7																		
0 = good	7/33 21.21%	4/33 12.12%	6/34 17.65%	7/34 20.59%	0.765	0.512	17/28 60.715%	16/28 57.14%	15/30 50%	15/30 50%	0.441	0.610	14/23 60.87%	14/23 60.87%	14/26 53.85%	14/26 53.85%	0.774	0.774
1 = bad	26/33 78.79%	29/33 87.88%	28/34 82.35%	27/34 79.41%			11/28 39.29%	12/28 42.86%	15/30 50%	15/30 50%			9/23 39.13%	9/23 39.13%	12/26 46.15%	12/26 46.15%		
Inferior angle: against thoracic spine																		
0 = good	17/33 51.52%	16/33 48.48	14/34 41.18%	12/34 35.29%	0.466	0.627	22/28 78.57%	21/28 75%	16/30 53.33%	17/30 56.67%	0.056	0.174	12/23 52.17%	12/23 52.17%	11/26 42.31%	10/26 38.46%	0.572	0.396
1 = bad	16/33 48.49%	17/33 51.52%	20/34 58.82	22/34 64.71%			6/28 21.43%	7/28 25%	14/30 46.67%	13/30 43.33%			11/23 47.83%	11/23 47.83%	15/26 57.69%	16/26 61.54		
Inferior angle of scapula more lateral than superior angle																		
0 = good	17/33 51.52%	15/33 45.45%	15/34 44.12%	14/34 41.18%	0.628	0.807	27/28 96.435	25/28 89.29%	28/30 93.33%	28/30 93.33%	1.000	0.665	23/23 100%	23/23 100%	26/26 100%	26/26 100%	0	0
1 = bad	16/33 48.48%	18/33 54.55%	19/34 55.88%	20/34 58.82			1/28 3.57%	3/28 10.71%	2/30 6.67%	2/30 6.67%			0	0	0	0		
Medial border of scapula parallel to spine																		
0 = good	28/33 84.85%	22/33 66.67%	21/34 61.76%	15/34 44.12%	0.0503	0.087	28/28 100%	26/28 92.86%	29/30 96.67%	29/30 96.67%	1.000	0.605	18/23 78.26%	17/23 73.91%	23/26 88.46%	23/26 88.46%	0.448	0.273
1 = bad	5/33 15.15%	11/33 66%	13/34 38.24%	19/34 55.88%			0	2/28 7.14%	1/30 3.33%	1/30 3.33%			5/23 21.74%	6/23 26.09%	3/26 11.54%	3/26 11.54%		
Acromion: left and right same level / height																		
0 = good	12/33 36.36%	12/33 36.36%	7/34 20.59%	7/34 20.59%	0.183	0.183	21/28 75%	21/28 75%	21/30 70%	21/30 70%	0.772	0.772	15/23 65.22%	15/23 65.22%	16/26 61.54%	16/26 61.54%	1.000	1.000
1 = bad	21/33 63.64%	21/33 63.64%	27/34 79.41%	27/34 79.41%			7/28 25%	7/28 25%	9/30 30%	9/30 30%			8/23 34.7%	8/23 34.7%	10/26 38.46%	10/26 38.46%		
Acromion higher than superior border of the scapula																		
0 = good	25/33 75.76%	25/33 75.76%	27/34 79.41	29/34 85.29%	0.776	0.369	25/28 89.29%	26/28 92.86%	27/30 90%	27/30 90%	1.000	1.000	21/23 91.30%	20/23 86.96%	26/26 100%	26/26 100%	0.215	0.096
1 = bad	8/33 24.24%	8/33 24.24%	7/34 20.59	5/34 14.71%			3/28 10.71%	2/28 7.14%	3/30 10%	3/30 10%			2/23 8.70%	3/23 13.04%	0	0		

Spine of scapula angled upwards																		
0 = good	25/33 75.76%	25/33 75.76%	31/34 91.18%	28/34 82.35%	0.109	0.560	28/28 100%	28/28 100%	30/30 100%	30/30 100%	0	0	23/23 100%	23/23 100%	25/26 96.15%	26/26 100%	1.000	0
1 = bad	8/33	8/33	3/34	6/34			0	0	0	0			0	0	1/26	0		
	24.24%	24.24%	8.82	17.65%											3.85%			
Coracoid process same height																		
0 = good	13/33 39.39%	14/33 42.42%	9/34 26.47%	9/34 26.47%	0.305	0.204	20/28 71.43%	20/28 71.43%	17/30 56.67%	18/30 60%	0.284	0.284	12/23 52.17%	12/23 52.17%	14/26 53.85%	13/26 50%	1.000	1.000
1 = bad	20/33 60.61%	19/34 57.58%	25/34 73.53%	25/34 73.53%			8/28 28.57%	8/28 28.57%	13/30 43.33%	12/30 40%			11/23 47.83%	11/23 47.83%	12/26 46.15%	13/26 50%		
Clavicle same height																		
0 = good	19/33 57.58%	19/33 57.58%	15/34 44.12%	15/34 44.12%	0.332	0.332	20/28 71.43%	20/28 71.43%	18/30 60%	19/30 63.33%	0.416	0.416	11/23 47.83%	11/23 47.83%	17/26 65.38%	17/26 65.38%	0.257	0.257
1 = bad	14/33 42.42%	14/33 42.42%	19/34 55.88%	19/34 55.88%			8/28 28.57%	8/28 28.57%	12/30 40%	11/30 36.67%			12/23 52.17%	12/23 52.17%	9/26 34.62%	9/26 34.62%		
Clavicle incline upwards																		
0 = good	28/33 84.85%	28/33 84.85%	31/34 91.18%	31/34 91.18%	0.476	0.476	28/28 100%	28/28 100%	30/30 100%	30/30 100%	0	0	21/23 91.30%	21/23 91.30%	26/26 100%	26/26 100%	0.215	0.215
1 = bad	5/33 15.15%	5/33 15.15%	3/34 8.82%	3/34 8.82%			0	0	0	0			2/23 8.70%	2/23 8.70%	0	0		
Whole medial border of scapula against thoracic wall																		
0 = good	13/33 39.39%	18/33 54.55%	18/34 52.94%	16/34 47.06%	0.330	0.628	28/28 100%	28/28 100%	33/33 100%	33/33 100%	0	0	11/23 47.83%	13/23 56.52%	19/26 73.08%	19/26 73.08%	0.086	0.247
1 = bad	20/33 60.61%	15/33 45.45%	16/34 47.06	18/34 52.94%			0	0	0	0			12/23 52.17%	10/23 43.48%	7/26 26.92%	7/26 26.92%		
Inferior third of medial border of scapula against thoracic wall																		
0 = good	16/33 48.48%	16/33 48.48%	15/34 44.12	13/34 38.24%	0.808	0.464	21/28 75%	21/28 75%	14/30 46.67%	18/30 60%	**0.035**	0.174	7/23 30.34%	8/23 34.78%	12/26 45.12%	12/26 45.12%	0.379	0.562
1 = bad	17/33 51.52%	17/33 51.52%	19/34 55.88%	21/34 61.67%			7/28 25%	7/28 25%	16/30 53.33%	12/30 40%			16/23 69.57%	15/23 65.22%	14/26 53.85%	14/26 53.85%		

Table 4.17: Odds ratio results for two specific markers used in the evaluation of the resting position of the scapula at six weeks.

Odds ratio of resting scapula at six weeks (95% CI)											
PRE SWIM						**POST SWIM**					
Inferior angle of scapula against thoracic wall											
LEFT			**RIGHT**			**LEFT**			**RIGHT**		
Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value
2.3 (0.5;10.6)	1.0	0.272	1.8 (0.4;7.8)	1.0	0.43	2.0 (0.4;8.9)	1.0	0.355	1.62 (0.38;6.89)	1.0	0.5
Inferior third of scapula against thoracic wall											
LEFT			**RIGHT**			**LEFT**			**RIGHT**		
Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value
5.4 (0.9;30.8)	1.0	0.033	2.25 (0.5;10.6)	1.0	0.292	4.3 (0.8;22.2)	1.0	0.05	2.0 (0.4;9.2)	1.0	0.432

The McNemar test for symmetry had been done to determine if any within group change occurred. In total 13 markers on the scapula were evaluated. Pre swim the intervention group (Table 4.18) reflected statistical within group improvement in 10/13 markers on the left side and two markers showed marginal significance. On the right side 11/13 markers showed statistical significant change and one marker showed a marginal significant change. The control group showed only statistical improvement in 5/13 of the markers on the left and marginal significance in one marker. On the right side 6/13 markers showed significant change and one showed marginal significance.

Post swim (Table 4.19) the intervention group improved significantly on the left side (10/13) and the right side (12/13). On the left side two markers showed marginal significant change. The control group improved significantly on 6/13 markers on both sides.

The within group results for the resting position of the scapula (Table 4.20 & 4.21) showed the deterioration after five months. Within the intervention group (pre and post swim) only 3/13 markers showed a significant change after five months. Two markers (left and right) showed marginal significant change. Within the control group 6/13 markers showed a significant improvement from baseline to five months. Two markers showed marginal significance.

Table 4.18: Summary of the McNemar test results of the resting scapula position (pre swim) from baseline to six weeks (Page 165-166).

Resting scapula position (pre swim)										
Groups	Change from baseline				Base vs. 6 weeks (ideal positioning)				P – Value	
	Improved		Deteriorate		Baseline		6 weeks			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Root of scapula level to T3 projecting to T4										
Intervention group	5/5 100%	6/6 100%	0/23	0/22	23/28 82.14%	22/28 78.56%	28/28 100%	28/28 100%	0.0235	0.0143
Control group	6/6 100%	6/6 100%	3/24 12.50%	3/24 12.50%	23/29 79.31%	23/29 79.31%	26/29 89.66%	26/29 89.66%	0.3173	0.3173
Inferior angle level to T7										
Intervention group	14/22 63.64%	14/25 56%	3/6 50%	1/3 33.33%	6/28 21.43%	3/28 10.71%	17/28 60.71%	16/28 57.14%	0.0076	0.0008
Control group	12/23 52.17%	3/7 42.86%	4/7 57.14%	15/30 50%	7/29 24.14%	7/29 24.14%	14/29 48.28%	14/29 48.28%	0.0707	0.0522
Inferior angle against thoracic wall										
Intervention group	8/13 61.54%	9/14 64.29%	1/15 6.67%	2/14 14.29%	15/28 53.57%	14/28 50%	22/28 78.57%	21/28 75%	0.0196	0.0348
Control group	7/17 41.18%	9/18 50%	4/13 30.77%	4/12 40%	12/29 41.38%	11/29 37.93%	16/29 55.17%	17/29 58.62%	0.2059	0.0833
Inferior angle lateral to superior angle										
Intervention group	13/14 92.86%	13/16 81.25%	0/14	0/12	14/28 50%	12/28 42.86%	27/28 96.43	25/28 89.29%	0.0003	0.0003
Control group	16/16 100%	16/16 100%	2/14 14.29%	2/14 14.29%	13/29 44.83%	13/29 44.83%	27/29 93.10%	27/29 93.10%	0.0010	0.0010
Medial border parallel to spine										
Intervention group	3/3 100%	9/9 100%	0/25	2/19 10.53%	25/28 89.29%	19/28 67.68%	28/28 100%	26/28 92.86%	0.0833	0.0348
Control group	12/13 92.31%	16/17 94.12%	0/17	0/13	16/29 55.17%	13/29 44.83%	28/29 96.55%	28/29 96.55%	0.0005	0.0001
Acromion left & right same level & height										
Intervention group	12/18 66.67%	12/18 66.67%	1/10 10%	1/10 10%	10/28 35.71%	10/28 35.71%	21/28 75.00%	21/28 75.00%	0.0023	0.0023
Control group	17/25 68.00%	17/25 68.00%	1/5 20%	1/5 20%	5/29 17.24%	5/29 17.24%	21/29 72.41%	21/29 72.41%	0.0002	0.0002

Acromion higher than superior border of the scapula										
Intervention group	7/8 87.50%	6/8 75%	2/19 10.53%	0/20	19/27 70.37%	20/28 71.43%	24/27 88.89%	26/28 92.86%	0.0956	0.0143
Control group	5/5 100%	3/4 75%	3/25 12%	2/26 7.69%	24/29 82.76%	25/29 86.21%	27/29 93.10%	26/29 89.66%	0.2568	0.6547
Spine of scapula angle upwards										
Intervention group	8/8 100%	8/8 100%	0/20	0/20	20/28 71.43%	20/28 71.43%	28/28 100%	28/28 100%	0.0047	0.0047
Control group	2/2 100%	4/4 1005	0/28	0/26	27/29 93.10%	25/29 86.21%	29/29 100%	29/29 100%	0.1573	0.0455
Coracoid process same height										
Intervention group	12/17 70.59%	11/16 68.75%	3/11 27.27%	3/12 25%	11/28 39.29%	12/28 42.86%	20/28 71.43%	20/28 71.43%	0.0201	0.0325
Control group	11/22 50%	11/22 50%	2/8 25%	2/8 25%	8/29 27.59%	8/29 27.59%	17/29 58.62%	17/29 58.62%	0.0126	0.0126
Clavicle same height										
Intervention group	10/13 76.92%	10/13 76.92%	5/15 33.33%	5/15 33.33%	15/28 53.57%	15/28 53.57%	20/28 71.43%	20/28 71.43%	0.1967	0.1967
Control group	9/16 56.25%	9/16 56.25%	5/14 35.71%	5/14 35.71%	14/29 48.28%	14/29 48.28%	18/29 62.07%	18/29 62.07%	0.2850	0.2850
Clavicle angle incline upwards										
Intervention group	5/5 100%	5/5 100%	0/23	0/23	23/28 82.14%	23/28 82.14%	28/28 100%	28/28 100%	0.0253	0.0253
Control group	2/2 100%	2/2 100%	0/28	0/28	27/29 93.10%	27/29 93.10%	29/29 100%	29/29 100%	0.1573	0.1573
Medial border against thoracic wall										
Intervention group	15/15 100%	14/14 100%	0/13	0/14	13/28 46.43%	14/28 50%	28/28 100%	28/28 100%	0.0001	0.0002
Control group	14/14 100%	15/15 100%	0/16	0/15	16/29 55.17%	15/29 51.72%	29/29 100%	29/29 100%	0.0003	0.0002
Inferior third against thoracic wall										
Intervention group	9/14 64.29%	9/13 69.23	2/14 14.29%	3/15 20%	14/28 50%	15/28 53.57%	21/28 75%	21/28 75%	0.0348	0.0833
Control group	4/16 25%	9/18 50%	4/14 28.575	4/12 33.33%	13/29 44.83%	11/29 37.93%	14/29 48.28%	17/29 58.62%	0.7055	0.0833

Table 4.19: Summary of the McNemar test results of the resting scapula position (post swim) from baseline to six weeks (Page 167-168).

