Freestyle Biomechanics and Shoulder Injuries in Competitive Swimming

LOUIS GEORGE DU PISANI

In fulfilment of the degree

MAGISTER ARTIUM

(Biokinetics)

in the

Faculty of Humanities

(Department of Exercise and Sport Sciences)

at the

University of the Free State

Study Leader:

Prof. F.F. Coetzee

BLOEMFONTEIN

January 2018

DECLARATION

THESIS TITLE:

Freestyle Biomechanics and Shoulder Injuries in Competitive Swimming

I, Louis George du Pisani, declare that the Master's Degree research dissertation that I herewith submit for the Master's Degree qualification at the University of the Free State is my independent work, and that I have not previously submitted it for a qualification at another institution of higher education.

SIGNATURE: Pisani

DATE: **5 January 2018**

ACKNOWLEDGEMENTS

I would like to thank the following people for their contributions to this dissertation through their assistance in the data collection and analysis:

- My Heavenly Father, for the grace and mercy to finish this work.
- My promoter, Prof. Derik Coetzee, I am eternally grateful to you for your supervision. Your assistance, guidance and input in this dissertation are greatly appreciated. Without you this would not have been possible.
- Prof. Robert Schall, University of the Free State, for your input and statistical support. I am truly grateful.
- Marco Markgraaff, who made all his resources and club available for this study.
- This study would not have been possible without the consent of the swimmers, for who I have great respect and feel much gratitude.
- My family, in particular my wife and father, for giving me continuous support during this research.

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Abstract

Introduction: Epidemiologic studies have consistently noted a high incidence and prevalence of shoulder pain and dysfunction in competitive swimmers. The reasons for this are probably not singular but many injuries originate from faulty techniques or mechanisms. Some specific freestyle technical flaws heavily stress the shoulders and can lead to overuse. An assessment of an injured swimmer's biomechanics should be conducted to identify factors that may contribute to injury. Improving stroke technique should be considered to prevent shoulder injuries.

Objectives: To determine the prevalence of shoulder injuries at the University of the Free State's swimming club (Kovsie Aquatics) during the 2014/2015 swimming season, and to investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries under these swimmers exist.

Methods: Sixteen competitive swimmers (6 male, 10 female) adhering to the inclusion criteria participated in the study. Demographic data, general swimming information, data on swim training load and shoulder injuries were collected. All participants were subjected to laboratory testing, followed by Aquanex+Video testing while sprinting freestyle over 10 metres. Freestyle biomechanics was analysed with the use of an analysis template. Data captured by the Aquanex+Video hand sensors were processed and analysed. The association between binary risk factors and the binary variable "shoulder injury" was assessed using Fisher's exact test, and the relevant P-value is reported. Furthermore, the risks of injury for subjects with the risk factor, and subjects without the risk factor are reported, together with an estimate and an exact 95% confidence interval (CI) of the risk ratio (RR). Similarly, the association between quantitative risk factors and shoulder injury was assessed using one-way ANOVA.

Results: In this study 62.5% of the participants presented with a shoulder injury during the 2014/2015 swimming season. Eighty percent of the female swimmers in this population presented with a shoulder injury, compared to 30% of the male swimmers. The 17 to 18 years age category seemed to be most susceptible to injury, with 75% of the swimmers in this age category presenting with a shoulder injury. Bilateral shoulder injuries were experienced by 70% of the injured swimmers, while 20% experienced symptoms on the right side only, and 10% only on the left side. Sixty percent of the injured participants experienced their symptoms only during the early pull through phase while 10% of the swimmers experienced symptoms only during the recovery phase. Thirty percent of the swimmers experienced symptoms during both the early pull through and recovery phase. Although none of the risk factors investigated in this study was statistically significant, the presence of the following freestyle pathomechanics increased the risk of shoulder injury, and should be considered in future research of this problem:

1. A right hand that crosses the midline upon hand entry;
2. Thumb first hand entry;
3. A left hand entering between the midline of the body and the shoulder Hand/Arm position where the shoulder is in hyperflexion with the fingers facing upward at the end of the entry phase;
4. Hand position outside the elbow during the early pull through phase;
5. Swimming ‘catch-up’ stroke.

Conclusion: In the current study the prevalence of shoulder injuries is alarmingly high at 62.5%. Female swimmers seem to be at a higher risk for shoulder injuries than their male counterparts. A relationship between certain freestyle pathomechanics and shoulder injuries in this population might exist, and some potential risk factors were identified. Due to the relatively small sample size of this study none of the risk factors for shoulder injury based on freestyle pathomechanics was statistically significant, thus only indications and directions for future research can be suggested.

Key words: **Freestyle Biomechanics, Shoulder Injuries, Competitive Swimming**

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1 CHAPTER ONE: Introduction and Problem Statement

1.1 Introduction

Swimming is a unique sport that combines upper and lower extremity strength exercises with cardiovascular training in a non-weight bearing environment (Wanivenhaus *et al*., 2012). Competitive swimmers begin their swimming careers as early as age seven, and most of them train and compete year round (Sein *et al*., 2010). Intensive training starts early, typically at the age of eight to eleven years, and the amount of training can be excessive (Bak, 2010).

Swim training involves repetitive overhead movement (Sein *et al*., 2010). During freestyle, 80% of the propulsion power is derived from the pull and 20% from the kick (King, 1995). In a competitive training program a swimmer can easily log up to a million arm strokes per year (McMaster, 1999), and can exceed 4000 strokes for one shoulder in a single workout, making swimming a common source of shoulder pathology (Tovin, 2006).

Epidemiologic studies have consistently noted a high incidence and prevalence of shoulder pain and dysfunction in competitive swimmers with the prevalence reported to be between 12% and 91% (Beach *et al*., 1992; McMaster *et al.,* 1998; Puckree & Thomas, 2006; Bansal *et al*., 2007; Wolf *et al.,* 2009; Sein *et al*., 2010; Tate *et al*., 2012) and incidence between 10% and 69% (Beach *et al., 1992;* McMaster & Troup, 1993). Repetitive micro trauma or overuse account for most injuries in swimming athletes, and with successful management usually do not require surgical intervention (McMaster, 1996).