Resting scapula position (post swim)										
Groups	Change from baseline				Base vs. 6 weeks (ideal positioning)				P – Value	
	Improved		Deteriorate		Baseline		6 weeks			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Root of scapula level to T3 projecting to T4										
Intervention	5/5 100%	6/6 100%	0/23	0/22	23/28 82.14%	22/28 78.57%	28/28 100%	28/28 100%	0.0253	0.0143
Control	6/6 100%	6/6 100%	3/24 12.50%	3/24 12.50%	23/29 79.31%	23/29 79.31%	26/29 89.66%	26/29 89.66%	0.3173	0.3173
Inferior angle level to T7										
Intervention	14/22 63.64%	14/25 56%	3/6 50%	1/3 33.33%	6/28 21.43%	3/28 10.71%	17/28 60.715	16/28 57.14%	0.0076	0.0008
Control	12/24 50%	11/23 47.83%	3/6 50%	3/7 42.86%	6/29 20.69%	7/29 24.14%	14/29 48.28%	14/29 48.28%	0.0325	0.0522
Inferior angle against thoracic wall										
Intervention	8/13 61.54%	9/14 64.29%	1/15 6.67%	2/14 14.29%	15/28 53.57%	14/28 50%	22/28 78.57%	21/28 75%	0.0196	0.0348
Control	8/18 44.445	10/19 52.63%	4/12 33.33%	4/11 36.36%	11/29 37.93%	10/29 34.48%	16/29 55.17%	17/29 58.62%	0.1317	0.0522
Inferior angle lateral to superior angle										
Intervention	13/14 92.86%	13/16 81.25%	0/14	0/12	14/28 50%	12/28 42.86%	27/28 96.43%	25/28 89.29%	0.0003	0.0003
Control	16/16 100%	17/17 100%	2/14 14.29%	2/13 15.38%	13/29 44.83%	12/29 41.38%	27/29 93.10%	27/29 93.10%	0.0010	0.0006
Medial border parallel to spine										
Intervention	3/3 100%	26/28 92.86%	0/25	2/19 10.53%	25/28 89.29%	19/28 32.14%	28/28 100%	26/28 92.86%	0.0833	0.0348
Control	12/13 92.31%	16/17 94.12%	0/17	0/13	16/29 55.17%	13/29 44.83%	28/29 96.55%	28/29 96.55%	0.0005	0.0001
Acromion left & right same level & height										
Intervention	12/18 66.67%	12/18 66.67%	1/10 10%	1/10 10%	10/28 35.71%	10/28 35.71%	21/28 75%	21/28 75%	0.0023	0.0023
Control	17/25 68%	17/25 68%	1/5 20%	1/5 20%	5/29 82.76%	5/29 17.24%	21/29 72.41%	21/29 72.41%	0.0002	0.0002

Acromion higher than superior border of the scapula										
Intervention	7/8 87.50%	6/8 75%	2/20 10%	0/20	20/28 71.43%	20/28 71.43%	25/28 89.29%	26/28 92.86%	0.0956	0.0143
Control	5/5 100%	3/4 75%	3/25 12%	2/26 7.69%	24/29 82.76%	25/29 86.21	27/29 93.10%	26/29 89.66%	0.2568	0.6547
Spine of scapula angle upwards										
Intervention	8/8 100%	8/8 100%	0/20	0/20	20/28 71.43%	20/28 71.43%	28/28 100%	28/28 100%	0.0047	0.0047
Control	2/2 100%	4/4 100%	0/28	0/26	27/29 93.10%	25/29 86.21%	29/29 100%	29/29 100%	0.1573	0.0455
Coracoid process same height										
Intervention	12/17 70.59%	11/16 68.75%	3/11 27.27%	3/12 25%	11/28 39.29%	12/28 42.86%	20/28 71.43%	20/28 71.43%	0.0201	0.0325
Control	11/22 50%	12/22 54.55%	2/8 15.38%	2/8 15.38%	8/29 27.59%	8/29 27.59%	17/29 58.62%	18/29 62.07%	0.0216	0.0075
Clavicle same height										
Intervention	10/13 76.92%	11/13 84.62%	5/15 33.33%	6/15 40%	15/28 53.57%	15/28 53.57%	20/28 71.43%	20/28 71.43%	0.1967	0.2253
Control	9/16 56.25%	10/16 62.50%	5/14 35.71%	5/14 35.71%	14/29 48.28%	14/29 48.28%	18/29 62.07%	19/29 65.52%	0.2850	0.1967
Clavicle angle incline upwards										
Intervention	5/5 100%	5/5 100%	0/23	0/23	23/28 82.14%	23/28 82.14%	28/28 100%	28/28 100%	0.0253	0.0253
Control	2/2 100%	2/2 100%	0/28	0/28	27/29 93.10%	27/29 93.10%	29/29 100%	29/29 100%	0.1573	0.1573
Medial border against thoracic wall										
Intervention	18/18 100%	13/13 100%	0/10	0/15	10/28 35.71%	15/28 53.57%	28/28 100%	28/28 100%	0.0000	0.0003
Control	14/14 100%	16/16 100%	0/16	0/14	16/29 55.17%	14/29 48.28%	29/29 1005	29/29 100%	0.0003	0.0001
Inferior third against thoracic wall										
Intervention	9/14 64.29%	10/14 71.43%	2/14 14.29%	3/14 21.43%	14/28 50%	14/28 50%	21/28 75%	21/28 75%	0.0348	0.0522
Control	5/17 29.41%	10/18 55.56%	4/13 30.77%	4/12 33.33%	12/29 41.38%	11/29 37.93%	14/29 51.72%	18/29 62.07%	0.4795	0.0522

Table 4.20: Summary of the McNemar test results of the resting scapula (pre swim) from baseline to five months (Page 169-170).

Groups	Change from baseline				Baseline vs. 5 months (ideal positioning)				P – Value	
	Improved		Deteriorate		Baseline		5 months			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Root of scapula level to T3 projecting to T4										
Intervention group	3/3 100%	3/4 75%	1/20 5%	0/19	20/23 86.96%	19/23 82.61%	22/23 95.65%	22/23 95/56%	0.3173	0.0833
Control group	6/6 100%	6/6 100%	0/20	0/20	19/25 76%	19/25 76%	25/25 100%	25/25 100%	0.0143	0.0143
Inferior angle level to T7										
Intervention group	11/18 61.11%	12/20 60%	2/5 40%	1/3 33.33%	5/23 21.74%	3/23 13.04%	14/23 60.87%	14/23 60.87%	0.0126	0.0023
Control group	10/19 52.63%	9/19 47.37%	3/7 42.86%	2/7 28.57%	7/25 28%	7/25 28%	13/25 52%	13/25 52%	0.0833	0.0578
Inferior angle against thoracic wall										
Intervention group	4/9 44.44%	3/9 33.33%	6/14 42.86%	5/14 35.71%	14/23 60.87%	14/23 60.87%	12/23 52.17%	12/23 52.17%	0.5271	0.4795
Control group	4/15 26.67%	3/15 20%	4/11 36.36%	4/11 36.36%	11/25 44%	11/25 44%	10/25 40%	9/25 36%	0.7055	0.4142
Inferior angle lateral to superior angle										
Intervention group	10/10 100%	13/13 100%	0/13	0/13	13/23 56.52%	13/23 56.52%	23/23 100%	23/23 100%	0.0016	0.003
Control group	16/16 100%	16/16 100%	0/10	0/10	10/25 40%	10/25 40%	25/25 100%	25/25 100%	0.0001	0.001
Medial border parallel to spine										
Intervention group	2/2 100%	8/9 88.89%	5/21 23.81%	5/14 35.71%	21/23 91.30%	14/23 60.87%	18/23 78.26%	17/23 73.91%	0.2568	0.4054
Control group	11/11 100%	13/14 92.86%	3/15 20%	2/12 16.67%	12/25 48%	12/26 46.15%	22/25 88%	23/26 88.46%	0.0075	0.0045
Acromion left & right same level & height										
Intervention group	11/15 73.33%	11/15 73.33%	4/8 50%	4/8 50%	8/23 34.78%	8/23 34.78%	15/23 65.22%	15/23 65.22%	0.0707	0.0707
Control group	14/21 66.67%	14/21 66.67%	3/5 60%	3/5 60%	5/25 20%	5/25 20%	15/25 60%	15/25 60%	0.0124	0.0124

Resting scapula position (pre swim)

Acromion higher than superior border of the scapula										
Intervention group	7/7 100%	8/8 100%	2/16 12.50%	3/15 20%	16/23 69.57%	15/23 65.22%	21/23 91.30	20/23 86.96%	0.0956	0.1317
Control group	6/6 100%	5/5 100%	0/20	0/21	19/25 76%	20/25 80%	25/25 100%	25/25 100%	0.0143	0.0253
Spine of scapula angle upwards										
Intervention group	8/8 100%	7/7 100%	0/15	0/16	15/23 65.22%	16/23 69.57%	23/23 100%	23/23 100%	0.0047	0.0082
Control group	3/3 100%	6/6 100%	1/23 4.35%	0/20	22/25 88%	19/25 76%	24/25 96%	25/25 100%	0.3173	0.0143
Coracoid process same height										
Intervention group	5/13 38.46%	4/12 33.33%	3/10 30%	3/11 27.27%	10/23 43.48%	11/23 47.83%	12/23 52.17	12/23 52.17%	0.4795	0.7055
Control group	9/20 45.00%	8/20 40%	1/6 23.08%	1/6 23.08%	5/25 20%	5/25 20%	13/25 52%	12/25 48%	0.0114	0.0196
Clavicle same height										
Intervention group	4/11 36.36%	4/11 36.36%	4/12 33.33%	4/12 33.33%	12/23 52.17%	12/23 52.17%	12/23 52.17%	12/23 52.17%	1.000	1.000
Control group	9/14 64.29%	9/14 64.29%	4/12 33.33%	4/12 33.33%	12/25 48%	12/25 50%	16/25 64%	16/25 64%	0.2482	0.2482
Clavicle angle incline upwards										
Intervention group	3/4 75%	3/4 75%	1/19 5.26%	1/19 5.26%	19/23 82.61%	19/23 82.61%	21/23 91.30%	21/23 91.30%	0.3173	0.3173
Control group	3/3 100%	3/3 100%	0/23	0/23	22/25 88%	22/25 88%	25/25 100%	25/25 100%	0.0833	0.0833
Medial border against thoracic wall										
Intervention group	5/11 45.45%	5/11 45.45%	6/12 50%	6/12 50%	12/23 52.17%	12/23 52.17%	11/23 47.83%	11/23 47.83%	0.7630	0.7630
Control group	7/11 63.64%	7/11 63.64%	3/15 20%	3/15 20%	14/25 56%	14/25 56%	18/25 72%	18/25 72%	0.2059	0.2059
Inferior third against thoracic wall										
Intervention group	3/11 27.27%	2/10 20%	7/12 58.33%	7/13 53.85%	12/23 52.17%	13/23 56.52%	8/23 34.785	8/23 34.785	0.2059	0.0956
Control group	4/13 30.77%	5/15 33.33%	5/13 38.46%	4/11 36.36%	13/25 52%	11/25 44%	11/25 44%	11/25 44%	0.4795	1.000

Table 4.21: Summary of the McNemar test results of the resting scapula (post swim) from baseline to five months (Page 171-172).

Resting scapula position (post swim)										
Groups	Change from baseline				Base vs. 5 months (ideal positioning)				P – Value	
	Improved		Deteriorate		Baseline		5 months			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Root of scapula level to T3 projecting to T4										
Intervention	3/3 100%	3/4 75%	1/20 5%	0/19	20/23 86.96%	19/23 82.61%	22/23 95.65%	22/23 95.65%	0.3173	0.0833
Control	6/6 100%	6/6 100%	0/20	0/20	19/25 76%	19/25 76%	25/25 100%	25/25 100%	0.0143	0.0143
Inferior angle level to T7										
Intervention	11/18 61.11%	12/20 60%	2/5 40%	1/3 33.33%	5/23 21.43%	3/23 13.04%	14/23 60.87%	14/23 60.87%	0.0126	0.0058
Control	10/20 50%	9/19 47.37%	2/6 33.33%	2/7 28.57%	7/25 28%	7/26 26.92%	13/25 52%	14/26 53.85%	0.0348	0.0578
Inferior angle against thoracic wall										
Intervention	4/9 44.44%	3/9 33.33%	6/14 42.86%	5/14 35.71%	14/23 60.87%	14/23 60.87%	12/23 52.17%	12/23 52.17%	0.5271	0.4795
Control	5/16 31.25%	3/16 18.75%	4/10 40%	3/10 30%	10/25 40%	10/25 40%	10/25 40%	9/25 36%	1.0000	0.6547
Inferior angle lateral to superior angle										
Intervention	10/10 100%	13/13 100%	0/13	0/10	13/23 56.52%	10/23 43.48%	23/23 100%	23/23 100%	0.0016	0.0003
Control	16/16 100%	17/17 100%	0/10	0/9	10/25 40%	9/25 36%	25/25 100%	25/25 100%	0.0001	0.0001
Medial border parallel to spine										
Intervention	2/2 100%	8/9 88.89%	5/21 23.81%	5/14 35.71%	21/23 91.30%	14/23 60.87%	18/23 78.26%	17/23 73.91	0.2568	0.4054
Control	11/11 100%	13/14 92.86%	3/15 20%	2/12 46.15%	15/25 60%	12/25 48%	22/25 88%	22/25 88%	0.0522	0.0075
Acromion left & right same level & height										
Intervention	15/23 65.22%	15/23 65.22%	4/8 50%	4/8 50%	8/23 34.78%	8/23 34.78%	15/23 65.22%	15/23 65.22%	0.0707	0.0707
Control	14/21 66.67%	14/21 66.67%	3/5 60%	3/5 60%	5/25 20%	5/25 20%	15/25 60%	15/25 60%	0.0124	0.0124

Acromion higher than superior border of the scapula										
Intervention	7/7 100%	8/8 100%	2/16 12.50%	3/15 20%	16/23 69.57%	15/23 65.22%	21/23 91.30%	20/23 86.96%	0.0956	0.1317
Control	6/6 100%	5/5 100%	0/20	0/21	19/25 76%	20/25 80%	25/25 100%	25/25 100%	0.0143	0.0253
Spine of scapula angle upwards										
Intervention	8/8 100%	7/7 100%	0/15	0/16	15/23 65.22%	16/23 69.57%	23/23 100%	23/23 100%	0.0047	0.0082
Control	3/3 100%	6/6 100%	1/23 4.35%	0/20	22/25 88%	19/25 76%	24/25 96%	25/25 100%	0.3173	0.0143
Coracoid process same height										
Intervention	5/13 38.46%	4/12 33.33%	3/10 30%	3/11 27.27%	10/23 43.48%	11/23 47.83%	12/23 52.17%	12/23 52.17	0.4795	0.7055
Control	9/20 45%	8/20 40%	1/6 16.67%	1/6 16.67%	5/25 20%	5/25 20%	13/25 52%	12/25 48%	0.0114	0.0196
Clavicle same height										
Intervention	4/11 36.36%	4/11 36.36%	5/12 41.67%	5/12 41.67%	12/23 52.17%	12/23 52.17%	11/23 47.83%	11/23 47.83%	0.7389	0.7389
Control	9/14 64.29%	9/14 64.29%	4/12 33.33%	4/12 33.33%	12/25 48%	12/25 48%	16/25 64%	16/25 64%	0.2482	0.2482
Clavicle angle incline upwards										
Intervention	3/4 75%	3/4 75%	1/19 5.26%	1/19 5.26%	19/23 82.61%	19/23 82.61%	21/23 91.30%	21/23 91.30%	0.3173	0.3173
Control	3/3 100%	3/3 100%	0/23	0/23	22/25 88%	22/25 88%	25/25 100%	25/25 100%	0.0833	0.0833
Medial border against thoracic wall										
Intervention	7/14 50%	5/10 50%	5/9 55.56%	5/13 38.46%	9/23 39.13%	13/23 56.52%	11/23 47.83%	13/23 56.62%	0.5637	1.000
Control	7/11 63.64%	7/12 58.33%	3/15 20%	2/14 14.29%	14/25 56%	13/25 52%	18/25 72%	18/25 72%	0.2059	0.0956
Inferior third against thoracic wall										
Intervention	2/11 18.185	3/11 27.27%	7/12 52.17%	7/12 52.17%	12/23 52.17%	12/23 52.17%	7/23 30.43%	8/23 34.78%	0.0956	0.2059
Control	5/14 35.71%	5/15 33.33%	12/26 46.15%	4/11 36.36%	12/25 48%	11/25 44%	11/25 44%	11/25 44%	0.7389	1.0000

DYNAMIC SCAPULA CONTROL

The two sided Fischer exact test had been applied to compare the dynamic scapula control of the intervention and control group from baseline to six weeks and baseline to five months pre swim (Table 4.22) and post swim (Table 4.24). The aspects evaluated were dysrhythmia, winging and tipping of the scapula. The rows represent the specific marker (dysrhythmia, winging and tipping) that was used to determine the dynamic scapula. If a marker was not present the NO was marked and if a marker was present the YES was marked. In the columns the specific markers were compared at baseline, six weeks and five months. These aspects were evaluated pre and post swim as explained in Chapter 3. No significant change was observed between the two group regarding dysrhythmia and scapular winging during gleno-humeral flexion.

Significant change was observed in tipping of the scapula. The intervention group showed significant less tipping on the left side (p=0.020) post swim and marginal significance on the right (p=0.068) post swim from baseline to five months. The intervention group however, reflected improvement (pre and post swim) with scapular tipping from six weeks to five months. Pre swim the improvement was from 17.86% (left & right) to 43.48% (left) and 39.13% (right). Post swim the improvement was from 10.71% (left and right) to 30.43% (left and right).

From baseline to six weeks the control group showed significant less tipping of the scapula on the right side (p=0.045) pre swim. The control group showed deterioration from six weeks to five months in the ability to control tipping of the scapula pre and post swim.

The odds ratio results as presented in (Table 4.23) suggest that the improvement in the intervention group regarding dysrhythmia of the scapula is 2.14 fold that of the control group on the left side pre swim from baseline to six weeks. On the right side the improvement was 2.0 fold better than the control group. Post swim the intervention group also demonstrated a better improvement than the control group.

The McNemar test for symmetry had been done to determine if any within group changes occurred in the dynamic control of the scapula pre swim at six weeks (Table

4.25). Within the intervention group dysrhythmia improved significantly after six weeks on the left and the right side (p=0.020) pre swim. Winging of the scapula during gleno-humeral flexion also decreased significantly in the intervention group on the left (p=0.002) and the right (p=0.002). Tipping of the scapula on the right side showed a marginal significant increase (p=0.083).

Within the control group winging decreased significantly on the left and right sides (p=0.007). No other significant changes were observed within the control group.

The post swim results at six weeks are summarised in Table 4.26. The intervention group showed significant improvement in dysrhythmia on the right side (p=0.011) and marginal significant improvement on the left side (p=0.095). Winging decreased significantly on the left side (p=0.002) of the intervention group. The control group showed significant decrease of dysrhythmia on the right side (p=0.008) and significant decrease in winging of the scapula on the left (0.002) and right (p=0.001) sides.

The within group results of the dynamic scapula control from baseline to five months showed a significant increase in dysrhythmia on the left (p=0.019) and right (p=0.008) sides for the intervention group pre swim (Table 4.27). Within the intervention group winging of the scapula showed no significant change when five month results have been compared with the baseline results. Although tipping of the scapula did not show significant change when baseline results have been compared with five months results, tipping showed a decrease from six weeks to five months within the intervention group.

The control group showed a significant decrease in winging from baseline to five months on the right side (p=0.033) and marginal significance on the left side (p=0.095) pre swim within group. Although compared to baseline the change was significant, when compared to six weeks, the result after five months reflected deterioration for the control group. No other significant changes were observed when the five month results have been compared to the baseline results for the control group.

Table 4.22: Summary of the two sided Fischer exact test results of the pre swim dynamic scapula control over time from baseline to six weeks and baseline to five months.

Dynamic scapula position (pre swim)																		
Out - come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Dysrhythmia																		
NO	13/32 40.63%	15/32 46.88%	10/34 29.41%	12/34 35.29%	0.440	0.453	19/28 67.86%	21/28 75%	13/29 56.14%	17/29 58.62%	0.111	0.263	2/23 8.70%	3/23 13.04%	7/25 28%	7/25 28%	0.140	0.292
YES	19/32 59.38%	17/32 53.13%	24/34 70.59%	22/34 64.71%			9/28 32.14%	7/28 25%	16/29 55.17%	12/29 41.38%			21/23 91.30%	20/23 86.96%	18/25 72%	18/25 72%		
Winging																		
NO	8/32 25%	9/32 28.13%	6/34 17.65%	5/34 14.71%	0.554	0.234	15/28 53.57%	18/28 64.29%	16/29 55.17%	15/29 51.27%	1.000	0.424	9/23 39.13%	9/23 39.13%	9/25 36%	9/25 36%	1.000	1.000
YES	24/32 75%	23/32 71.88%	28/34 82.35%	29/34 85.29%			13/28 46.43%	10/28 35.71%	13/29 44.83%	14/29 48.28%			14/23 60.87%	14/23 60.87%	16/25 64%	16/25 64%		
Tipping																		
NO	11/32 34.38%	12/32 37.50%	10/34 29.41%	10/34 29.41%	0.793	0.603	5/28 17.86%	5/28 17.86%	7/29 24.14%	13/28 44.83%	0.747	0.045	10/23 43.48%	9/23 39.13%	5/25 20%	5/25 20%	0.120	0.207
YES	21/32 65.63%	20/32 62.50%	24/43 70.59%	24/34 70.59%			23/28 82.14%	23/28 82.14%	22/29 75.86%	16/29 55.17%			13/23 56.52%	14/23 60.87%	20/25 80%	20/25 80%		

Key: No = dysrhythmia, winging and tipping absent, Yes = dysrhythmia, winging and tipping present.

Table 4.23: Odds ratio for intervention, pre and post swim, dynamic scapula control change from baseline to six weeks.

Dynamic scapula position at 6 weeks (95%CI)											
PRE SWIM						**POST SWIM**					
Dysrhythmia											
LEFT			**RIGHT**			**LEFT**			**RIGHT**		
Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value	Intervention	Control	P value
2.14 (0.6;8.4)	1.0	0.260	2.0 (0.4;8.6)	1.0	0.34	1.23 (0.3;4.4)	1.0	0.70	1.8 (0.6;6.4)	1.0	0.34

Table 4.24: Summary of the two sided Fischer exact test results of the post swim dynamic scapula control over time from baseline to five months.

Dynamic scapula position (post swim)																		
Out - come	Baseline						6 weeks						5 months					
	Intervention		Control		P value		Intervention		Control		P value		Intervention		Control		P value	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Dysrhythmia																		
0 = good	5/32 15.63%	9/32 28.13%	5/34 14.71%	6/34 17.65%	1.000	0.384	9/28 32.14%	15.28 53.57%	8/29 27.59%	12/29 41.38%	0.777	0.431	4/23 17.39%	4/23 17.39%	2/25 8%	2/25 8%	0.407	0.407
1 = bad	27/32 84.38%	23/32 71.88%	29/34 85.29%	28/34 82.35%			19/28 67.86%	13/28 46.43%	21/29 72.41%	17/29 58.62%			19/23 82.61%	19/23 82.61%	23/25 92%	23/25 92%		
Winging																		
0 = good	7/32 21.88%	9/32 28.13%	1/34 2.94%	1/34 2.94%	0.025	0.005	15/28 53.57%	12/28 42.86%	11/29 37.93%	13/29 44.83%	0.292	1.000	5/23 21.74%	5/23 21.74%	5/25 20%	5/25 20%	1.000	1.000
1 = bad	25/32 78.13%	23/32 71.88%	33/34 97.06%	33/34 97.06%			13/28 46.43%	16/28 57.14%	18/29 62.07%	16/29 55.17%			18/23 78.26%	18/23 78.26%	20/25 80%	20/25 80%		
Tipping																		
0 = good	7/32 21.88%	8/32 25%	6/34 17.65%	6/34 17.65%	0.762	0.554	3/28 10.71%	3/28 10.71%	4/29 13.79%	5/29 17.24%	1.000	0.706	7/23 30.43%	7/23 30.43%	1/25 4.0%	2/25 8%	0.020	0.068
1 = bad	25/32 78.13%	24/32 75%	28/34 82.35%	28/34 82.35%			25/28 89.29%	25/28 89.29%	25/29 86.21%	24/29 82.76%			16/23 69.57%	16/23 69.57%	24/25 96%	23/25 92%		

Table 4.25: Summary of the McNemar test results of the pre swim dynamic scapula control over time from baseline to six weeks.

Dynamic scapula position (pre swim) symmetry											
Groups	**Change from baseline**				**Base vs. time 6 (ideal positioning)**				**P – Value**	
	Improved		**Deteriorate**		**Baseline**		**Time 6 weeks**			
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Dysrhythmia										
Intervention group	10/17 58.82%	10/15 66.67%	2/11 18.18%	2/13 15.38%	11/28 39.29%	13/28 46.43%	19/28 67.86%	21/28 75%	0.0209	0.0209
Control group	8/20 40%	9/18 50%	4/9 44.44%	3/11 27.27%	9/29 31.03%	11/29 37.93%	13/29 44.83%	17/29 58.62%	0.2482	0.0833
Winging of scapula										
Intervention group	9/22 40.91%	12/21 57.14%	0/6	1/7 14.29%	6/28 21.43%	7/28 25%	15/28 53.57%	18/28 64.29%	0.0027	0.0023
Control group	12/23 52.17%	12/24 50%	2/6 33.33%	2/5 40%	6/29 20.69%	5/29 17.24%	16/29 52.17%	15/29 51.72%	0.0075	0.0075
Tipping of scapula										
Intervention group	3/18 16.67%	3/17 17.65%	8/10 80%	9/11 81.82%	10/28 35.71%	11/28 39.29%	5/28 17.86%	5/28 17.86%	0.1317	0.0833
Control group	4/20 20%	7/20 35%	6/9 66.67%	3/9 33.33%	9/29 31.03%	9/29 31.03%	7/29 24.14%	13/29 44.83%	0.5271	0.2059

Table 4.26: Summary of the McNemar test results of the post swim dynamic scapula control over time from baseline to six weeks.

Dynamic scapula position										
Groups	**Change from baseline**				**Base vs. time 6 (ideal positioning)**				**P – Value**	
	Improved		**Deteriorate**		**Baseline**		**Time 6 weeks**			
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Dysrhythmia										
Intervention group	7/24 29/17%	9/21 42.86%	2/4 50%	1/7 14.29%	4/28 14.29%	7/28 25%	9/28 32.14%	15/28 53.57%	0.0956	0.0114
Control group	6/24 25%	7/24 29.17%	3/5 60%	0/5	5/29 17.24%	5/29 17.24%	8/29 27.59%	12/29 41.38%	0.3173	0.0082
Winging of scapula										
Intervention group	9/22 40.91%	9/20 45%	0/6	5/8 62.50%	6/28 21.43%	8/28 28.57%	15/28 53.57%	12/28 42.86%	0.0027	0.2850
Control group	10/28 35.71%	12/28 42.86%	0/1	0/1	1/29 3.45%	1/29 3.45%	11/29 37.93%	13/29 44.83%	0.0016	0.0005
Tipping of scapula										
Intervention group	1/22 4.55%	1/21 4.76%	4/6 66.67%	5/7 71.43%	6/28 21.43%	7/28 25%	3/28 10.71%	3/28 10.71%	0.1797	0.1025
Control group	2/23 8.70%	3/23 13.04%	4/6 66.67%	4/6 66.67%	6/29 20.69%	6/29 20.69%	4/29 13.79%	5/29 17.24%	0.4142	0.7055

Table 4.27: Summary of the McNemar test results of the pre swim dynamic scapula control over time from baseline to five months.

Dynamic scapula position (pre swim) symmetry										
Groups	**Change from baseline**				**Base vs. 5 months (ideal positioning)**				**P – Value**	
	Improved		**Deteriorate**		**Baseline**		**5 months**			
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Dysrhythmia										
Intervention group	1/14 7.14%	0/13	8/9 88.89%	7/10 70%	9/23 39.13%	10/23 43.48%	2/23 8.70%	3/23 13.04%	0.0196	0.0082
Control group	3/17 17.65%	3/16 18.75%	4/8 50%	5/9 55.56%	8/25 32%	9/25 36%	7/25 28%	7/25 28%	0.7055	0.4795
Winging of scapula										
Intervention group	6/18 33.33%	5/15 33.33%	2/5 40%	4/8 50%	5/23 21.74%	8/23 34.78%	9/23 39.13%	9/23 39/13%	0.1573	0.7389
Control group	7/21 33.33%	7/22 31.82%	2/4 50%	1/3 33.33%	4/25 16%	3/25 12%	9/25 36%	9/25 36%	0.0956	0.0339
Tipping of scapula										
Intervention group	5/15 33.33%	6/14 42.86%	3/8 37.50%	6/11 54.55%	8/23 34.78%	11/25 44%	10/23 43.48%	9/23 39.13%	0.4795	0.7630
Control group	2/18 12.50%	1/16 6.25	6/9 66.67%	5/9 55.56%	9/25 36%	9/25 36%	5/25 20%	5/25 20%	0.1573	0.1025

Table 4.28: Summary of the McNemar test results of the post swim dynamic scapula control over time from baseline to five months.

Dynamic scapula position (post swim) symmetry										
Variables	Change from baseline				Base vs. 5 months (ideal positioning)				P – Value	
	Improved		Deteriorate		Baseline		5 months			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Dysrhythmia										
Intervention group	3/20 15%	4/19 21.05%	2/3 66.67%	4/6 66.67%	3/23 13.04%	5/23 21.74%	4/23 17.39%	4/23 17.39%	0.6547	0.7055
Control group	2/20 10%	2/20 10%	5/5 100%	5/5 100%	5/25 20%	5/25 20%	2/25 8%	2/25 8%	0.2568	0.2568
Winging of scapula										
Intervention group	2/18 11.11%	3/17 17.65%	2/5 40%	4/8 50%	5/23 21.74%	8/23 34.78%	5/23 21.74%	5/23 21.74%	1.0000	0.7055
Control group	4/24 16.67%	5/24 20.83%	0/1	1/1 100%	1/25 4%	1/25 4%	5/25 20%	5/25 20%	0.0455	0.1025
Tipping of scapula										
Intervention group	6/18 33.33%	6/19 31.58%	4/5 80%	3/6 50%	5/23 21.74%	5/23 21.74%	7/23 30.43%	7/23 30.43%	0.5271	0.4795
Control group	0/19	1/19 5.26%	5/6 83.33%	5/6 83.33%	6/25 24%	6/25 24%	1/25 4%	2/25 8%	0.0253	0.1025

The within group results at five months post swim is summarised in Table 4.28. No significant change was observed within the intervention group. However, although dysrhythmia and winging increased from six weeks to five months in both groups, tipping of the scapula only decreased over time in the intervention group (Table 4.25, 4.26, 4.27 and 4.28). The only significant within group change has shown a decrease of winging in the control group on the left side (p=0.045). Although the control group showed within significant change, winging in the control group increased from six weeks to five months. No other significant within group change was observed at five months post swim.

CONCLUSION

The results obtained from this study have been reported in this chapter. Significant between group differences were noticed in two markers used to determine the resting position of the scapula in the intervention group. The ability to control scapula tipping during gleno-humeral flexion was significantly better in the intervention group when compared to the control group after five months (post swim).

The PMI showed clinical significant improvement for both groups; however the control group showed deterioration from six weeks to five months. The improvement in PMI for the intervention group from baseline to five months has been supported by the change in thoracic expansion. The intervention group showed a decrease in upper thoracic expansion and an increase in lower thoracic expansion.

No between group differences were observed for the agonistic muscle function. Serratus anterior and middle fibres of Trapezius showed a significant change from baseline to six weeks and baseline to five months in muscle function. However for most of the characteristics evaluated both these muscles reflected deterioration from six weeks to five months.

Only the intervention group showed within group improvement for the lower fibres of Trapezius from baseline to six weeks. This improvement was noticeable after five months for both groups and unlike Serratus and the middle fibres of Trapezius no deterioration was observed in lower Trapezius from six weeks to five months.

Within the intervention group 10/13 (left) and 11/13 (right) of the markers used to determine the resting position of the scapula showed significant improvement compared to the 5/13 (left) and 6/13 (right) of the control group. After the 200m swim this improvement was maintained. Dysrhythmia and winging of the scapula decreased significantly within the intervention group after six weeks. The resting position of the scapula and dynamic scapula control reflected deterioration from six weeks to five months in both groups.

In Chapter 5 the results will be discussed in relation to other studies.

CHAPTER 5

DISCUSSION

The aim of this study was to determine if lateral costal breathing exercises in conjunction with scapular retraining exercises have a short term and long term effect on the scapular position of competitive swimmers, from level two up to senior national level.

The results demonstrate that lateral costal breathing exercises, together with scapula muscle retraining contributed to certain aspects of the ideal positioning and control of the scapula in swimmers, in the short term and in the long term. The only aspects of the resting position of the scapula that were affected are the position of the inferior angle of the scapula and the position of the inferior third of the medial border of the scapula. Only the ability to control scapula tipping was affected therefore, the hypothesis has been rejected.

Three main findings have emerged from this study that needs to be explored further. The first is the statistical significant change in the scapula position. The second is the change in Pectoralis minor length from baseline to five months. The third is the change in the agonistic as well as stability function of the scapula stabilisers, specifically the lower fibres of Trapezius and Serratus anterior. These main findings will be discussed in accordance with the objectives set for this study, but the flow of the discussion will deviate from the order of the objectives outlined in chapter one.

The results of each main finding will be interpreted, discussed and compared to other literature. Limitations that were identified in the literature or during the course of the current study will be highlighted and discussed. Finally, the results will be brought into perspective.

The ***first main finding*** of the current study, to be discussed, is the significant change in the position of the scapula (Table 4.15, 4.16) between the intervention and control groups. Significant changes had been observed in the resting position of the scapula as well as in the dynamic control of the scapula regarding tipping of the scapula (Table 4.24). The change in the position of the distal medial border and inferior angle of the scapula were observed after six weeks of supervised intervention. Scapula tipping was significantly less in the intervention group after five months; these changes were only observed on the left side. The significant changes were observed after the 200 meter swim.

The above mentioned findings can be interpreted in the following manner: in the first place, posterior tipping increased significantly (resting scapula position and dynamic scapula control) which implies that the length of the antagonist (Pectoralis minor) increased to such an extent that it allowed the scapula to move into the new range (Struyf et al. 2012, Lynch et al.2010, Tate et al. 2010). This increase in Pectoralis minor length is seen in the change of PMI over five months (Table 4.2). In the second place, the significant change in the position of the inferior medial border and inferior angle is the result of effective recruitment of the scapula stabilisers, specifically Serratus anterior and the lower fibres of Trapezius (Kibler et al. 2013; Struyf et al. 2012b; Tate et al. 2010; Bak 2010). In the third place, the dynamic scapula control (posterior tipping) is maintained during active gleno-humeral flexion. This control of the scapula indicates that the scapula stabilisers were not only strengthened agonistically, but their function to stabilise the scapula against the thoracic wall and the ability to control the scapula movement improved as well (Table 4.25, 4.26) (Worsley et al. 2013, Roy et al. 2009; Magarey and Jones 2003).