McMaster (1999) further stated that shoulder pain is not only the most common complaint for swimmers it also has a high potential to have an impact on a swimmer's ability to compete. It has been suggested that swimmers with interfering shoulder pain might not progress in training and will therefore not compete as effectively (McMaster & Troup, 1993), and injuries to the shoulder can be devastating (McMaster, 1999). Shoulder problems under the swimming population resemble that of the disabled thrower's shoulder, but the clinical findings associated dysfunctions are not quite the same (Bak, 2010). Swimmers with shoulder pain should therefore be evaluated and treated as a separate clinical entity, aimed toward underlying pathology and dysfunction (Bak, 2010).

1.2 Problem Statement

The reasons for the high incidence and prevalence of shoulder injuries under swimmers are probably not singular, and as result there seems to be no single identifiable clinical entity of ‘swimmer’s shoulder’ (McMaster, 1996). Although there is a substantial amount of information on risk factors for shoulder injuries in swimmers, up to date information on the correlation between specific freestyle stroke biomechanics and shoulder injuries seem to be few and wide spread.

1.3 Objectives of the Study

McMaster (1996) postulated that many injuries originate from faulty techniques or mechanisms, and an assessment of injured athletes’ biomechanics must be made to identify factors that may contribute to injury.

From of the literature freestyle pathomechanics correlating with shoulder injury include:

- Hand entry:
    - that crosses the midline of the long axis of the body *(Johnson et al.*, 2003);
    - further from the midline and thus lateral to the shoulder (Scovazzo *et al.,* 1991);
    - with the thumb first (Johnson *et al.,* 2003);
- Shoulder hyperflexion at the end of hand entry (Yanai & Hay, 1998; Yanai *et al.*, 2000; Becker & Havriluk, 2012);
- A dropped elbow during the early pull through phase (Yanai & Hay, 1998);
- An inability to generate force during the late pull through phase causing an increase in force development during the vulnerable early pull through phase of the contralateral arm (Pink & Tibone, 2000);
- Swimming catch-up stroke (Becker & Havriluk, 2012).

Therefore, the objectives of this study are to:

1. Determine the shoulder injury prevalence at the University of the Free State's swimming club (Kovsie Aquatics), during the 2014/2015 swimming season.
2. Investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries amongst swimmers from the latter swimming club exist.

1.4 Hypothesis

The hypothesis for this study is:

- There is a correlation between certain freestyle biomechanical hand and arm positions (pathomechanics) and shoulder injuries amongst swimmers from the Kovsie Aquatics swimming club.

2 CHAPTER TWO: Literature Review

The high volume of training involved in competitive swimming result in cumulative overload injuries (Rodeo, 1999). Competitive swimmers practice 6 to 7 days a week and swim on average between 10 000 and 14 000m each day (Sein *et al.*, 2010). Most injuries and complaints encountered in swimming athletes are repetitive micro trauma or overuse, and successful management does not usually require surgical intervention (McMaster, 1996).

2.1 Epidemiology of Injuries

Swimming has a distinct profile of injuries and medical conditions (Kammer *et al.,* 1999). Common problems seen among swimmers include 'swimmers shoulder', an overuse injury that causes inflammation of the supraspinatus and/or the biceps brachii tendon (Kammer *et al.*, 1999). Measurement of prevention of sports injuries cannot be done in isolation. They form part of what might be called a 'sequence of prevention' (Figure 2-1; van Mechelen *et al.*, 1992).

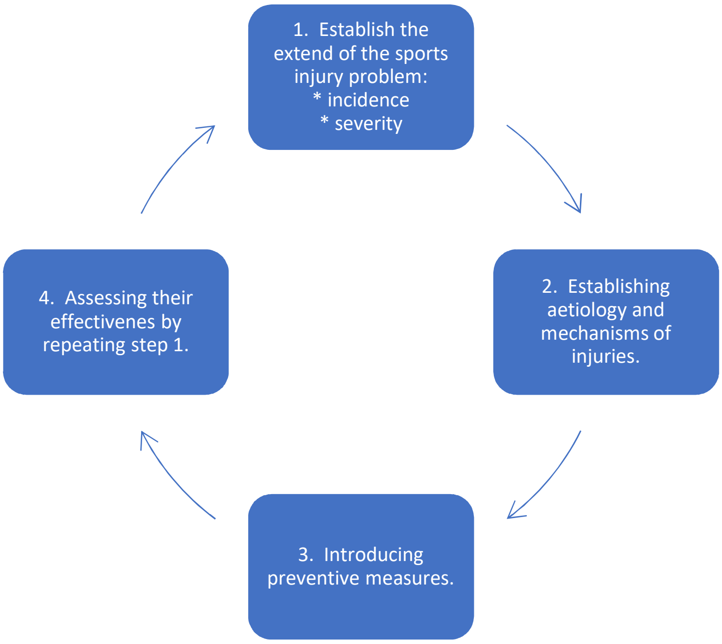


Figure 2-1 The sequence of prevention of sports injuries

According to van Mechelen *et al.* (1992) the problem should firstly be identified and described in terms of incidence and severity of sports injuries. Then the factors and mechanisms that play a part in the occurrence of sports injuries should be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of sports injuries. The measure should be based on the aetiological factors and the mechanisms as identified in the second step. Finally, the effect of the measure must be evaluated by repeating the first step (Van Mechelen *et al.,* 1992)

2.2 The Prevalence and Incidence of Shoulder Injuries in Freestyle

Four strokes are recognized in competitive swimming: freestyle, butterfly, backstroke, and breaststroke (Wanivenhaus *et al*., 2012). Regardless of the stroke performed in competition, swimmers spend a considerable time swimming freestyle (Wanivenhaus *et al*., 2012). Kammer *et al*. (1999) enumerated that irrespective of the swimmers' speciality, 75% to 90% of training is done in freestyle.

An exceptionally low prevalence (3%) of shoulder pain was reported in competitive Canadian swimmers (Kennedy & Hawkins, 1974). More recent studies reported the prevalence and incidence of shoulder injuries ranging from 17% to 91% (Beach *et al.*, 1992; McMaster & Troup, 1993; McMaster *et al.,* 1998; Puckree & Thomas, 2006; Bansal *et al*., 2007; Wolf *et al.,* 2009; Sein *et al*., 2010; Tate *et al*., 2012).

Wolf *et al.* (2009) not only found freestyle to be the most common stroke, it was also associated with the highest total number of injuries in their five-year survey of 94 National College Athletic Association (NCAA) Division I swimmers from the University of Iowa. The region most often injured by both male and female swimmers, was the shoulder and upper arm, which accounted for 31% and 36% respectively of the injuries in each group. Shoulder injuries were the most frequent injury to result in lost time (Wolf *et al.*, 2009).