The results of the current study can be compared to two other studies that also evaluated the effect of scapular control and stabiliser retraining on scapular positioning (Worsley et al. 2013; Roy et al. 2009). The results of the previous studies indicate that scapular retraining exercises and the ability to control the scapula during gleno-humeral movement favoured a better aligned and positioned scapula. Controlling the scapular position and scapula retraining exercises were done separately in both of the previous studies (Worsley et al. 2013; Roy et al. 2009). In the current study the scapula exercises had been performed in conjunction with control of the scapula position which resulted in a better aligned scapula.

The second similarity between the current study and those done by Worsley et al. (2013) and Roy et al. (2009) entails the fact that feedback had been provided during execution of the exercises. Worsley et al. (2013) gave verbal and kinaesthetic feedback and while performing the exercises the patient used a mirror for visual feedback. Roy et al. (2009) provided only verbal feedback during the exercises. In the current study both verbal and kinaesthetic feedback had been provided. The swimmers were constantly reminded to 'lengthen the position between the ear and shoulder' or 'to open the chest'. These similarities indicate that sufficient exteroceptive feedback and input are imperative to ensure optimum recruitment of stabilising muscles.

The essence of supervision and exteroceptive feedback has also been front staged in the current study when a comparison had been done between the results of the position of the resting scapula after six weeks and after five months. The intervention group reflected deterioration in the resting scapula position. A possible explanation could be ascribed to the lack of supervision. During the intervention period from baseline to six weeks, the swimmers received feedback on the position of the scapula and the quality of muscle contraction had also been monitored. During the period that followed from the first six weeks of exercising until five months of exercising, the swimmers (intervention and control groups) had no feedback or input regarding the control and the quality (control of eccentric contraction and good dissociation of movement) of the exercises performed.

The dynamic scapula control (posterior tipping) changed significantly only on the left side (intervention group). As earlier discussed, this change in scapular position has developed in consequence of a lengthened Pectoralis minor and better recruitment and control of the scapula stabilisers. However, the changes that took place in Pectoralis minor and the stabilisers were bilateral in the intervention group. The only explanation for the unilateral change in scapular position is the preferred side of breathing. Breathing side dominance can have an effect on shoulder girdle muscle strength and gleno-humeral range of motion (Riemann et al. 2011; Seifert et al. 2005), which can cause muscle imbalances. These muscle imbalances can lead to cervical pain (Pollard and Fernandez 2004) and can cause asymmetry in the stroke technique (Seifert et al. 2005). One of the limitations of the current study; is that breathing side dominance had not been documented.

A point of importance that needs to be emphasised is that in the current study, the significant change in the posterior tipping of the scapula has taken place after the 200 meter swim session, implying that fatigue did not affect the function of the scapula stabilisers during the swim session. This finding is contradictory to a study conducted on 50 competitive swimmers (n=25 healthy, n=25 impingement) by Su et al. (2004). It has been previously noted that Serratus anterior and Trapezius (middle and lower fibres) are susceptible to fatigue during and after a swim session (Kibler et al. 2013; Bak 2010; Su et al. 2004). In the study conducted by Su et al. (2004) the focus was only on agonistic strengthening of Serratus anterior and upper Trapezius. Correct recruitment and good quality of muscle contraction (ideal range and no compensatory movements) were not addressed by Su et al. (2004).

The motor learning approach which had been followed in the current study may be the reason why fatigue did not have an effect on the stabilisers. This statement can be explained by means of the application of three principles of motor learning. The first principle is that optimum musculoskeletal balance is needed (Magarey and Jones 2003). Such balance is determined by sufficient muscle length, in this case Pectoralis minor length, mobility of fascial tissue and optimum recruitment of the stabilising muscles (Magarey and Jones 2003). The change in scapular position affected the length-tension relationship of the stabilising muscles (Worsley et al. 2013; Struyf et al. 2011b; Roy et al. 2009). This well aligned position of the scapula favoured optimum recruitment of the lower fibres of Trapezius and Serratus muscles resulting in a stable scapula.

The second principle is that in ideal optimum function; much more quality of contraction is required from a muscle than only agonistic strength (Kibler et al. 2013; Worsley et al.

2013, Roy et al. 2009; Magarey and Jones 2003). Ideal sequence of activation, concentric contraction and eccentric control, isometric inner range hold and avoidance of any compensatory movements are also essential for optimum muscle function (Kibler et al. 2013; Worsley et al. 2013, Roy et al. 2009; Magarey and Jones 2003). Due to the stable position of the scapula, the stabilisers could contract effectively. Furthermore, both the scapula movement and the scapula position could be controlled.

Once these characteristics have been addressed, the third principle of task specific retraining patterns becomes applicable as seen in this study. During the intervention, exercises were performed in different ranges of gleno-humeral flexion and abduction. Lateral costal breathing exercise was facilitated while doing the retraining exercises and assuring a well-positioned scapula. The ability to dissociate between upper and lower thoracic expansion (Table 4.3) while doing the exercises, ensured the biomechanical advantage of unloading the Pectoralis minor. The stable scapula, as discussed in the previous paragraph, is not only beneficial to the scapula stabilisers, it seems to have the ability to contribute to a stable base for effective Pectoralis minor contraction, an important accessory breathing muscle for swimmers.

The ***second main finding*** of the current study is the change in Pectoralis minor length from baseline to five months. Although this change in Pectoralis minor length had not been significant between the two groups it is important to mention that the intervention group never reflected deterioration in the PMI as demonstrated by the control group (Figure 4.2 and 4.3).

The clinical significant change of 0.4 in the PMI from baseline to five months, within the intervention group, can be interpreted in the following way: first the reciprocal stretch that was used during the intervention was effective and could contribute in the change in PMI (Lynch et al. 2010). Second, the length gained in Pectoralis minor was maintained over time although swimmers kept on training and even increased training to prepare for the national championships.

The result of length change in Pectoralis minor in the current study is in line with other studies, however the outcome measures which had been incorporated to evaluate the effect of the stretches, differ. The effect of Pectoralis minor stretches is measured with pain and function questionnaires (Tate et al. 2010; McClure et al. 2004; Borstad and Ludewig 2005), the total scapular distance test (Lynch et al. 2010), posture (McClure et al. 2004) and gleno-humeral range of motion (McClure et al. 2004). One possible reason that could be ascribed to the fact that no other study could be found where PMI had been utilized as the outcome measure is insufficient consistency in the baseline value.

The baseline values of PMI of the current study (Table 4.2) are in line with values presented by Struyf et al. (2012a). The findings of the current study differ from results obtained in other studies (Cools et al. 2010; Borstad 2008; Borstad and Ludewig 2005) (refer to page 34-36).

There are three possible reasons to explain the discrepancy in baseline values of PMI in the mentioned studies. The first explanation is the position in which the arm is placed during the measurement of the anatomical length of Pectoralis minor. In the studies conducted by Struyf et al. (2012a:5), Cools et al. (2010:682), Borstad (2008:171) and Borstad and Ludewig (2005:230) the arm is placed next to the patient's side with the elbow in extension. In this position of elbow extension, Biceps brachii may have an influence on the scapula position (tipping the scapula anteriorly) as the long head of Biceps brachii originates from the coracoid process (Agur and Dalley 2009). In the current study the elbow had been flexed to eliminate the effect of Biceps brachii on the position of the scapula (Lewis and Valentine 2007).

The second explanation is the position of the scapula during the measurement of the anatomical length of Pectoralis minor. When a muscle's length is measured, the origin and insertion of the muscle should be the furthest apart. Sufficient length of Pectoralis minor will allow scapula retraction and posterior tipping without any trick movements like thoracic or lumbar extension (Lynch et al. 2010). In none of the previous studies (Cools et al. 2010; Borstad 2008; Borstad and Ludewig 2005) evidence could be found that any instruction to retract and posteriorly tip the scapula was documented. In the current study the swimmer had been instructed to posteriorly tip the scapula to the available range. The swimmer was stopped if any trick movements had occurred (Page 94).

The third possible explanation is the instrument utilized for the actual measurement of muscle length. Both the Vernier calliper® and a measuring tape showed good validity when compared to an electromagnetic motion capture system (Borstad 2008). When the distance between two points is measured with the digital calliper, (Vernier calliper®) soft tissue bulk will not have any effect on the measurement (Page 94). When the same distance is measured with a measuring tape muscle bulk could affect the measurement and result in an inaccurate measurement.

The discrepancy in baseline values might also suggest that a 'golden standard' in PMI may be research population specific. Consensus regarding a standard guideline regarding the starting position will contribute to a standardised measuring technique.

The change in Pectoralis minor length, within the intervention group, has been confirmed by means of two other outcome measures which had been applied in the current study. In the first place the effect of a stretched Pectoralis minor on the breathing pattern is confirmed with the changes in thoracic expansion over time (Table 4.3). In the second place the effect of a lengthened Pectoralis minor on the scapula position is confirmed with the significant decrease in posterior tipping as discussed.

The effect of the changed length of Pectoralis minor, on the breathing pattern of swimmers, is confirmed by means of the changes which had been observed in thoracic expansion. The intervention group reflected a decrease in upper thoracic expansion and an increase in lower thoracic expansion over time (Table 4.3). This change in thoracic expansion can be interpreted as a change towards a more ideal breathing pattern. In the control group, upper and lower thoracic expansion decreased over time, however an explanation of this finding is not clear. The FVC of the swimmers had been evaluated but there was no indication of any change over time in either group (Table 4.4). This can imply that although the breathing pattern of the swimmers changed (as discussed previously) the intervention did not have any effect on the lung function of the swimmers, specifically the FVC.

Previous studies conducted on swimmers to address the respiratory system focussed on strengthening of the inspiratory and expiratory muscles regardless of the *breathing pattern* used during exercises (Kilding et al. 2010; Mickleborough et al. 2008; Wells et al. 2005). Although they found significant changes in FVC, these interventions did not enhance performance.

No other study could be found where the effect of lateral costal breathing dissociation exercises was evaluated on lung function, specifically FVC, in swimmers. The FVC values of the swimmers in the current study are generally higher than FVC values which were published in previous studies; 2.7–4.0 (Kilding et al. 2010), 5.32–5.94 (Mickleborough et al. 2008) and 3.8–5.6 (Wells et al. 2005). The ages of the swimmers and the levels of participation in the latter three studies correlate with those analysed in the current study. Comparison between the studies is problematic because all the studies were done in different countries and the discrepancy in these findings can possibly be attributed to the difference in altitude. A possible explanation to the higher values recorded in the current study is the subjective component of the spyrometry test; a second limitation of the current study. All the evaluations for the study were done in one room and the possibility of participants yielding to pretence under peer pressure cannot be overlooked. Another possible explanation of the higher FVC values could be that some of the swimmers involved in the current study, are members of the national swim team. It has been documented that these super athletes, due to their intensive training programme, have acquired higher FVC values (Kilding et al. 2010; Mickleborough et al. 2008; Wells et al. 2005).

The long term increase in PMI and the subsequent change in Pectoralis minor muscle length, which was maintained over time regardless of the high volume training of swimmers, is in alignment with the motor learning approach as well. This imply that although Pectoralis minor was used as an accessory breathing muscle, the scapula served as a stable base to allow sufficient contraction of Pectoralis minor without shortening it. Furthermore, it implies that although the swimmer used repetitive gleno-humeral flexion and medial rotation as needed within the swim stroke, Pectoralis minor did not shorten adaptively. The observation that Pectoralis minor did not shorten adaptively can be due to the fact that the scapula stabilisers and Pectoralis minor worked effectively in the reciprocal movement pattern during swimming.

The change in Pectoralis minor length resulted in a posteriorly tipped scapula. This position favours optimum function of the scapula and of the muscles attached to it (Cools et al. 2013; Worsley et al. 2013; Struyf et al. 2011b; Roy et al. 2009). The results of the muscle function evaluated in the study, will be discussed hereunder.

The ***third main finding*** of the current study encompasses the change in the agonistic function as well as in the stability function of the scapula stabilisers, specifically the lower fibres of Trapezius and Serratus anterior. No significance between group changes were observed for any of the three muscles which had been evaluated. The within group changes (both groups) observed showed significant change from baseline to six weeks as well as from baseline to five months (Table 4.7, 4.8, 4.13, 4.14). Only the intervention group showed significant change in the function of the lower fibres of Trapezius at six weeks; however both groups reflected an improvement from baseline to five months. Different to Serratus anterior and the middle fibres of Trapezius, the lower fibres of Trapezius showed improvement in muscle function from six weeks to five months.

The aim of retraining the muscles in the current study was to address the agonistic function of each muscle but also to address the stability and control needed to fulfil their role as a force couple to ensure optimum scapular positioning. The significant change in concentric contraction (Table 4.7, 4.10, 4.13) implies that the agonistic function of the scapula stabilisers had been addressed (De Mey et al. 2012; Arlotta et al. 2011, Oyama et al. 2010, Hardwick et al. 2006; Cools et al. 2007b; Ekstrom et al. 2003; Decker et al. 1999). The significant change in the other characteristics of muscle function that were measured is evident in the change of the resting scapula (Table 4.18) as well as the change in the dynamic scapula control during gleno-humeral flexion (Table 4.25). The change in the dynamic control of the scapula implies that the recruitment and activation of the stabilisers had been addressed effectively (Worsley et al. 2013; Roy et al. 2009). The change in the dynamic scapula position implies that the muscles gained control to fulfil their stability function during gleno-humeral flexion.

The agonistic function of the lower fibres of Trapezius, of the intervention group, reflected significant within group improvement after six weeks (Table 4.13). For Serratus anterior and the middle fibres of Trapezius, both groups showed significant change for the agonistic muscle function from baseline to six weeks (Table 4.7, 4.10), but deterioration from six weeks to five months. The lower fibres of Trapezius however, reflected further significant change in terms of improvement from six weeks to five months for both groups (Table 4.14).

The significant change in lower Trapezius to contract agonistically within the intervention group after six weeks can be explained as follow: The intervention group did lateral costal breathing dissociation exercises during the dry land intervention programme. The effects of the breathing exercises are three fold. In the first place the intervention group showed a more normal breathing pattern which could be seen in the change of thoracic expansion post intervention (Table 4.3). The dissociation in thoracic movement unloaded the Pectoralis minor and possibly strengthened the diaphragm. In the second place, the lengthened Pectoralis minor allowed posterior tipping of the scapula (Table 4.24), which is only evident in the intervention group. In the third place the more posteriorly tipped position of the scapula favoured the possibility to retrain the lower fibres of Trapezius (Cools et al. 2003a) agonistically as being demonstrated in this study.

The change in function of lower Trapezius was not so evident after six weeks and is different to the changes observed in Serratus anterior and the middle fibres of Trapezius from baseline to six weeks (Figure 4.4, 4.5, 4.6). A possible explanation for this obvious difference could be the fact that the lower Trapezius is not used agonistically during the swim action (Figure 2.5) (Heinlein et al. 2010, Pollard and Fernandez 2004). Serratus anterior and middle fibres of Trapezius are continuously activated during the swim action (Heinlein et al. 2010, Pollard and Fernandez 2004). Although the agonistic function of lower Trapezius is upward rotation and posterior tipping, it has been documented that although the lower fibres of Trapezius does not show much change in muscle fibre length during upward rotation of the scapula, the isometric tone in the muscle changes (Arlotta et al. 2011, Kinney et al. 2008, Cools et al. 2007a, Cools et al. 2003a). This effect could possibly be explained by the predominantly type I muscle fibres in the lower Trapezius (Cools et al. 2002). The main function of predominantly type I muscles is to provide stability and postural hold (Marieb 2004). This means that the impact of torque production of the lower fibres of Trapezius during upward rotation is limited (Cools et al. 2002). This may explain why no activity of lower Trapezius had been noted in the biomechanical analysis of the swim stroke where upward rotation took place with load and high speed (Heinlein et al. 2010).

Serratus anterior and the middle fibres of Trapezius reflected deterioration from six weeks to five months. After five months the eccentric control, the ability to perform the muscle test without fatigue and the ability to perform the test with relaxed breathing showed deterioration for both groups. Although the control group still showed a significant change in the ability to perform the test without fatigue, this change should be interpreted with caution (Table 4.8, 4.11).

The first possible explanation for the deterioration noted in muscle function of Serratus anterior and middle fibres of Trapezius (Table 4.7, 4.11), from six weeks to five months, is insufficient supervision during execution of the exercises. During the first six weeks, swimmers had constantly been reminded to breathe throughout the duration of the exercise by both the researcher and the physiotherapy students under whose assistance they performed the exercises. The emphasis on eccentric control was enforced by counting out loud while performing the exercise. The counting gave guidance to the speed and control of the exercise and counting out loud forced the swimmer to breathe while doing the exercise. This deterioration emphasise the importance of feedback and good control of muscle activation during exercise (Worsley et al. 2013; Holtermann et al. 2010; Roy et al. 2009).

The second possible explanation for this deterioration could be the fact that Serratus anterior functions at 75% of its maximum strength during the entire swim stroke (Fernandez et al. 2012; Heinlein et al. 2010; Pollard and Fernandez 2004). Due to the repetitive nature of swimming, Serratus anterior needs endurance to fulfil its function of upward scapula rotation and protraction during the swim stroke. This could possibly serve as an explanation why, after five months, not all of the swimmers were able to perform the muscle test for Serratus anterior without fatigue. During the first six weeks the inner range of the muscle contraction was held for ten seconds and the exercise was repeated ten times. The aim was to strengthen the muscle in its shortened position and indirectly improve endurance. In the time frame between six weeks and five months, most of the exercises had been done without supervision. During this unsupervised period the required level of quality performance with precision, had probably not been maintained.

Optimum function of Trapezius (middle and lower fibres) and Serratus anterior are the main contributors to scapula stability (Struyf et al. 2011c). The significant change in the resting position of the scapula in the intervention group after six weeks implies significant recruitment and activation of Trapezius (middle and lower fibres) and Serratus anterior (Table 4.18).

The results of the current study can be compared to studies conducted by Worsley et al. (2013) and Roy et al. (2009). The focus of these studies was to incorporate scapula positioning and retraining of the scapula stabilisers. These studies have been discussed earlier (Table 2.11) but an important aspect to be highlighted is the significant change in scapula position after an intervention where scapular control and quality of muscle contraction formed the core focus. In the current study the focus during the intervention was on controlled muscle contraction, without any compensatory movements while breathing in a relaxed manner.

Although not all the characteristics of muscle function within the Trapezius (middle and lower fibres) and Serratus anterior muscles reflected significant changes and in some instances only on one side (Table 4.7, 4.8, 4.10, 4.11, 4.13, 4.14), the significant change in the resting position of the scapula, on the left and the right sides, had been very obvious. These bilateral more ideal positioned scapulae could be explained as a result of motor control and temporal activation (De Mey et al. 2012; Magarey et al. 2003). Cools et al. (2003a) demonstrated a delay in activation of the scapular stabiliser (Trapezius middle fibres) on the non-injured side of patients who were complaining of shoulder pain. They argued that adaptive neuromuscular changes took place that resulted in an altered activation pattern because of pain. In the current study, the swimmers had no pain, but the argument of neuromuscular changes influencing temporal recruitment patterns has been instrumental in the explanation of these changes in the scapula position. The stabilisers in the current study showed significant within group changes in the intervention group (Table 4.18, 4.25) and as a result they function as a force couple on a posteriorly tipped scapula. This resulted in an ideal temporal pattern of recruitment and resulted in a bilateral better resting position of the scapula.

The ability of the stabilisers to control scapular movement during gleno-humeral flexion within the intervention group could be seen in the significant decrease in dysrhythmia during gleno-humeral flexion (Table 4.25, 4.26, 4.27). The significant decrease in dysrhythmia within the control group can then be interpreted as optimum functioning of the Trapezius (middle and lower) and Serratus anterior muscles. The ability to fulfil the agonistic function of upward rotation and protraction but also the ability to control the scapula around multiple axes through the range of gleno-humeral flexion, engendered task specific control (Cools et al. 2013; Kibler et al. 2013; De Mey et al. 2012; Oyama et al. 2010).

Both groups reflected significant within group decrease in scapular winging. The significant change in muscle function for Serratus anterior within both groups (Table 4.7, 4.8) can explain this finding (Struyf et al. 2011b).

The control group showed significant change in tipping of the scapula after six weeks (Table 4.22). This was an unexpected finding. The muscle activation of Serratus anterior and Trapezius middle fibres improved significantly for both groups. Within the control group the lower fibres of Trapezius did not reflect any significant improvement. A possible explanation could be ascribed to the observation of the intervention group during the evaluation period. All swimmers were evaluated in the same room and in a random order. Discussion and observation could possibly lead to this unexpected finding.

After five months both groups reflected deterioration in the resting position of the scapula. Dysrhythmia and winging increased as well. Although the agonistic function of the stabilisers still showed significant change from baseline to five months the ability to control the scapula position (resting as well as dynamic) was not convincing. It is possible that a muscle can be strong, yet lacks the ability to fulfil its stability function (Magarey and Jones 2003). This deterioration could be attributed to inadequate precision during performance of the exercises and this resulted in decreased quality of muscle function.

Three other limitations of the current study should be mentioned. First, the swimmers are highly trained athletes room for improvement is limited. This might explain the limited change that was observed specifically regarding the FVC. Secondly the study was limited to one swim club in Pretoria to assure homogeneity within the training program. The disadvantage of using participants from one club was that we started off with the correct sample size, but no provision could be made for any drop outs. The third limitation pertains to limited financial resources which complicate efforts to examine the effect of the altered breathing pattern on swim stroke and breathing frequency by means of video recording. A forth limitation is that both groups were evaluated simultaneously in the same room. Although the research assistants were blinded to the group allocation of swimmers, a swimmer could observe while another was tested for muscle function and scapular positioning (resting as well as dynamic). This visual observation could have an effect on the outcome as seen in the significant change in the control group from baseline to six weeks regarding scapular tipping (Table4.22).

To summarise; the effect of lateral costal breathing exercises had a significant effect on the resting position of the scapula as well as on the dynamic scapula control, specifically on posterior tipping of competitive swimmers. In the short term the resting position reflected significantly less tipping, although on the left side only. Over five months significantly less tipping occurred in the intervention group and this improvement was evident on the left and the right side.

The influence of a movement controlled intervention that applied to the principles of motor learning was clearly noticeable in the change of PMI, altered thoracic expansion, change in muscle function and ultimately in the change of the scapula position over six weeks.

After five months it became evident that the significant increase in dysrhythmia had probably been an indication of the insufficiency regarding both supervision and feedback on the quality of exercises. However, regardless of the increase in dysrhythmia, the ability to control posterior tipping of the scapula can be seen as a result of a task specific pattern (lateral costal breathing) that was emphasized within the intervention group.

The results have been discussed and compared to the literature in this Chapter. The limitations of this study and literature have been identified. In Chapter 6 the importance of this study will be highlighted. Concluding remarks will be documented.

CHAPTER 6

CONCLUSION

Swimmers depend on accessory breathing muscles for adequate ventilation and this explains the overuse of Pectoralis minor. Adding to the ventilatory demand on Pectoralis minor is repetitive gleno-humeral flexion and medial rotation in the swim stroke that results in adaptive shortening of Pectoralis minor. The anteriorly tipped position of the scapula remains a problem and a source of dysfunction within the competitive swimmer.

The aim of this study therefore was to determine if lateral costal breathing exercises in conjunction with scapula retraining exercises had an effect on the resting as well as dynamic scapula position in competitive swimmers. The intervention was done over a six weeks period. Evaluations were done at baseline, after six weeks and after five months. The conclusion drawn from this study will be presented addressing all the objectives as set in Chapter one. The clinical contribution of this study will be highlighted followed by the contribution of this study to the body of knowledge for physiotherapists.

The most significant finding of this research was the effect of the lateral costal breathing exercises on the position of scapula tipping. The effect of a lateral costal breathing pattern in conjunction with scapular retraining exercises was seen in the resting scapula position as well as the dynamic scapula control after the 200 meter swim session. The effect of a breathing pattern was previously evaluated on the stabilisers of the trunk. This study is the first, to the authors' knowledge, to determine the effect of a lateral costal breathing pattern in conjunction with scapula retraining exercises on the scapula position. In the short term effective recruitment and activation of the stabilisers was seen in the more ideal scapula position. The effect on scapula stabiliser control during gleno-humeral flexion was evident in the long term.

The continuous increase in PMI, indicating an increase in Pectoralis minor length, demonstrates the importance of muscle balance between the agonist (lower fibres of

Trapezius) and the antagonist (Pectoralis minor). Pectoralis minor gained length because of the muscle's stretches, as previously documented. However Pectoralis minor did not show adaptive shortening as the season intensified to prepare for the national trials. This confirms the biomechanical principle that a dynamic stable base (scapula) is needed for a muscle to contract from to function optimally (Pectoralis minor). The breathing exercises contributed to better thoracic dissociation and unloaded Pectoralis minor.

The baseline values obtained from this study for PMI contradicts values reported in other studies. The values obtained in this study are applicable to competitive swimmers in South Africa and can be used in follow up studies to compare with other overhead athletes like tennis players. These values can be compared to swimmers in other swim clubs and other countries. The method of evaluation is clearly described and easy to repeat.

The effect of the lateral costal breathing pattern on the scapular stabilisers is best seen in the activation and control of the lower fibres of Trapezius. The low load retrain principle resulted in activation of the lower fibres of Trapezius. This activation of the lower fibres was possible because the scapula could tilt posteriorly, optimising retraining of the lower fibres. Although the lower fibres of Trapezius are not used agonistically within the swim stroke, ideal activation is necessary for optimum scapula positioning. This finding highlights the importance of low load retraining of the scapula stabilisers, specifically the lower fibres of Trapezius in competitive swimmers.

Fatigue of scapula stabilisers was also identified as a problem in competitive swimmers due to the high training volume. The significant changes observed in the current study after the 200 meter sprint swim session imply the scapula stabilisers could maintain their stability function even when fatigued.

Professional and clinical contribution of the study

The contribution to the professional body of knowledge is the effect of a lateral costal breathing pattern on the resting scapula position, dynamic control of the scapula as well as the scapula stabilisers. This study highlights the importance of a multi – structural approach. Soft tissue was stretched, muscle function, with emphasis on the quality of muscle function, was addressed and movement patterns (lateral costal breathing dissociation) were integrated into function and exercises.

The ***clinical contribution*** of the study**,** with regards to the field of physiotherapy, is the outcome measures that had been implemented and the baseline values obtained for PMI. The muscle function test did not only focus on the agonistic function of the muscle. The other characteristics that were also evaluated gave a better understanding to muscle function and the integration of the muscle function into posture and functional movement patterns, as seen in the resting and dynamic scapula. The baseline values obtained from this study (PMI) as well as the results obtained from the muscle function evaluation may serve as baseline information for future studies.

Evaluation techniques should be valid, affordable and clinical applicable. The landmarks that were used to evaluate the resting scapula position adhere to this criteria and it is a useful method to evaluate the three dimensional status of the resting scapula.

The ***clinical contribution***, with regards to swimmers, is twofold. In the first place the effect of the intervention on scapular tipping, the increase in Pectoralis minor length and the better function of the lower fibres of Trapezius, may contribute to the prevention of shoulder injuries in competitive swimmers. If recurrence of shoulder injuries can be limited, it could result in extension of the swimmer's career. In the second place, the increase in lower thoracic expansion (in the intervention group) may contribute to improved biomechanics of the ribs on thorax. This improved thoracic biomechanics may lead to improved trunk mobility and stability and ultimately have an influence on the swimmers' technique and performance.

I conclude that lateral costal breathing exercises can affect the scapula position in competitive swimmers in the short term. An important principle to focus on during such an intervention is ideal positioning of the scapula and good quality of muscle retraining and control. The importance of balance within the musculoskeletal system is highlighted in the study. Pectoralis minor length contributed to a posteriorly tipped and therefore to a better positioned scapula, but in return the ideal positioned scapula served as a stable base for Pectoralis minor to function from during gleno-humeral flexion. The importance of cognitive input and exteroceptive feedback during an exercise program, even for competitive swimmers, is demonstrated by the deterioration in the position of the scapula after five months.

The conceptual framework that was developed in Chapter 1 has been accepted. Recommendations from this study will be presented in Chapter 7.

CHAPTER 7

RECOMMENDATIONS

From this study the following recommendations have been made:

1. Recruitment and optimum activation of the lower fibres of Trapezius should be part of the dry land programme for swimmers. During dry land training the main focus on muscle function is to strengthen and increase endurance of the muscles. It is possible that a muscle can be classified as strong but lacks the ability to fulfil its stability function. Special care should be taken to recruit and activate the lower fibres of Trapezius without any resistance.

2. Lateral costal breathing exercises had only been facilitated during the dry land training in the current study. Integration into pool training could result in an optimal task specific breathing pattern for competitive swimmers.

3. The baseline values obtained for PMI in competitive swimmers could serve as a guideline for other studies. The baseline values can be used to compare the results from other studies conducted on swimmers nationally as well as internationally. Furthermore, the baseline values, mean and standard deviation data obtained from this study can be used to calculate the sample size of other studies on competitive swimmers. This baseline data on competitive swimmers could be compared to other overhead sport athletes, like tennis players.

4. Serratus anterior should be strengthened for its function of protraction as well as upward rotation of the scapula. In most of the training programmes the focus for Serratus anterior strengthening is protraction of the scapula. Protraction only strengthens the upper fibres of Serratus anterior. Exercises above 90° of gleno-humeral abduction should be added to the training

program. With the shoulder above 90° the lower fibres of Serratus anterior is activated. To optimise the effectiveness of Serratus anterior, muscle recruitment, strength and endurance should be addressed. As a scapula stabiliser optimum recruitment of Serratus anterior is essential to fulfil its stability function. From the literature it is evident that Serratus anterior is contracted 75% of the swim stroke and therefor focus of the training program should be on strengthening and enhancing endurance of the muscle.

5. A study could be conducted where the resting position of the scapula is evaluated, using the thirteen markers as described in this study, compared to evaluation with an electromagnetic system. The visual evaluation of the scapula is affordable and easy to perform in any clinical setting. Surface palpation of the scapula is a valid method of determining the actual position of the scapula. Comparing the resting position (determined by validated markers) to an electromagnetic system may add to the options physiotherapists have in the clinical setting, specifically next to the sport field, to evaluate the resting scapula position.

6. The resting and dynamic scapula position was evaluated after a 200 meter sprint session. The impact of lateral costal breathing exercises on the scapula stabilisers, the resting scapula position and dynamic scapular control should be evaluated after a swim training session (two hours). Two hundred meter sprint is a longer distance than most of the swimmers will swim in race, but the swimmer needs stability of the scapula during training (two hours) as well.

7. The effect of lateral costal breathing exercises in conjunction with scapular retraining exercises could be evaluated on the range of gleno-humeral motion in competitive swimmers. Swimmers have a distinct rounded shoulder posture and associated with this posture type is excessive medial rotation of the gleno-humeral joint. The result is lack of lateral rotation of the gleno-humeral

joint. A more cranially. This position of the glenoid fossa could possibly allow more lateral rotation of the gleno-humeral joint.

8. The effect of the lateral costal breathing exercises had not been evaluated on the swim stroke. It would be recommended to evaluate the effect of the breathing exercises on the stroke technique.

9. The competitive swimmers are an elite group of athletes with specific stroke techniques. The intervention could be evaluated on a group of junior swimmers with the aim of a cohort study.