In a cross sectional study done on a group of 80 elite swimmers, 43 (54%) reported unilateral shoulder pain, and 30 (37%) others reported bilateral shoulder pain (Sein *et al*., 2010). Thus 73 (91%) of the swimmers included, presented with shoulder pain and only the remaining seven swimmers (9%) stated they had no shoulder pain. Thirty five per cent of the swimmers specialized in freestyle and ninety per cent of the 80 swimmers spent more than 50% of their training time in freestyle (Sein *et al.,* 2010). The authors concluded that the injury risk for shoulder pain doubled if swim training exceeded 15 hours per week, and swimmers were four times as likely to have shoulder pain if swimming distance topped 35 km per week (Sein *et al*., 2010).

Sixty-four per cent (64%) of the usable respondents' questionnaires, from Kwazulu Natal South Africa, reported actual shoulder injuries (Puckree & Thomas, 2006).

These included impingement, supraspinatus and bicipital tendonitis, bursitis and muscle strain (Puckree & Thomas, 2006). The majority (70%) of the swimmers attributed their injuries to freestyle, which they swam most of the time (Puckree & Thomas, 2006). Similar to the results above, Beach *et al.* (1992) indicated that 87% of their 32 Division I swimmers experienced shoulder pain in their lifespan, while 69% experienced some degree of shoulder pain at the time of this study. Thirty one percent of the swimmers reported shoulder pain that was affecting their swimming ability (Beach *et al.,* 1992).

Bansal *et al*. (2007) found a prevalence of shoulder impingement syndrome at 17% in their study of 161 male competitive swimmers. McMaster and Troup (1993) concluded that an incidence of about 10% in age group swimmers, 13% of senior development swimmers and 26% of the elite team swimmers experienced current interfering shoulder pain. The prevalence of a shoulder injury seems to be higher at 47% for age group, 66% for senior development and 73% for elite (McMaster & Troup, 1993). Thirty five percent (14 swimmers) noted significant interfering shoulder pain to be present at the time of assessment in their study on 40 senior national and elite swimmers (McMaster *et al.,* 1998).

The inconsistent findings may be due to the different study designs used (retrospective vs. prospective), and the definition of the severity of the injury. For instance, Wolf *et al.* (2009) defined an injury as: "...any musculoskeletal problem suffered as a consequence of team related activity that resulted in a visit to an athletic trainer or physician", whereas McMaster and Troup (1993) defined a shoulder injury as: "that which interfered with training or progress in training as opposed to post exercise muscle soreness". Notwithstanding, the high incidence and/or prevalence of shoulder injuries in swimmers, the literature is beset with controversy surrounding its aetiology.

2.3 Aetiology of Overuse Injuries

Overuse injuries are thought to be the predominant injury type in sports that involve long, monotonous training sessions, for example, cycling, swimming and long-distance running, as well as in technical sports that involve the repetition of similar movement patterns such as throwing and jumping (Clarsen *et al*., 2013).

2.3.1 Definition of an Overuse Injury

In the consensus statements, an overuse injury is defined as “an injury caused by repetitive microtrauma, without a single identifiable event responsible for the injury” (Fuller *et al*., 2006). Bahr (2009) reported that overuse injuries have also been defined as ‘gradual onset injuries’, while Knight (2008) defined overuse injuries as: “Injuries caused by low-intensity forces of long duration.” The classification of acute and overuse injuries is simple in most cases, but sometimes it may not be that obvious (Bahr, 2009). Occasionally symptoms may have a sudden onset, but in actuality the injury is a result from a long-term process. Bahr (2009) further remarked the cause of overuse injuries to be repetitive low-grade forces exceeding the tolerance of tissues. Figure 2-2. Profile of chronic micro traumatic soft tissue injuryillustrates the pathological process that is often under way for a period of time before the athlete notices the symptoms (Leadbetter, 1992). If this process continues, the ability of the tissue to repair and adapt, can be exceeded, resulting in a clinical overuse injury with symptoms (Bahr, 2009).

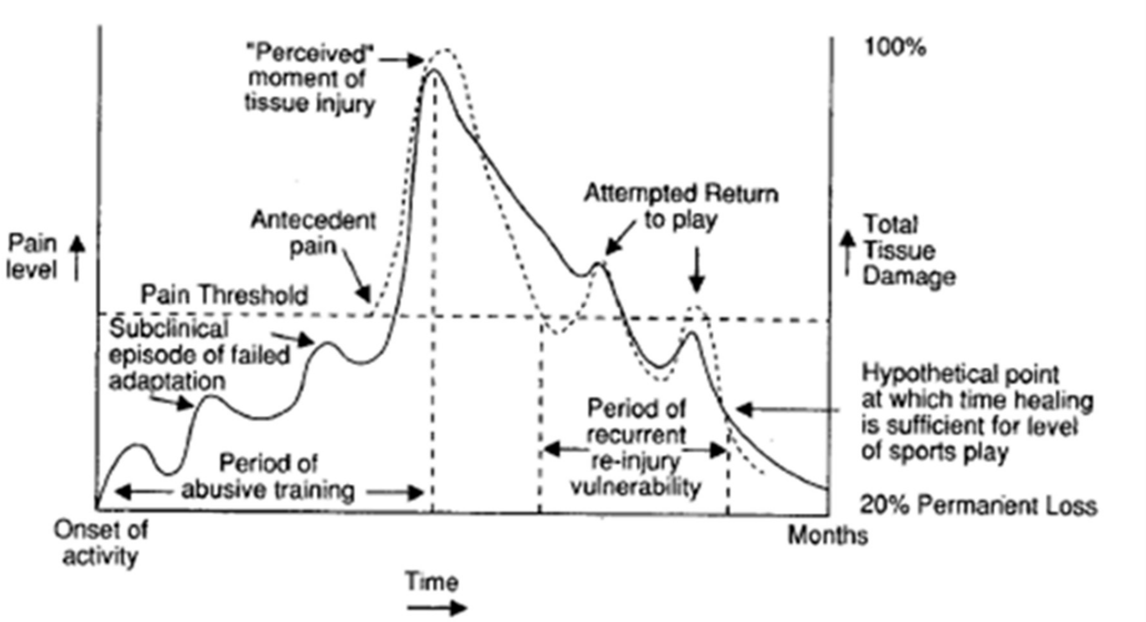


Figure 2-2. Profile of chronic micro traumatic soft tissue injury (Leadbetter, 1992)