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ANNEXURE 1

KEY DEFINITIONS

Abduction: Movement of the gleno-humeral joint away from the midline or axis of the body in the frontal plane about a sagittal axis (Levangie and Norkin 2001)

Adaptive shortening: Tightness that occurs as a result of a muscle remaining in a shortened position, not necessarily due to a muscle contraction (Kendall et al. 2005)

Agonistic function: Prime mover, muscle that bears the primary responsibility for effecting a particular movement (Marieb 2004)

Blow bottle: A home-made device made out of plastic and filled with tap water (Sehlin et al. 2007)

Breathing dissociation exercises: Deep breathing exercises emphasizing inspiration and dissociate between upper thoracic and lower thoracic movement (Pryor and Prasad 2008)

Concentric contraction: When a muscle shortens while contracting (Kendall et al. 2005)

Dissociation of movement: The ability to dissociate different body parts (gleno-humeral from scapulo thoracic / upper thoracic from lower thoracic) during movement (Magarey and Jones 2003)

Dynamic scapula position / control: The ability to position and control scapular movement during moving of the gleno-humeral joint (McClure et al. 2009a)

Dysfunction: Inability to function properly; functional impairment (Kendall et al. 2005)

Dyskinesis of the scapula: The presence of scapula dysrhythmia, scapula winging or scapula tipping (McClure et al. 2009a)

Dysrhythmia of the scapula: The scapula demonstrates premature or excessive elevation or protraction, non-smooth or stuttering motion during gleno-humeral elevation or lowering, or rapid downward rotation during gleno-humeral lowering (McClure et al. 2009a)

Eccentric contraction: When a muscle lengthens while contracting (Kendall et al. 2005)

Extensibility: The property of a muscle that permits it to lengthen or be elongated (Kendall et al. 2005)

Feedback: The sensory information that is available as the result of a movement that a person has produced (Shumway-Cook and Woollacott 2007)

Flexion: The act of bending a joint or limb in the body by the action of flexors (Levangie and Norkin 2001)

Forced vital capacity: The amount of air than can be forcibly exhaled from the lungs after taking the deepest breath possible (Pryor and Prasad 2008)

Frontal plane: The frontal plane divides the body into front and back halves (Levangie and Norkin 2001)

Full range of motion: The distance and direction a joint can move to its full potential (Levangie and Norkin 2001)

Horizontal abduction: Moving the gleno-humeral joint in a horizontal plane while the gleno-humeral joint is in abduction (Levangie and Norkin 2001)

Isometric contraction: Increase in muscle tension without change in muscle length (Kendall et al. 2005)

Lateral rotation: rotation of a joint away from the midline of the body in the transverse plane about a longitudinal axis (Levangie and Norkin 2001)

Length – tension relationship: The muscle length-tension relationship is the relationship between the length of the muscle fibre and the force that the muscle fibre produces at that length (Levangie and Norkin 2001)

Level 2 swimmer: A level is age, distance and stroke specific which is determined by time (refer to SwimSA.co.za)

Level 3 swimmer: A level is age, distance and stroke specific which is determined by time (refer to SwimSA.co.za)

Motor control: The ability to regulate the mechanisms essential to movement and how that movement is controlled (Shumway-Cook and Woollacott 2007)

Motor learning: The acquisition or modification of movement, an interaction of the individual with the task and the environment (Shumway-Cook and Woollacott 2007)

Muscle balance: A state of equilibrium that exists when there is a balance between the strength of opposing muscles acting on a joint, providing ideal alignment for movement and optimal stabilisation (Kendall et al. 2005)

Muscle endurance: Muscular endurance is the ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time (Levangie and Norkin 2001)

Muscle function: An integration of the correct muscle activation pattern and strength to allow optimum function (Comerford and Mottram 2001)

Muscle recruitment: Muscle recruitment is modulated by the higher central nervous system and is powerfully influenced by the afferent proprioceptive system along with many psycho-social factors (Comerford and Mottram 2012)

Muscle retraining: Occurs once muscle recruitment and timing of activation are corrected. This results in optimum function of the muscle as an agonist, synergist and antagonist (Shumway-Cook and Woollacott 2007)

Muscle strength: Refers to the amount of force a muscle can produce with a single maximal effort. Size of muscle cells and the ability of nerves to activate them are related to muscle strength (Marieb 2004; Levangie and Norkin 2001)

Muscle timing of activation: Ideal timing of activation is recruitment of a muscle in anticipation of movement (Comerford and Mottram 2012)

Normal: Confirming to a standard (Kendall et al. 2005)

Passive range of motion: Movement through available range of motion, performed by another individual without participation by the subject (Kendall et al. 2005)

Pectoralis minor index: Calculated by dividing the resting muscle length of Pectoralis minor by the subject's height and multiply it by 100 (muscle length / swimmers height x 100) (Cools et al. 2010)

Posterior axillary line: A coronal line on the posterior torso marked by the posterior axillary fold (Levangie and Norkin 2001)

Pronation: A rotational movement of the forearm at the radio ulnar joint in the transverse plane about a longitudinal axis (Levangie and Norkin 2001)

Reliable test: A test that produces the same results on successive trails (Kendall et al. 2005)

Resting Scapula position: The position of the scapula on the thoracic wall at rest (Nijs et al. 2007)

Sagittal plane: Divides the body into a left and a right half (Levangie and Norkin 2001)

Scaption: Movement of the gleno-humeral joint in a plane 45° anterior to the frontal plane (McClure et al. 2009a)

Scapulohumeral rhythm: The scapula is stable with minimal motion during the initial 30° to 60° of humeral elevation, then smoothly and continuously rotates upward during elevation and smoothly and continuously rotates downward during humeral lowering (McClure et al. 2009a)

Scapula tipping: The inferior angle of the scapula become prominent dorsally, rotating about the horizontal axis (Struyf et al. 2011b)

Scapula winging: The entire medial border of the scapula become prominent dorsally, rotation about the vertical axis (Struyf et al. 2011b)

Senior national level swimmer: A level is age, distance and stroke specific which is determined by time (refer to SwimSA.co.za)

Shoulder: Refers to the gleno-humeral joint as well as surrounding soft tissue.

Shoulder girdle: Refers to the 'girdle' which is formed by the scapula, clavicle and humerus. It includes the scapulo thoracic, gleno-humeral, acromioclavicular and sternoclavicular joints as well as surrounding soft tissue.

Stabilisers: Muscles of the body that act to stabilize one joint so a desired movement can be performed in another joint (Levangie and Norkin 2001)

Substitution: The action of muscles in attempting to function in place of other muscles that fails to perform because of weakness or pain (Kendall et al. 2005)

Task specific patterns / function: The ability to perform a task to meet the requirements of the environment and / or the task (Shumway-Cook and Woollacott 2007)

Thoracic expansion: The ability of the thorax to expand as a result of breathing (Pryor and Prasad 2008)

Trick / compensatory movement: A movement that is used to substitute the desired movement due to weakness or abnormal movement patterns (Magarey and Jones 2003)

Valid test: One that measures, quantitatively and qualitatively, what it purports to measure (Kendall et al. 2005)

ANNEXURE 2

SWIMMER'S INFORMATION LEAFLET & INFORMED CONSENT FORM FOR CLINICAL TRIAL / INTERVENTION RESEARCH

TRIAL TITLE: Effect of lateral costal breathing dissociation exercises on the position of the scapula in level two up to senior national level swimmers

INTRODUCTION

You are invited to volunteer for a research study. This information leaflet is to help you to decide if you would like to participate. Before you agree to take part in this study you should fully understand what it is and what is expected of you. If you have any questions, which are not fully explained in this leaflet, do not hesitate to ask the investigator, Elzette Korkie. You should not agree to take part unless you are completely happy about all the procedures involved. You are welcome to discuss your inclusion in this trail with your physiotherapist and coach.

WHAT IS THE PURPOSE OF THIS TRIAL?

You are a competitive swimmer. According to current research 80% of swimmers have problems with their shoulders during their swimming career. The reasons for these problems are: weak muscles, shortened muscles and abnormal movement patterns. To prevent these injuries good training and exercises of the so called stabilizing muscle are important. Although all these causes are identified and treated, shoulder problems remain the biggest joint problem for swimmers.

In this trail the emphasis is going to be on breathing exercises. A swimmer does not only use the diaphragm to breathe, he / /she uses all the other muscle that can help with breathing, as well. One of these helping muscles plays a big role in the position and work of the shoulder joint. This muscle is attached to your ribs and to your shoulder. The aim of this trail is to determine the influence of breathing exercises together with shoulder exercises on the position of the shoulder blade. You will be given an exercise to blow into a bottle (500ml Coke bottle) to teach you controlled breathing and to strengthen your breathing muscles. None of these exercises will have a negative effect on your technique or fitness. The expected outcome of this trail *may* be a better position for the shoulder joint complex and this will help you to have a better stroke technique, less possibility for the structures in the shoulder joint to be compressed and a better long volume that may help you with your breathing cycle.

WHAT IS THE DURATION OF THIS TRIAL?

If you decide to take part you will be one of approximately 72 swimmers. You will be assessed by physiotherapists and exercises will be given to you by a physiotherapist. When you are assessed the girls and ladies will be asked to wear a two piece swimsuit and the boys and men will be asked to wear a speedo so that the shoulder girdle is free to move and the muscles of the shoulder girdle are visible. The study will last from September 2012 until April 2013. The study will be carrying out as follow:

3 – 7 September 2012: Assessment

10 September 2012 – 19 October 2012: Specific exercises will be given to you three times per week. These sessions will be in consultation with your coaches.

22 -26 October 2012: Assessment

29 October 2012 – 23 November 2012: You will continue with your exercises

26 -30 November 2012: Assessment

April 2013: Final assessment

EXPLANATION OF PROCEDURES TO BE FOLLOWED

This study is about assessment and strengthening of the muscles around your shoulder and the muscles that help you to breathe. With the first assessment you will fill in a form about yourself and your swim career. You will then put on your swim suit or speedo and the assessment will begin. The first part of the assessment will be to measure the distance from your breast bone to your shoulder with a digital ruler. Then the position of your shoulder blade bone will be evaluated. To evaluate the position marks will be made on specific points with a body marker. There after the muscle strength of your shoulder girdle will be assessed for strength. You will now blow into a Spirometer which measures your lung function. The first part of the evaluation will be completed when the distance that your ribs movement during a deep inhalation is measured with a cloth tape.

The second part of the assessment is in the swimming pool. Mr Ball will take you through a warm up and then you will swim 200m freestyle.

The third part of the assessment the procedure regarding the position of the shoulder blade bone, the muscle strength and the lung function will be repeated.

HAS THE TRIAL RECEIVED ETHICAL APPROVAL?

This clinical trial protocol was submitted to the Faculty of Health Sciences Research Ethics Committee, University of Pretoria and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki (last update: October 2008), which deals with the recommendations guiding doctors in biomedical research involving human/subjects. A copy of the declaration may be obtained from the investigator should you wish to review it.

WHAT ARE YOUR RIGHTS AS A PARTICIPANT IN THIS TRIAL?

Your participation in this trial is entirely your choice and you can refuse to participate or stop at any time without stating any reason. Your withdrawal will not affect your access to other medical care. The investigator has the right to stop you from participating in the study if it is considered to be in your best interest. If it is detected that you did not give an accurate history or did nor follow the guidelines of the trial and the regulations of the trial facility, you may be withdrawn from the trial at any time.

IS ALTERNATIVE TREATMENT AVAILABLE?

Yes, you can continue with your current swim program or you can consult you physiotherapist and ask for exercises to strengthen your shoulder girdle.

MAY ANY OF THESE TRIAL PROCEDURES RESULT IN DISCOMFORT OR INCONVENIENCE?

The aim of this study is to strengthen specific muscles around the shoulder girdle. If those specific muscles of you are not strong enough you may feel stiff a day or two after the exercises. I, the investigator will be available to assist you with advice and / treatment to relief this muscle soreness.

WHAT ARE THE RISKS INVOLVED IN THIS TRIAL?

The exercises that are part of this trail may be new to you and this may cause muscle stiffness. If so, inform the investigator immediately so that she can attend to it.

INSURANCE AND FINANCIAL ARRANGEMENTS

It will cost you nothing to participate in this trail. All that will be asked from you is to bring one empty 500ml Coke bottle with, with the first evaluation in September 2012. All the other equipment will be provided (elastic bands and weights). You will not receive any compensation for your participation in this trial.

You must notify the investigator (Elzette Korkie – 082 890 1793) immediately of any research related complications, side effects and/or injuries during the trial.

SOURCE OF ADDITIONAL INFORMATION

For the duration of the trial, the physiotherapist conducting the trail will be Elzette Korkie. If at any time during the trail, you feel that any symptoms are causing any problems, or you have any questions during the trial, please do not hesitate to contact her. Elzette Korkie can contact at: 082 890 1793 / 012 3542023 / ekorkie@medic.up.ac.za / BBM pin 27C41D1F.

CONFIDENTIALITY

All the information that is gathered in this trail will not be shared with anyone. Information that may be reported in scientific magazines will not include any information which identifies you as a patient in this trial. In connection with this trial, it might be important for people in the health profession, the Faculty of Health Sciences Research Ethics Committee, University of Pretoria, as well as your personal doctor and physiotherapist, to be able to review your records of this trial.

You will be informed of any finding that may be important to your health or continued participation in this trial but this information will not be given to any other third party except those listed in the previous paragraph, without your written permission.

INFORMED CONSENT

I hereby state that I have been informed by the physiotherapist, Elzette Korkie about the type of exercises of this trail, how it will be carried out, the benefits and the risks of this clinical trial. I have also received, read and understood the above written information (Patient Information Leaflet and Informed Consent) regarding the clinical trial. I am aware that the results of the trial, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a trial report. I may, at any stage, withdraw my consent and participation in the trial and it will not count against me. I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the trial.

____________________________ ______________________ _________

Swimmer's name (Please print) Swimmer's signature Date

I, Elzette Korkie, herewith confirm that the above patient has been informed fully about the nature, conduct and risks of the above trial.

____________________________ ______________________ _________

Investigator's name (Please print) Investigator's signature Date

____________________________ ______________________ _________

Witness's name* (Please print) Witness's signature Date

VERBAL PATIENT INFORMED CONSENT (applicable when swimmer cannot read or write)

I, the undersigned, Elzette Korkie, have read and have explained fully to the swimmer, named ____ and/or his/her relative, the patient information leaflet, which has indicated the nature and purpose of the trial in which I have asked the patient to participate. The explanation I have given has mentioned both the possible risks and benefits of the trial and the alternative treatments available for his/her illness. The patient indicated that he/she understands that he/she will be free to withdraw from the trial at any time for any reason and without jeopardizing his/her subsequent injury attributable to the drug(s) used in the clinical trial, to which he/she agrees.

I hereby certify that the patient has agreed to participate in this trial.

_________________________ _____________________ ________

Swimmer's name (Please print) Swimmer's signature Date

I, Elzette Korkie, herewith confirm that the above patient has been informed fully about the nature, conduct and risks of the above trial.

_________________________ _____________________ ________

Investigator's name (Please print) Investigator's signature Date

_________________________ _____________________ ________

Witness's name* (Please print) Witness's signature Date

ANNEXURE 3

Swimmer information

Swimmer information				
Name & Surname:				
ID:		SwimSA accredited:	YES	NO
Age:	Height:	Weight:		
Stroke and participation information				
Preferred stroke style:				
Preferred distance:	Sprint	Mid distance	Distance	
Level of participation:	Level 2	Level 3	Senior national level	
Hours of practise per week:				
Coach:				
Do you participate in any other sport:	Yes	NO		
If yes, please specify:				
Medical information				
Do you suffer from any lung infection now?				
Did you fracture your shoulder or shoulder bone previously?				
Have you been diagnosed with asthma?	YES	NO		

Who diagnosed you?		
Do you use an asthma pump?	YES	NO
If yes, how regularly?		
Consent given	YES	NO
Trail number allocated to the swimmer	Coach:	Nr:

ANNEXURE 4

Evaluation process

Intervention group		**Control group**	
Baseline evaluation (12 September – 8 October 2012)			
Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position	Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position
Researcher C	Spyrometry & thoracic expansion	Researcher C	Spyrometry & thoracic expansion
Standardised warm up and 200 meter free style swim			
Researcher A	Dynamic and resting scapular position	Researcher A	Dynamic and resting scapular position
Intervention for six weeks (8 October – 16 November 2012)			
Evaluation after 6 weeks intervention (19 – 26 November 2012)			
Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position	Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position

Researcher C	Spyrometry & thoracic expansion	Researcher C	Spyrometry & thoracic expansion
Standardised warm up and 200 meter free style swim			
Researcher A	Dynamic and resting scapular position	Researcher A	Dynamic and resting scapular position
The swimmers continued with their swim programme and exercises.			
Final evaluation after five months (March / April 2013)			
Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position	Researcher A & B	Pectoralis minor length Resting scapula position Muscle function Dynamic scapular position
Researcher C	Spyrometry & thoracic expansion	Researcher C	Spyrometry & thoracic expansion
Standardised warm up and 200 meter free style swim			
Researcher A	Dynamic and resting scapular position	Researcher A	Dynamic and resting scapular position

ANNEXURE 5

Data Collection Form

Swimmer trail number:	Date:

M Pectoralis minor length: (cm)	Left:	Right:

Static scapula position		**L**	**R**
Root of scapula spine	Level to T3 projecting to T4		
Inferior angle	Below T7		
	Against thoracic wall		
Inferior angle relation to superior angle	Inferior angle should be lateral to superior angle		
Medial border position	Parallel to spine		
Acromion position	Left & right level / same height		
	Higher than superior border of the scapula		
Position of the spine of the scapula	Angled upwards		
Coracoid process position	Same height		
Clavicle position	Same height		
	Incline upwards		
Medial scapula border	Whole border against thoracic wall		
	Inferior third of border against thoracic wall		

Scapula dynamic position										
	1		**2**		**3**		**4**		**5**	
	L	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
Ideal scapulohumeral movement										
Dysrhythmia										
Winging										
Tipping										

Test of muscle function for Trapezius middle fibres		
Quality of muscle contraction	**✓ = yes** **✗ = no**	
	L	**R**
The active range of muscle contraction equals the passive range scapula retraction		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles		
Smooth eccentric control		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk		
The swimmer can hold this inner range position for fifteen seconds (two repetitions)		
The swimmer can perform the test without fatigue		
The swimmer can perform the test with relaxed breathing		

Trick movements (if applicable) (Indicate R/L)			
Scapular elevation or retraction (movement of the inferior angle or superior-medial corner superiorly)		Scapular downward rotation (movement of the acromion inferiorly)	
Gleno-humeral horizontal abduction (gleno-humeral instead of scapular movement)		Gleno-humeral adduction	
Thoracic extension			

Test of muscle function for Trapezius lower fibres		
Quality of muscle contraction	**✓ = yes** **✗ = no**	
	L	**R**
The active range of muscle contraction equals the passive range of scapula retraction and upward rotation		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles		
The swimmer can smoothly control the eccentric return		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk		
The swimmer can hold this inner range position for fifteen seconds (two repetitions)		
The swimmer can perform the test without fatigue		
The swimmer can perform the test with relaxed breathing		

Trick movements (if applicable) (Indicate L/R)			
Scapular elevation (movement of the inferior angle medially or superior-medial corner superiorly)		Scapular downward rotation (movement of the acromion inferiorly)	
Gleno-humeral extension (gleno-humeral instead of scapular movement)		Gleno-humeral adduction	
Thoracic extension or rotation			

Test of muscle function for Serratus anterior		
Quality of muscle contraction	**✓ = yes** **✗ = no**	
	L	**R**
The active muscle contraction range equals the passive range of scapula protraction		
The swimmer can hold the concentric contraction for three seconds, without trick movements of other muscles		
The swimmer can smoothly control the eccentric return		
Swimmer can perform the test without proximal fixation of the shoulder girdle or trunk		
The swimmer can hold this inner range position for fifteen seconds (two repetitions)		
The swimmer can perform the test without fatigue		
The swimmer can perform the test with relaxed breathing		

Trick movements (if applicable) (Indicate L/R)			
Thoracic flexion		Scapular winging (the medial border of the scapula not in contact with the thoracic wall)	
Scapular tipping (the inferior angle of the scapula not in contact with the thoracic wall)		Scapular elevation (movement of the inferior angle or superior-medial corner superiorly)	
Scapular downward rotation (movement of the acromion inferiorly)		Scapular depression (movement of the inferior angle or superior-medial corner inferiorly)	
Thoracic rotation			

Spyrometry test	**1**	**2**	**3**
Force vital capacity			

Thoracic expansion	**1**	**2**	**3**
Upper thoracic (cm)			
Lower thoracic (cm)			

ANNEXURE 6

PARENT/GUARDIAN INFORMATION LEAFLET & INFORMED CONSENT FORM FOR CLINICAL TRIAL / INTERVENTION RESEARCH

Trial: Effect of lateral costal breathing dissociation exercises on the position of the scapula in level two up to senior national level swimmers

WHAT IS THIS TRAIL ABOUT?

80% of swimmers suffer from shoulder injuries during their swimming career. These injuries include muscle impingement, irritation of the structures in the shoulder and muscle pain and strain. The causes for these injuries are; weak muscles, shortened muscles and abnormal movement patterns. This weakness of the muscles and shortness of other shoulder muscles result in a shoulder blade that is not in a good position. This bad position of the shoulder blade is one of the major causes of shoulder problems. To prevent these injuries good training and exercises of the so called stabilizing muscle are important. Although all these causes are identified and treated, shoulder problems remain the biggest joint problem for swimmers.

A second aspect that is addressed in this trail is the breathing pattern of swimmers. Swimmers have a very fast, high rate breathing pattern and this lead to fatigue of the diaphragm and other breathing muscles. The swimmer then depends on all the accessory (helping) breathing muscles. One of these breathing muscles is also one of the muscles that shorten very easily in swimmers. In this trail the emphasis is going to be on breathing exercises. The aim of this trail is to give exercises to stretch this muscle and strengthen the muscles around the shoulder joint. The swimmer will be given an exercise to blow into a bottle (500ml Coke bottle) to teach the swimmer controlled breathing and to strengthen the breathing muscles. None of these exercises will have a negative effect on the swimmer’s technique or fitness.

WHAT ARE THE BENEFITS AND RISKS INVOLVED IN THIS TRIAL?

The main aspect of this trial is exercises. These exercises include strengthening and stretching exercises for the muscles around the shoulder and the shoulder blade. Another component of the exercises is breathing exercises. The benefits that may come out of this program are good positioning of the shoulder blade that has a positive effect on shoulder movement and good function of the shoulder blade stabilisers that contributes directly to good shoulder movement. As earlier said the one of the main aims of this trail will be breathing exercises. The main aim of this breathing exercise is to strengthen the breathing muscles and to take the load of the accessory breathing muscles. This may lead to better long function and to help the swimmer to have ‘more breath’ when swimming.

The possible risks of this trail may be muscle soreness. Like it is with all exercises the swimmer might be stiff after the first few session because it may be a new type of exercise for the swimmer, however because the swimmer is fit the possibility for muscle pain is very little. The breathing exercises are developed to mimic the way the swimmer breathes when he / she is swimming, so it should not cause any problem or discomfort if the swimmer is diagnosed with asthma.

DISCONTINUATION OF TRIAL TREATMENT

The swimmer is free to discontinue participation from the trial at any stage.

INSURANCE AND FINANCIAL ARRANGEMENTS

There will be no cost implications for your child to participate in this trail. All that will be asked from your child is to bring one empty 500ml Coke bottle with, with the first evaluation 3 - 7 September 2012. All the other equipment will be provided (elastic bands and weights). Your child will not receive any compensation for his / her participation in this trial.

You must notify the investigator (Elzette Korkie – 082 890 1793) immediately of any research related complications, side effects and/or injuries during the trial.

If a research related injury occurs, you have not given up any of the legal rights which your child otherwise would have as a participant in this trial by signing this form.

SOURCE OF ADDITIONAL INFORMATION

For the duration of the trial, the physiotherapist conducting the trail will be Elzette Korkie. If at any time during the trail, you feel that any symptoms are causing any problems, or you have any questions during the trial, please do not hesitate to contact her. The telephone number is 082 890 1793 / 012 354 2023 and the e - mail address is ekorkie@medic.up.ac.za.

CONFIDENTIALITY

All information obtained during the course of this trial is strictly confidential. Data that may be reported in scientific journals will not include any information which identifies your child as a participant in this trial. In connection with this trial, it might be important for domestic and foreign regulatory health authorities and the Faculty of Health Sciences Research Ethics Committee, University of Pretoria, as well as your personal doctor, to be able to review your child's medical records pertaining to this trial.

Any information uncovered regarding your child's test results or state of health as a result of your child's participation in this trial will be held in strict confidence. You will be informed of any finding of importance to your child's health or continued participation in this trial but this information will not be disclosed to any third party in addition to the ones mentioned above without your written permission.

INFORMED CONSENT FOR PARENTS / GUARDIANS (on behalf of minors under 18 years old)

I hereby confirm that I have been informed by the investigator, Elzette Korkie (Physiotherapist) about the nature, conduct, benefits and risks of this clinical trial. I have also received, read and understood the above written information (Patient Information Leaflet and Informed Consent) regarding the clinical trial.

I am aware that the results of the trial, including my child's personal details regarding date of birth, initials and diagnosis will be anonymously processed into a trial report. I may, at any stage, without prejudice, withdraw my consent for my child's participation in the trial. I have had sufficient opportunity to ask questions and (of my own free will) declare my child prepared to participate in the trial.

Parent/Guardian(s) Name

______________________   _________________________   ________

(Please print)   Parent/Guardian(s) Signature   Date

Patient's Name

______________________   _________________________   ________

(Please print)   Patient's Signature *   Date

(*Minors competent to understand must participate as fully as possible in the entire procedure.)

Investigator's Name

______________________   _________________________   ________

(Please print)   Investigator's Signature   Date

Witness's Name

______________________   _________________________   ________

(Please print)   Witness's Signature   Date

VERBAL PATIENT INFORMED CONSENT (applicable when patients cannot read or write)

I, the undersigned, Elzette Korkie, have read and have explained fully to the parent,

____ and / or his/her relative, the patient information leaflet, which has indicated the nature and purpose of the trial in which I have asked the parent's child to participate. The explanation I have given has mentioned both the possible risks and benefits of the trial and the alternative treatments available for his/her child. The parent indicated that he/she understands that his/her child will be free to withdraw from the trial at any time for any reason. I hereby certify that the parent has agreed to participate in this trial.

Parent/Guardian(s) Name

____________________	______________________	________
(Please print)	Parent/Guardian(s) Signature	Date

Patient's Name

____________________	______________________	________
(Please print)	Patient's Signature *	Date

(*Minors competent to understand must participate as fully as possible in the entire procedure.)

Investigator's Name

____________________	______________________	________
(Please print)	Investigator's Signature	Date

Witness's Name

____________________	______________________	________
(Please print)	Witness's Signature	Date

ANNEXURE 7

SWIMMERS INFORMATION LEAFLET & INFORMED CONSENT FORM FOR CLINICAL TRIAL / INTERVENTION RESEARCH

Trial: Effect of lateral costal breathing dissociation exercises on the position of the scapula in level two up to senior national level swimmers

WHAT IS THIS TRAIL ABOUT?

80% of swimmers suffer from shoulder injuries during their swimming career. These injuries include muscle impingement, irritation of the structures in the shoulder and muscle pain and strain. The causes for these injuries are; weak muscles, shortened muscles and abnormal movement patterns. This weakness of the muscles and shortness of other shoulder muscles result in a shoulder blade that is not in a good position. This bad position of the shoulder blade is one of the major causes of shoulder problems. To prevent these injuries good training and exercises of the so called stabilizing muscle are important. Although all these causes are identified and treated, shoulder problems remain the biggest joint problem for swimmers.

A second aspect that is addressed in this trail is the breathing pattern of swimmers. Swimmers have a very fast, high rate breathing pattern and this lead to fatigue of the diaphragm and other breathing muscles. The swimmer then depends on all the accessory (helping) breathing muscles. One of these breathing muscles is also one of the muscles that shorten very easily in swimmers. In this trail the emphasis is going to be on breathing exercises. The aim of this trail is to give exercises to stretch this muscle and strengthen the muscles around the shoulder joint. The swimmer will be given an exercise to blow into a bottle (500ml Coke bottle) to teach the swimmer controlled breathing and to strengthen the breathing muscles. None of these exercises will have a negative effect on the swimmer’s technique or fitness.

WHAT ARE THE BENEFITS AND RISKS INVOLVED IN THIS TRIAL?

The main aspect of this trial is exercises. These exercises include strengthening and stretching exercises for the muscles around the shoulder and the shoulder blade. Another component of the exercises is breathing exercises. The benefits that may come out of this program are good positioning of the shoulder blade that has a positive effect on shoulder movement and good function of the shoulder blade stabilisers that contributes directly to good shoulder movement. As earlier said the one of the main aims of this trail will be breathing exercises. The main aim of this breathing exercise is to strengthen the breathing muscles and to take the load of the accessory breathing muscles. This may lead to better long function and to help the swimmer to have ‘more breath’ when swimming.

The possible risks of this trail may be muscle soreness. Like it is with all exercises the swimmer might be stiff after the first few session because it may be a new type of exercise for the swimmer, however because the swimmer is fit the possibility for muscle pain is very little. The breathing exercises are developed to mimic the way the swimmer breathes when he / she is swimming, so it should not cause any problem or discomfort if the swimmer is diagnosed with asthma.

DISCONTINUATION OF TRIAL TREATMENT

The swimmer is free to discontinue participation from the trial at any stage.

INSURANCE AND FINANCIAL ARRANGEMENTS

There will be no cost implications for you to participate in this trail. All that will be asked from you is to bring one empty 500ml Coke bottle with, with the first evaluation 3 - 7 September 2012. All the other equipment will be provided (elastic bands and weights). You will not receive any compensation for his / her participation in this trial.

You must notify the investigator (Elzette Korkie – 082 890 1793) immediately of any research related complications, side effects and/or injuries during the trial.

If a research related injury occurs, you have not given up any of the legal rights which you otherwise would have as a participant in this trial by signing this form.

SOURCE OF ADDITIONAL INFORMATION

For the duration of the trial, the physiotherapist conducting the trail will be Elzette Korkie. If at any time during the trail, you feel that any symptoms are causing any problems, or you have any questions during the trial, please do not hesitate to contact her. The telephone number is 082 890 1793 / 012 354 2023, the e - mail address is ekorkie@medic.up.ac.za and the BBM pin is 27C41D1F.

CONFIDENTIALITY

All information obtained during the course of this trial is strictly confidential. Data that may be reported in scientific journals will not include any information which identifies you as a participant in this trial. In connection with this trial, it might be important for domestic and foreign regulatory health authorities and the Faculty of Health Sciences Research Ethics Committee, University of Pretoria, as well as your personal doctor, to be able to review your medical records pertaining to this trial.

Any information uncovered regarding your test results or state of health as a result of your participation in this trial will be held in strict confidence. You will be informed of any finding of importance to your health or continued participation in this trial but this information will not be disclosed to any third party in addition to the ones mentioned above without your written permission.

SWIMMERS INFORMED CONSENT

I hereby confirm that I have been informed by the investigator, Elzette Korkie (Physiotherapist) about the nature, conduct, benefits and risks of this clinical trial. I have also received, read and understood the above written information (Patient Information Leaflet and Informed Consent) regarding the clinical trial.

I am aware that the results of the trial, including my personal details regarding date of birth, initials and diagnosis will be anonymously processed into a trial report. I may, at any stage, without prejudice, withdraw my consent for my participation in the trial. I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the trial.

Parent/Guardian(s) Name

______________________	_________________________	________
(Please print)	Parent/Guardian(s) Signature	Date

Patient's Name

______________________	_________________________	________
(Please print)	Patient's Signature *	Date

(*Minors competent to understand must participate as fully as possible in the entire procedure.)

Investigator's Name

______________________	__________________________	________
(Please print)	Investigator's Signature	Date

Witness's Name

_____________________	_________________________	________
(Please print)	Witness’s Signature	Date

VERBAL PATIENT INFORMED CONSENT (applicable when patients cannot read or write)

I, the undersigned, Elzette Korkie, have read and have explained fully to the swimmer,____ and/or is/her relative, the swimmers information leaflet, which has indicated the nature and purpose of the trial in which I have asked the swimmer to participate. The explanation I have given has mentioned both the possible risks and benefits of the trial and the alternative treatments available for him / her. The swimmer indicated that he/she understands that he / she will be free to withdraw from the trial at any time for any reason. I hereby certify that the swimmer has agreed to participate in this trial.

Parent/Guardian(s) Name

______________________	______________________	________
(Please print)	Parent/Guardian(s) Signature	Date

Patient's Name

______________________	______________________	________
(Please print)	Patient's Signature *	Date

(*Minors competent to understand must participate as fully as possible in the entire procedure.)

Investigator's Name

______________________	______________________	________
(Please print)	Investigator's Signature	Date

Witness's Name

______________________	______________________	________
(Please print)	Witness’s Signature	Date

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 20 Oct 2016.
* **IRB** 0000 2235 IORG0001762 Approved dd 13/04/2011 and Expires 13/04/2014.

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YUNIBESITHI YA PRETORIA
Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

Faculty of Health Sciences Research Ethics Committee
Fakulteit Gesondheidswetenskappe Navorsingsetiekkomitee

DATE: 6/09/2012

NUMBER	**163/2012**
TITLE OF THE PROTOCOL	The effect of lateral costal breathing dissociation exercises on the position of the scapula in swimmers level two up to senior national level
PRINCIPAL INVESTIGATOR	**Student Name & Surname:** Mrs Francina Korkie **Dept:** Physiotherapy; Steve Biko Academic Hospital; University of Pretoria. **Cell:** 082 890 1793 **E-Mail:** ekorkie@medic.up.ac.za
SUB INVESTIGATOR	Merle Snyckers, Carien Lourens, Marlize Cochrane, Silmara Hanekom and Steven Ball
STUDY COORDINATOR	Prof AJ van Rooijen, Mrs A Marais
SUPERVISOR	Not Applicable
STUDY DEGREE	PhD
SPONSOR COMPANY	Not applicable
MEETING DATE	5/09/2012

The Protocol and Informed Consent Document were approved on 5/09/2012 by a properly constituted meeting of the Ethics Committee subject to the following conditions:

1. The approval is valid for 3 years period [till the end of December 2015], and
2. The approval is conditional on the receipt of 6 monthly written Progress Reports, and
3. The approval is conditional on the research being conducted as stipulated by the details of the documents submitted to and approved by the Committee. In the event that a 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.

Members of the Research Ethics Committee:

Prof M J Bester	(female)BSc (Chemistry and Biochemistry); BSc (Hons)(Biochemistry); MSc(Biochemistry); PhD (Medical Biochemistry)
Prof R Delport	(female)BA et Scien, B Curationis (Hons) (Intensive care Nursing), M Sc (Physiology), PhD (Medicine), M Ed Computer Assisted Education
Dr NK Likibi	MBB HM – Representing Gauteng Department of Health) MPH
Dr MP Mathebula	(female)Deputy CEO: Steve Biko Academic Hospital; MBCHB, PDM, HM
Prof A Nienaber	(female) BA(Hons)(Wits); LLB; LLM; LLD(UP); PhD; Dipl.Datametrics(UNISA) – Legal advisor
Mrs MC Nzeku	(female) BSc(NUL); MSc(Biochem)(UCL, UK) – Community representative
Prof L M Ntlhe	MbChB (Natal) FCS (SA)
Snr Sr J Phatoli	(female) BCur(Eet.A); BTec(Oncology Nursing Science) – Nursing representative
Dr R Reynders	MBChB (Prêt), FCPaed (CMSA) MRCPCH (Lon) Cert Med. Onc (CMSA)
Dr T Rossouw	(female) MBChB (cum laude); M.Phil (Applied Ethics) (cum laude), MPH (Biostatistics and Epidemiology (cum laude), D.Phil
Dr L Schoeman	(female) B.Pharm, BA(Hons)(Psych), PhD – Chairperson: Subcommittee for students' research

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Mr Y Sikweyiya	MPH; SARETI Fellowship in Research Ethics; SARETI ERCTP; BSc(Health Promotion)Postgraduate Dip (Health Promotion) – Community representative
Dr R Sommers	(female) MBChB; MMed(Int); MPharmMed – **Deputy Chairperson**
Prof TJP Swart	BChD, MSc (Odont), MChD (Oral Path), PGCHE – School of Dentistry representative
Prof C W van Staden	MBChB; MMed (Psych); MD; FCPsych; FTCL; UPLM - **Chairperson**

DR R SOMMERS; MBChB; MMed(Int); MPharmMed.
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

♦ Tel:012-3541330 ♦ Fax:012-3541367 / 0866515924 ♦ E-Mail: manda@med.up.ac.za
♦ Web: //www.healthethics-up.co.za ♦ H W Snyman Bld (South) Level 2-34 ♦ Private Bag x 323, Arcadia, Pta, S.A., 0007

ANNEXURE 9

Consent form of model

I, ____, give consent that the photos taken may be used in the following protocol: *The effect of lateral costal breathing exercises on the scapular position in swimmers from level two up to senior national level.*

I understand that I will not receive any remuneration for these photos. I give consent that these photos may be used in presentations and publications that emanate from this study.