According to Fredberg and Stengaard-Pedersen's (2008) review article it seems possible that tendons have a baseline mechanical strength, which are dependent on the loading history of the tendon (training level). Abate *et al*. (2009) remarked that exercise increases the strength of the tendon, but when the individual threshold is overcome, micro-damage may occur. The tendon may not be able to adapt fast enough after a rapid increase in training load, frequency, or duration (Fredberg & Stengaard-Pedersen, 2008) or have inadequate recovery time (Abate *et al.*, 2009). The mechanical strength of the tendon may be exceeded, and a small injury may occur. As a normal part of tendon remodelling and under normal circumstances, this small injury will heal (Fredberg & Stengaard-Pedersen, 2008). If the training and overloading continues, these small injuries result in progressive tendon changes that, after an asymptomatic period of several months, slowly aggravate and finally reach the pain limit and become symptomatic as depicted in Figure 2-3 (Fredberg & Stengaard-Pedersen, 2008).

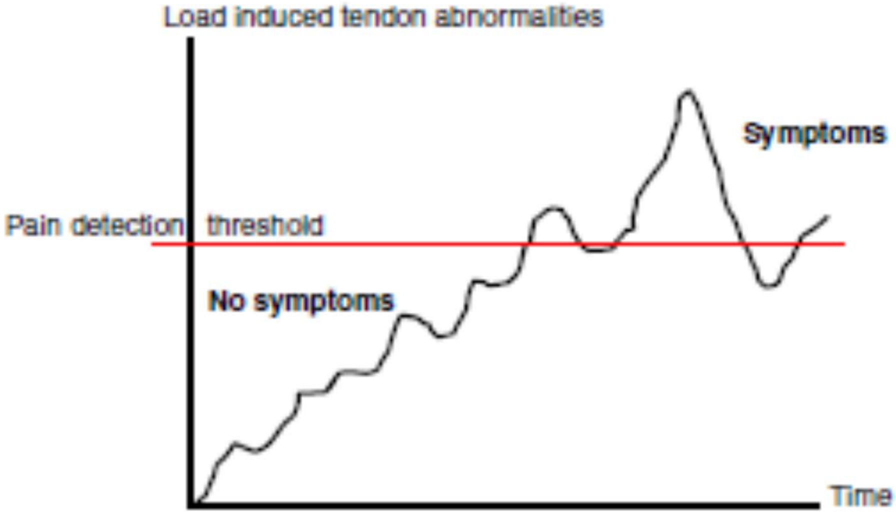


Figure 2-3. The 'Iceberg' Effect (Fredberg & Stangaard-Pederson, 2008)

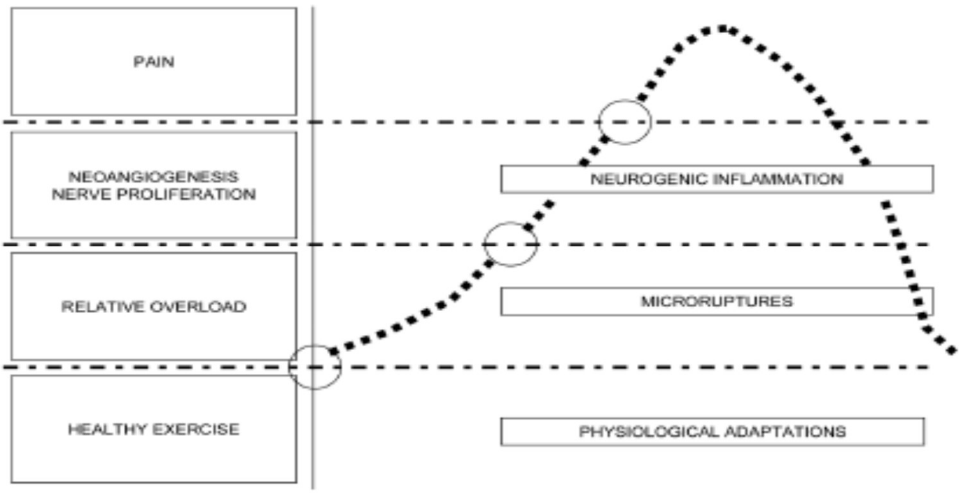


Figure 2-4. The 'Iceberg' Effect

Abate *et al.* (2009) contends that a very thin line divides healthy and non-healthy physical exercise (Figure 2-4). When athletes resume sporting activities after an inadequate rehabilitation period, during which pain recedes to just below the detection threshold while most of the intra-tendinous abnormalities still exist, the ‘iceberg theory’ explains the frequent relapse of symptoms.

2.4 Overuse Shoulder Injuries in the Swimming Shoulder

Overuse injuries occur mostly in endurance sports that require long training sessions and include monotonous routine (such as swimming, long-distance running, cycling and cross-country skiing), and in more technical sports, which include a large number of repetitive movements of same kind (i.e. tennis, high jumping and weight lifting), (Bahr, 2009).

Swim training involves repetitive overhead movement (Sein *et al.*, 2010). In a competitive training program a swimmer can easily log up to a million arm strokes per year (McMaster, 1999) and can exceed 4000 strokes for one shoulder in a single workout, making swimming a common source of shoulder pathology (Tovin, 2006). Most of the swimming propulsive force is derived from the arms, with the legs adding stabilization as well as propulsive force (McMaster, 1996). King (1995) suggests that 80% of the propulsion power is derived from the pull and 20% from the kick during freestyle. Considering the above, it is not surprising that repetitive micro trauma or overuse account for most injuries in swimming athletes (McMaster, 1996), but not all swimmers who train under similar conditions develop significant interfering shoulder pain. The reasons for this are probably not singular, and as result there seems to be no single identifiable clinical entity of ‘swimmer’s shoulder’ (McMaster, 1996).

2.4.1 Causes of Shoulder Pain in Swimmers

According to Sein *et al*. (2010) a clear consensus as to the cause of shoulder pain in swimmers is lacking. Bak (2010) stated that the significant challenge lies in identifying which of the following is the root cause of shoulder injuries: scapular dysfunction, anterior instability, or tendinopathy. Sein *et al*. (2010) nominated supraspinatus tendinopathy (i.e. supraspinatus tendinosis or tendonitis) as another candidate cause of swimmer’s shoulder.