____

PJ Korkie

____

Parental consent

ANNEXURE 10

Feedback form

BASELINE INDIVIDUAL FEEDBACK

Test: shoulder blade	Inner side of shoulder blade against chest wall	Lower tip of shoulder blade against chest wall
At rest (Oct 2012)	Left no Right yes	Yes
At rest (Nov 2012)		

Test: shoulder blade	Movement pattern of the shoulder blade	Range of movement	Trick movement
With shoulder movement (Oct 2012)	Not ideal	Good	None
With shoulder movement (Nov 2012)			

Muscle test	Can activate muscle	Can control muscle contraction	Trick movement used
Trapezius middle fibres (Oct 2012)	Left no Right yes	No	Shoulder shrug Lacks endurance
Trapezius middle fibres (Nov 2012)			
Trapezius lower fibres (Oct 2012)	Left Yes Right no	No	Shoulder shrug Lacks endurance
Trapezius lower fibres (Nov 2012)			
Serratus anterior (Oct 2012)	No	No	Shoulder shrug Lacks endurance
Serratus anterior (Nov 2012)			

INDIVIDUAL FEEDBACK AFTER SIX WEEKS

Test: shoulder blade	Inner side of shoulder blade against chest wall	Lower tip of shoulder blade against chest wall
At rest (Oct 2012)	Yes	Left side yes Right side no
At rest (Nov 2012)	Yes	Left side yes Right side no

Test: shoulder blade	Movement pattern of the shoulder blade	Range of movement	Trick movement
With shoulder movement (Oct 2012)	Not ideal	Decreased	Yes
With shoulder movement (Nov 2012)	Much better although lower angle of shoulder blade tip with movement	Ideal	No

Muscle test	Can activate muscle	Can control muscle contraction	Trick movement used
M Trapezius middle fibres (Oct 2012)	No	No	Shoulder shrug Shoulder movement
M Trapezius middle fibres (Nov 2012)	Yes	Yes	You lack endurance
M Trapezius lower fibres (Oct 2012)	No	No	Shoulder shrug Shoulder movement
M Trapezius lower fibres (Nov 2012)	No	No	Shoulder shrug Shoulder movement
M Serratus anterior (Oct 2012)	No	No	Shoulder shrug Upper back bending
M Serratus anterior (Nov 2012)	No	No	Upper back bending

Why is ideal positioning of the scapula (shoulder blade) important?

Ideal positioning of the shoulder blade is one of the most important factors for ideal shoulder function. When the shoulder blade is ideally aligned, shoulder function can be optimized because:

1. The space between the joint ends is large enough for muscles to move through the space without being impinged.
2. The upper part (acromion) is lifted and this is very important for any overhead activities (like swimming).
3. When the shoulder joint is well aligned the muscles are in a good position (good length) and this contributes to effective and good muscle strength.

How does one obtain an ideal scapula position?

Ideal scapula position is dependant on good muscle length, ideal muscle strength and good posture. The muscles that were tested during your evaluation are the muscles that are needed to keep the scapula in good position in rest and to control the scapula position during movement.

There are three main muscle groups: the first group contributes to good joint position, the second group controls movement and the third group help us to move fast and gives us strength. Each group of muscles plays a crucial role in movement. However, if one group is weakened another group will take over BECAUSE we want to move. The group that is most prone to take over are the third group, and because they take over the role of other muscles they become overactive (muscle spasms) and shortened. The end result of muscles being shortened is joints in a non – ideal position. This has a domino effect, because some muscles are shortened, the joint is malaligned and the other muscles will have difficulty to contract effectively. The results are loss of joint range of motion and loss of muscle power. Because we want and need to move we overcome this loss of joint range and muscle power by using trick movements (when asked to take your arm above your head and there is loss of range or power you will trick (compensate) with a lower back bend).

STRETCH

Pectoralis minor stretches

- Lie on a towel roll, thick enough to keep the shoulder girdle from the surface. The towel must be aligned with your spine.
- Flattens your lower back curve against the towel and flex your shoulders and elbows to 90° above the chest, with your fore arms and palms touching.
- Lower your elbows sideways, keeping the angle between the upper arm and the chest (not dropping the shoulder to the waist) and keeping the forearm parallel to the surface.
- Pull the shoulder blades towards one another. Relax your shoulders. Hold this stretch for 30 seconds, repeat it 5 times.

EXERCISES

REMEMBER! COUNT OUT LOUD WHEN YOU DO THESE EXERCISES.

RELAX YOUR SHOULDER GIRDLE – KEEP THE DISTANCE BETWEEN YOUR SHOULDER AND EARS

Trapezius middle fibres

Category one

Starting position	End position
	

- Stand against a wall, with your feet three to five centimeters from the wall. Make ***sure your upper back is touching the wall*** and your lower back is neither touching nor in a hollow position.
- Lift your shoulders sideways to 90°, bend your elbows and place your fore arms against the wall.
- Pull your shoulder blades together.
- Your shoulders must be relaxed (***not shrugged against your ears***).
- Hold this position for ten seconds (***count loud to ten***) and repeat it for ten times.
- Once you can do the exercise without any compensation and hold the position for ten seconds ten repetitions you can do to the exercise describe for category two.

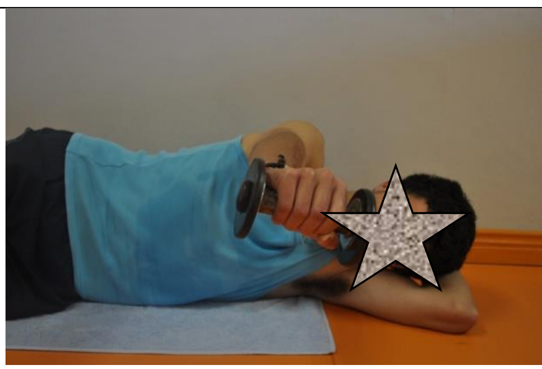
Category two

Starting position	**End position**
	

- Lie prone with the shoulder joint at 90°, elbows bend and thumbs pointing forward
- Pull your shoulder blade towards your spine (relax your shoulder muscles)
- Hold this position for ten counts (count loud) and return to the starting position in four counts
- Repeat 10 times 10

Category three

<u>Exercise 1 (use the weight as indicated to you)</u>

Starting position	**End position**
	

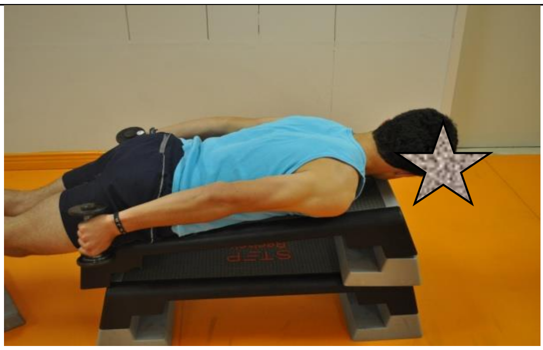
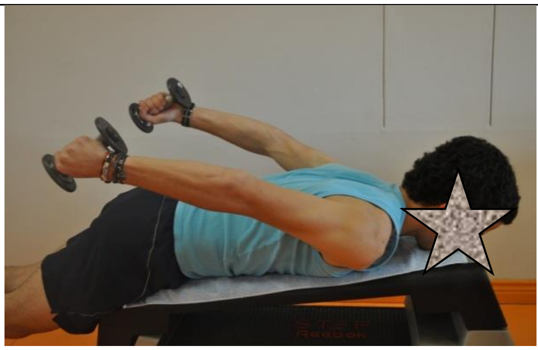
- Lie on your side with your elbow straight (remember the distance between your shoulder and your ear)
- Move your hand (weight) to be in line with your face – while counting to four (15 repetitions x 3) BREATHE!
- As you return….COUNT TO FOUR!

Exercise 2

Starting position	End position
	

- Lie on your side, upper arm on your side and elbow bend
- KEEP your elbow tucked in your side and lift the weight to the roof (COUNT TO FOUR!)
- 4 counts down – 15 repetitions x 3

Exercise 3

Starting position	End position
	

- Prone – arms by side, thumbs down
- Keep your elbows straight and lift your hands to the back – 4 COUNTS
- Return on 4 counts – 15x3

Trapezius lower fibres

Starting position	End position
	

REMEMBER TO BREATHE!!

- Lie prone, with your head on your hands and elbows diagonal (picture)
- Take the shoulder blade towards your mid back (***NO shoulder or elbow movement***)
- If it is too difficult, place a rolled face towel under your elbow and upper arm
- Your elbow should lift from the surface 3-5cm
- Hold this position for ten seconds (***count loud to ten***)
- Lower back in four counts
- Repeat 10 times
- Once you can do the exercise without any compensation and hold the position for ten seconds ten repetitions you will go on to the exercise describe for category two.

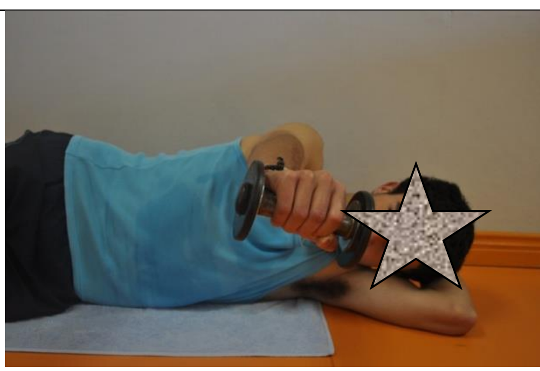
Category two

Starting position	**End position**
	

- Prone, shoulder in diagonal position – **NO SHRUGGING!**
- Take you shoulder blade diagonally down to your mid back – if this is too difficult – bend your elbow – COUNT to FOUR
- HOLD for ten counts
- Count to FOUR while returning to the starting position
- If you can do this exercises 10 times PERFECTLY – you may proceed…

Category three

Exercise 1

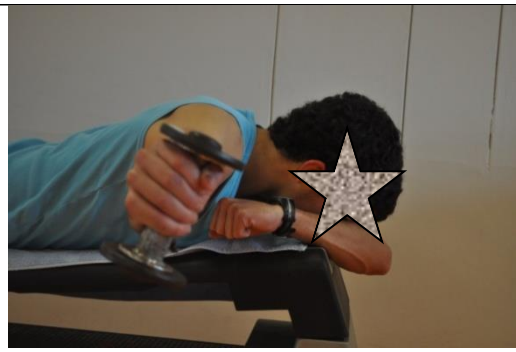
Starting position	**End position**
	

As previously describe – remember to BREATHE and to COUNT!

Exercise 2

Starting position	**End position**
	

Exercise 3

Starting position	**End position**
	

- Prone, thumb facing forward
- Lift you hand to be in line with your shoulder – THUMB facing to the roof…4 COUNTS!
- DOWN in 4 counts – RELAX…keep your shoulder out of your ear
- 15x3 repetitions

Rehabilitation of M Serratus anterior

Category one

Starting position	End position
	

- Stand one step away from a smooth wall, with the dominant foot against the wall and the non-dominant foot shoulder width apart.
- Bend both shoulders and elbows to 90°.
- Place the little finger side against the wall (**thumbs facing backwards**)
- While sliding the fore arms up against the wall in a V shape, transfer your weight to the front dominant leg.
- While sliding relax your shoulders (**NO shrugging**)
- **Count** while sliding up, hold for ten seconds, slide down on **4 seconds and repeat ten times**

Category two

Starting position	End position
	

- 4 point kneeling

- Push your chest AWAY from the FLOOR – make your shoulder blades wide - BREATHE
- If your shoulder DROPS – keep the weight on both hands – and progress to half weight on your left hand – until you manage NOT to drop
- Take your weight on your right hand – lift your left hand from the floor – you may not DROP on your right shoulder – PUSH away from the floor
- COUNT to ten – repeat ten times

Category three

Exercise 1

Push up against wall	**Classic push up**
	

- Wall push up, 4 point kneeling push up – full body push up
- Stay in 'push up' position for ten counts – LOUD – return on four counts
- 15x3 repetitions

Exercise 2

Starting position	**End position**
	

- Sit, feet supported

- Lift your hands diagonally (NOT DIRECT FORWARD) – thumbs up – elbows straight
- Keep the distance between your ears and your shoulder
- Count to four – up – count to four down
- 15x3 repetitions

Breathing exercises (CONTROL GROUP)

- Fill a 500ml Coke bottle with FRESH tap water to a mark of 10 cm.
- Insert the tube given to you.
- Inhale for 6 counts.
- Blow into the water for 4 counts (blowing bubbles)
- Repeat 5 times. 2/day

Breathing exercises (INTERVENTION GROUP)

- Fill a 500ml Coke bottle with FRESH tap water to a mark of 10 cm.
- Insert the tube given to you.
- Place the elastic band around your chest (at the level of the lower end of your breast bone).
- Inhale for six counts against the resistance of the elastic band, keeping the shoulder girdle relaxed and opened.
- Exhale for four counts, *keeping your chest wall against the elastic band for two counts.*
- Repeat 5 times. 2/day

Contact details: 082 890 1793 Elzette

Date: 11 / 7 /2012

LETTER OF CLEARANCE FROM THE BIOSTATISTICIAN

This letter is to confirm that the researcher(s)/student(s),

with the name(s) Ms ELZETTE KORKIE

Studying at the University of PRETORIA

discussed the Project with the title ______

with me.

I hereby confirm that I am aware of the project and also undertake to assist with the Statistical analysis of the data generated from the project.

The analytical tool that will be used will be ANCOVA, MIXED MODEL ANALYSIS, DESCRIPTIVE STATISTICS OF LONGITUDINAL DATA. Also refer attached section from protocol re sample size and data analysis.

to achieve the objective(s) of the study.

Name P J BECKER   Date 11/7/12

Signature ______   Tel: 012-339-8519

Department or Unit BIOSTATISTICS UNIT, MRC, PTA

MEDICAL RESEARCH COUNCIL
Biostatistics Unit
Private Bag X385
Pretoria
0001
Tel: 012 339 8523 / Fax: 012 339 8582

Official Stamp of Biostatistician
11/7/12

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

TuksAquatics

20th June 2012

To Whom It May Concern:

RE: Doctoral Study – Ms. E Korkie

This is to state that Ms. E Korkie, senior Lecturer in the Depratment Physiotherapy and myself, have been discussing her Doctoral proposal over the last few months and how this can be applied specifically to the TuksSwimmers.

This is to state that I have full knowledge of the scope of the research and will make the TuksSwimming club available for this research. Individual approval of each swimmer and parent will need to be obtained as per the ethics code, however I believe this will be more beneficial to our program and thus informed consent of the swimmers should not be a hinderance.

I am excited about this applied research within our program and look forward to developing this relationship between the department and TuksSwimming

Please feel free to contact me if you have any questions.

Yours Sincerely

Ball

Mr S. Ball

BA(HMS)(Hons)Biokinetics: CSCS(NSCA): ASCA Level 5 Coach

MANAGER: TuksAquatics

Building and Room no: TuksAquatics Complex
University of Pretoria
PRETORIA 0002
Republic of South Africa

Tel: (012) 420 6148

Fax: 086 636 4014

Email address: steven.ball@up.ac.za

www.up.ac.za

January 2015

To whom it may concern,

I, Laurette Malan, ID no. 6101150071018, hereby declare that I have thoroughly edited all the documents in constitution of the PhD thesis: *Effect of lateral costal breathing dissociation exercises on the position of the scapula in level two up to senior national level swimmers*, of FE Korkie.

Yours sincerely
Laurette Malan
MPhil (Business Ethics) (Pretoria)
BA Hons (German) (Pretoria)
BA Ed (Pretoria)
Mobile: +971 554704284