Contrary to this ‘one factor as the root cause’ approach, Meeuwisse (1994) suggested a multifactorial approach (Figure 2-5) to advance the understanding of athletic injury, and could be used to assess the aetiology or causation thereof. This multifactorial model attempted to account for the interaction of multiple risk factors, both internal/intrinsic and external/extrinsic (Meeuwisse *et al*., 2007). It highlighted the importance of examining intrinsic predisposing factors as well as extrinsic factors that interact to make an athlete susceptible to injury, before an injury-inciting event occurs (Meeuwisse *et al*., 2007).

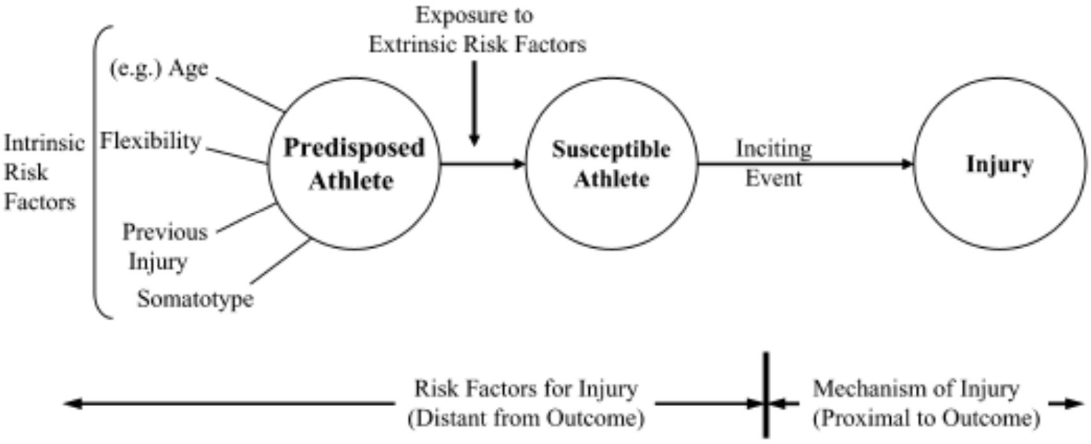


Figure 2-5. Multifactorial model of athletic injury aetiology

Bahr and Krosshaug (2005) noted that especially for overuse injuries, the inciting event can sometimes be distant from the outcome. As an example, for a stress fracture in a long distance runner, the inciting event is usually not the single training session when pain became evident (referring to Figure 2-5), but the training and competition programme he or she has followed over the previous weeks or months (Bahr & Krosshaug, 2005). Until a complete description is available which includes information on all the contributing factors, it may be difficult to predict which factors may be modifiable through intervention (Bahr & Krosshaug, 2005).

After considering all of the above it seems logical that a critical step in the sequence (Figure 2-1) is to establish the causes (Bahr & Krosshaug, 2005). According to the latter authors this includes obtaining information on why a particular athlete may be at risk in a given situation (i.e. identify modifiable intrinsic and extrinsic risk factors), and how injuries happen (injury mechanisms/inciting events).

Bahr and Krosshaug (2005) used Meeuwisse's multifactorial model and applied it to Anterior Cruciate Ligament and therefore acute injuries (Figure 2-6).

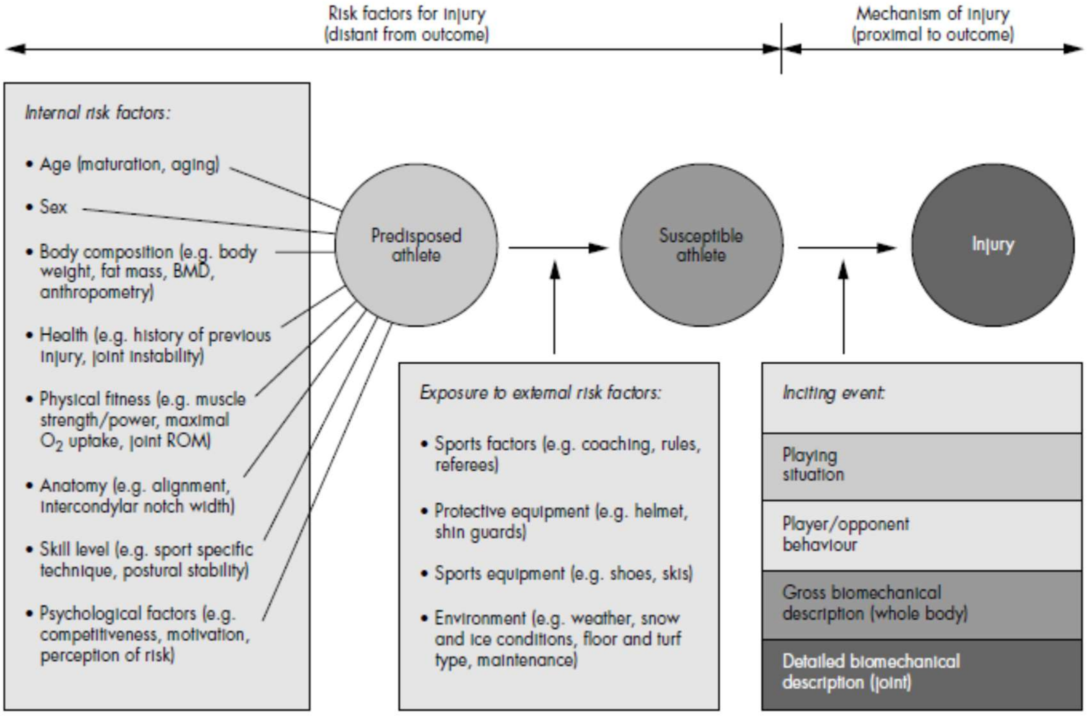


Figure 2-6. Comprehensive model for injury causation
(BMD - Body Mass Index; ROM - Range of Motion)

Meeuwisse *et al*. (2007) elaborated on these previous models, and proposed an updated version. In a real-life sporting environment, a participant's risks are dynamic and can change frequently, where one exposure can alter an athlete's intrinsic risk factors and change their predisposition to injury (Meeuwisse *et al*., 2007). The athlete can then be exposed to the same or different extrinsic risk factors and have a different susceptibility (Meeuwisse *et al*., 2007). This paints a recursive picture where an athlete can enter a given athletic event cyclically with a differing set of risk factors even though most other elements of the athlete and playing environment may remain constant (Meeuwisse *et al*., 2007).

In 2007 the model seen in Figure 2-7 was proposed by Meeuwisse *et al*. (2007). It is recursive in that one exposure can alter risk factors and allow the athlete to cycle through the model repeatedly. Aside from the possibility of retirement from sport, this model can be seen to operate independent of outcome (Meeuwisse *et al.,* 2007).

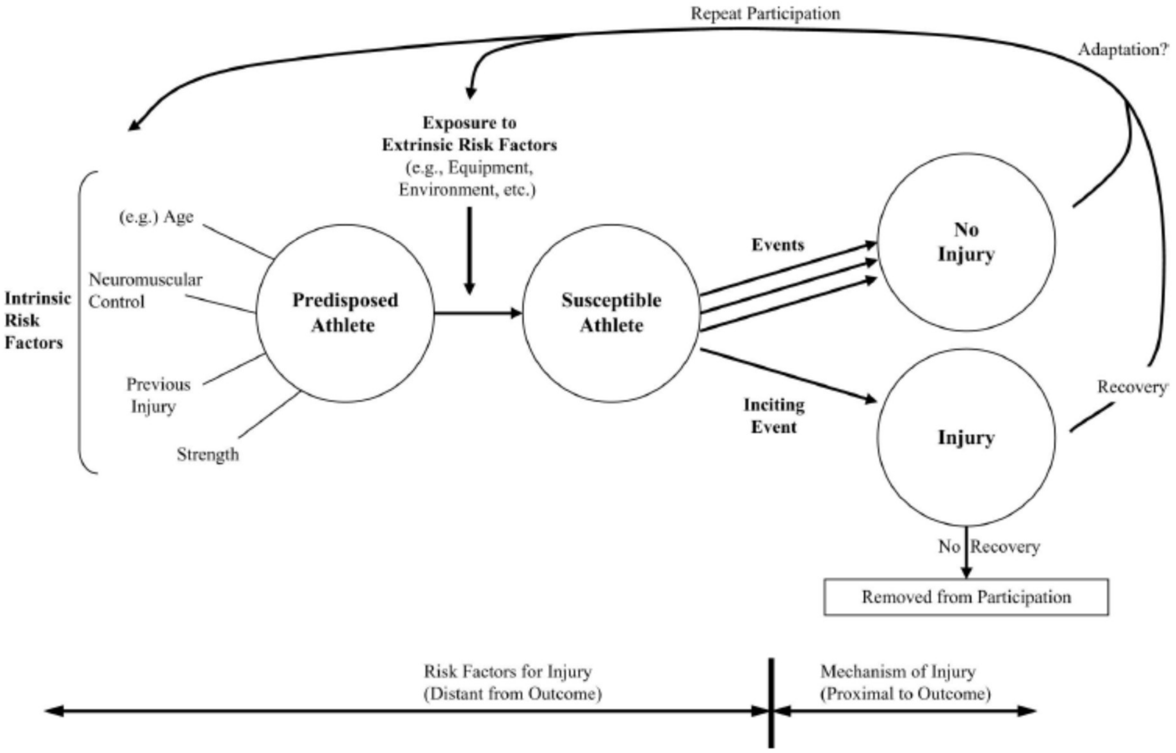


Figure 2-7. A dynamic recursive model of the aetiology of sport injuries

The contributing modifiable and non-modifiable risk factors (both internal and external) in swimming can be illustrated by adopting and modifying the model proposed by Meeuwisse *et al.* (2007). This will illustrate the contribution and interaction of these risk factors in terms of shoulder injuries in swimmers and enable the healthcare professional to identify risk factors and manage modifiable risk factors. By means of elimination the best management strategy of the shoulder injury and injury risk can be facilitated.

2.5 Defining the Term 'Swimmer's Shoulder'

The term “Swimmer’s Shoulder” was first introduced by Kennedy and Hawkins in 1974 (Kennedy & Hawkins, 1974). This term has been applied to a variety of complaints involving pain in the shoulders of competitive swimmers without specific reference to cause (McMaster *et al*., 1998). According to Allegrucci *et al*. (1994) ‘Swimmer’s Shoulder’ can be related to pathology of the acromioclavicular joint, rotator cuff, long head of the biceps brachii, glenoïd labrum, or any form of shoulder instability. Brushøj *et al.* (2007) added that this term covers a variety of pathologies including labral wearing and sub-acromial impingement. Tovin (2006) suggested that ‘swimmer’s shoulder’ is a musculoskeletal condition that results in symptoms in the area of the lateral aspect of the shoulder, sometimes confined to the subacromial region.

Conversely, Van Dorssen *et al*. (2014) suggested that this term is nondescript and a confusing catch all term which does not really advance our understanding. The latter authors further contended that this term ought to be replaced by an individualised and more specific diagnosis. It should account for individual contributing factors (intrinsic and extrinsic) and suspected pathology of each injured swimmer. This will allow for a clearer approach and tailored treatment (van Dorssen *et al*., 2014).

Pink and Tibone (2000) suggested that global pain experience by swimmers has led clinicians to make global diagnoses, such as swimmer’s shoulder. They attribute the creation of this catch all term to the delay of the swimmer to report the injury as soon as symptoms are experienced. Failing to do this causes inflammation to set in, causing a more global pain, and masking the inciting symptoms (Pink & Tibone, 2000). The reaction to this was non-specific treatment with limited success as demonstrated by the fact that more than half of shoulder injuries in swimmers recur (Pink & Tibone, 2000).

2.6 Pathologies Associated with ‘Swimmer’s Shoulder’

Allegrucci *et al*. (1994) suggested that although the term ‘swimmer’s shoulder’ is not an accurate clinical diagnosis, it discloses the fact that swimmers place high demands on their shoulders. The following section outlines pathologies associated with ‘swimmer’s shoulder’.

2.6.1 Subacromial Impingement

The impingement of subacromial structures has been proposed as a major cause of shoulder problems that often occur among freestyle swimmers (Yanai & Hay, 1998). Impingement refers to the mechanical phenomenon in which contact between the greater tuberosity of the humerus and the acromial arch creates compressive force on the sub-acromial structures (Brushøj *et al.*, 2007). Shoulder impingement and instability are two of the most common dysfunctions discussed in overhand athletes according to Allegrucci *et al.* (1994). Primary impingement can be defined as impingement caused by outlet stenosis in the subacromial space in a stable shoulder (Sorenson & Jorgenson, 2000). However, Wanivenhaus *et al.* (2012) explained that impingement in the competitive swimmer is typically caused by altered kinematics due to muscle fatigue or laxity rather than subacromial pathological changes, which are observed in other patient populations. This secondary form of impingement can be defined as impingement secondary to glenohumeral instability (Sorenson & Jorgenson, 2000).

Subacromial or intra-articular impingement may occur in various positions during the swimming stroke (Wanivenhaus *et al.*, 2012). In the case of subacromial impingement, the bursal surface of the rotator cuff impinges against the anteroinferior acromion, while in intra-articular impingement, the rotator cuff tendons and/or biceps tendon impinges on the anterosuperior glenoid and labrum (Wanivenhaus *et al.*, 2012).

2.6.2 Supraspinatus Tendinopathy

Swim volume-induced supraspinatus tendinopathy with associated supraspinatus tendon thickening may be an intrinsic factor for development of swimmer’s shoulder (Sein *et al.*, 2010).

2.7 Risk Factors

Given the prevalence of shoulder injuries under swimmers, numerous risk factors for shoulder injury in swimmers are proposed in the literature (van Dorssen *et al*., 2014).

Risk factors in sport are any factors that may increase the potential for injury (Emery, 2003). Risk factors may be intrinsic (age, conditioning etc.) or extrinsic (weather, field, conditions etc.) to the individual participating in the sport (Emery, 2003). The latter author further explained that modifiable risk factors refer to those that have the potential to be altered to reduce injury rates. Risk factors that cannot be altered are referred to as non-modifiable risk factors and may affect the relationship between modifiable risk factors and injury. Identification of these factors will assist in defining high-risk populations (Emery, 2003).

However, Bak (2010) stated that the aetiology of swimmer's shoulder related to intrinsic and extrinsic factors, and these factors are listed below in Table 2-1.

Table 2-1 Aetiology of swimmer's shoulder

Extrinsic Factors	Intrinsic Factors
Training volume – absolute and sudden increases	Excessive laxity/general joint hypermobility
Technical Errors	Isolated joint hyperlaxity
Hand paddles	Posture, core stability, and increased thoracic kyphosis
	Scapular dyskinesis
	Glenohumeral internal rotation deficit (G.I.R.D.)
	Rotator cuff imbalance
	Lack of flexibility/stiffness (posterior capsule, anterior capsule, anterior cuff, and pectoralis minor)

2.7.1 Non-modifiable Intrinsic Risk Factors

2.7.1.1 Age

Tate *et al.* (2012) reported high school swimmers to be most symptomatic in their study of 236 female swimmers between 8 and 77 years of age. According to Puckree and Thomas (2006) swimmers between the ages of 15 and 16 years were significantly more injured compared with the other age categories.

2.7.1.2 Gender

In the study done by Mountjoy *et al.* (2010) during the 13th FINA World Championships 2009, female athletes had a higher risk of injury than male athletes. However, contrary to this, Ristolainen *et al.* (2009) found no correlation between risk of injury and gender.

2.7.1.3 Combination of Age and Gender

Becker (2011) reported that swimmer's shoulder syndromes, under female swimmers, are likely to occur approximately three times over a career span:

- The first occurrence is usually during early to mid-adolescence when the body weight is likely to increase and arm strength is not fully developed while the swimmer is moving to a higher age group.
- The second period is in the later stages of high school competition. Although the body weight is almost settled, the upper body is not sufficiently strong enough to withstand the harder training.
- The third period is during the transition from high school to college swimming. Collegiate swimming often entails dramatic increases in training volume and intensity.

Becker (2011) further suggested that in males, two peak times for onset of injury occur:

- First, at the end of the second growth spurt, when the body size increases but shoulder muscles are not yet developed.
- The second time when injury occurs is the high training point of the freshman year, when the yardage exceeds previous distances and these increases occur over a period of a few days.

It seems evident that some of the risk factors associated with shoulder injuries in the developing body is a lack of strength due to growth (or in increase in body weight without a subsequent immediate increase in strength) and an increase in training volume and/or intensity. Even though age and gender are not modifiable, the prevention of shoulder injuries in swimmers lies in identifying those at risk, and managing them accordingly. Strength is a modifiable risk factor and shoulder injuries can, according to Becker (2011), be prevented if dry land strengthening programs are initiated. Training volume and intensity should also be manipulated to manage swimmers at risk of shoulder injury, and ensure pain free swimming participation.

Abgarov *et al.* (2012) concluded in a study on 170 University swimmers, where he found that the earlier males start swimming, the greater their risk of acquiring a swimming related injury, thus supporting the notion that an early start (i.e., early specialization) predisposes males to more injuries during their swimming careers.

2.7.1.4 Previous Shoulder Injury

Alarmingly, Walker *et al*. (2012) stated that the recurrence of shoulder injuries in swimming is frequent. Exploring the literature, there seem to be a significant independent association between a positive past history of shoulder injury and subsequent shoulder injury risk (Walker *et al.,* 2012; Abgarov *et al.*, 2012). These authors further reported that swimmers with a history of interfering shoulder pain were 4.1 times more likely to sustain a recurring injury. In the same study, swimmers with a history of significant shoulder injury were 11.3 times more likely to sustain a recurring injury.

To conclude, a history of shoulder injury is a non-modifiable risk factor, but it can be used as a marker to identify swimmers at risk of injury and preventative efforts should be implemented (Walker *et al*., 2012).

2.7.2 Modifiable Intrinsic Risk Factors

Bansal *et al*. (2007) avers that intrinsic risk factors significantly associated with shoulder impingement syndrome in swimmers include atraumatic anterior instability, past history of shoulder pain and inadequate treatment. The onset of symptoms may be associated with impaired posture, glenohumeral joint mobility, neuromuscular control, or muscle performance (Tovin, 2006). Following are potentially modifiable intrinsic risk factors as described in the literature.

2.7.2.1 Scapular Dyskinesis

Scapular dyskinesis is seen in the majority of overhead athlete’s shoulder with overuse pain syndromes and may be caused by an inhibition on activation patterns of the scapula stabilising muscles (i.e. serratus anterior and subscapularis etc.), (Burkhart *et al.,* 2003; Bak, 2010). During activity, patients with shoulder pain and symptoms, the scapula is placed in a more abducted, protracted, and laterally displaced position than in symptom free subjects (Bak, 2010).

According to Cools *et al.* (2003) overhead athletes presenting with impingement symptoms showed a delay in muscle activation of the middle and lower trapezius muscle and a lack of coordination between the different trapezius muscle parts (upper, middle, and lower).

2.7.2.2 Shoulder Laxity

Proper joint mechanics necessitates gleno-humeral stability, and it's absence is associated with significant disability (McMaster *et al.,* 1998). The latter authors further elaborated the degree of inherent shoulder laxity to be a common denominator in the aquatic athlete with interfering shoulder pain. While pathologic shoulder laxity may be unidirectional, it is often multi directional in swimmers. The superior migration of the humeral head may lead to secondary definable causes of shoulder pain such as impingement (McMaster *et al*., 1998). The latter authors also found a significant correlation between clinical score of glenohumeral joint laxity and interfering shoulder pain in senior national and elite swimmers. Sein *et al*. (2010), however, contends that repetitive swimming does not increase shoulder joint laxity and doubts that joint laxity is the major contributor to swimmer's shoulder. They found the high incidence of tendinopathy to relate with the time spent in training (hours swum per week) and distance per week.

In their review study Heinlein and Cosgarea (2010) compared studies that correlated gleno-humeral joint laxity with shoulder pain to studies that found no significant association. The study indicated that the literature was inconclusive on whether gleno-humeral joint laxity is a primary cause of pain (Heinlein & Cosgarea, 2010).

2.7.2.3 Shoulder Instability

Allegrucci *et al.* (1994) suggested that glenohumeral instability can develop from disruption of static stabilizers (ligaments, labrum, and capsule) or fatigue or weakness of the dynamic stabilizers (musculature). Secondary impingement can therefore be caused by rotator cuff dysfunction (i.e. fatigue or injury) or as a result of instability due to lax static stabilisers (Allegrucci *et al.*, 1994).

2.7.2.4 Range of Motion

It is possible that swimmers with limited shoulder external rotation who performed their stroke at the end of their available range of motion are at an increased risk of impingement during arm recovery, particularly in the presence of overuse related tendon thickening (Walker *et al.,* 2012). In the same study, swimmers with greater external rotation were also at increased risk of shoulder injury. This might be explained by the compromised ability of the passive structures to provide stability and detrimental changes in the neuromuscular control of the active stabilizing musculature like the subscapularis (Walker *et al.,* 2012). According to the latter authors swimmers with shoulder external range of motion (ROM) of more than 100º or less than 93º were at an increased risk of developing a shoulder injury than those with mid-range motion. This supports the hypothesis by Blanch (2004) who avers that there is a 'window' of optimal shoulder ROM. Walker *et al.* (2012) further remarked that the literature frequently describes that the loss of internal rotation ROM is due to tightness of the posterior capsule but found no correlation between internal rotation ROM and swimming shoulder injuries.

2.7.2.5 Muscle Imbalance

EMG analysis on swimmers with painful shoulders revealed that the most prominent abnormality is a weakness of the serratus anterior and increased activity of the rhomboids major and minor during the pull by Pink *et al.* (1991). The resulting mechanical imbalance ("floating scapula") increases anterior impingement of the biceps brachii and supraspinatus.

Based on the EMG (with fine wire electrodes) findings of 14 Collegiate and Masters Swimmers while swimming freestyle, Scovazzo *et al*. (1991) found the following differences between swimmers with painful shoulders and those with normal shoulders:

- Hand Entry - Significantly less muscle activity in the rhomboids, upper trapezius, middle and anterior deltoids in the swimmers with painful shoulders.
- Pulling - Significantly less activity in the serratus anterior and significantly more in the rhomboids in those subjects with painful shoulders. At the exact time that the serratus anterior was dysfunctioning and exhibiting abnormally low levels of activity, the rhomboids were exhibiting significantly more in the painful shoulder.
- Hand Exit and Early recovery – Significantly less muscle activity in the anterior and middle deltoids and significantly more in the infraspinatus in the group with

painful shoulders. The infraspinatus externally rotates the humerus to avoid the painful internal rotation.
- Mid-recovery – significantly less muscle action in the subscapularis for the swimmers with painful shoulders.

Scovazzo *et al*. (1991) found no difference in the muscle firing pattern, nor amplitude, between swimmers with painful and normal shoulders in the posterior deltoid, supraspinatus, teres minor, pectoralis major, or latissimus dorsi during the freestyle stroke.

2.7.2.6 Fatigue

According to Tovin (2006) symptoms that develop as a result of fatigue can also affect stroke mechanics. The author further elaborated that the proposed mechanism of failure concerning the swimming shoulder joint, is initiated with fatigue.

The serratus anterior in the healthy shoulder stabilizes the scapula in upward rotation and protraction (Tovin, 2006). This position of upward rotation and protraction avoids impingement of the biceps brachii tendon and rotator cuff by creating adequate subacromial space (under the coraco-acromial arch) for the biceps brachii tendon and rotator cuff to move (Scovazzo *et al.,* 1991). It also aids in maintaining a good approximation between the humeral head and the glenoid fossa (Tovin, 2006). Once the scapula is in position, at the beginning of the pull through, it effectively reverses the origin and the insertion and is used to pull the body over the arm. If the serratus anterior fatigues, it would not be able to add this propulsive motion (Scovazzo *et al.,* 1991). They also found a difference in muscle activity (as measured with a fine wire EMG) between painful and normal shoulders. During the pull through, the serratus anterior in the painful shoulders were not as active as it was in the normal shoulders (Scovazzo *et al*., 1991). Pink *et al*. (1991) agreed that the subscapularis and serratus anterior are active throughout the stroke cycle in freestyle swimming, and therefore susceptible to fatigue.

2.7.2.7 Flexibility

According to Tovin (2006) the cause of primary impingement is usually a tight posterior capsule (causing the humeral head to migrate anteriorly) or abnormal acromial morphology. The author elaborated that primary impingement syndrome is less common than secondary impingement in competitive swimmers. Tate *et al.*

(2012) found a reduced latissimus dorsi flexibility in symptomatic young swimmers, whereas pectoralis minor tightness and decreased core endurance were associated with symptoms in swimmers aged 12 years and more.

2.7.3 Non-Modifiable Extrinsic Risk Factors

Risk factors in sport are any factors that may increase the potential for injury (Meeuwisse, 1991). Risk factors may be intrinsic (age, conditioning etc.) or extrinsic (weather, field, conditions etc.) to the individual participating in the sport (Emery, 2003). Risk factors that cannot be altered are referred to as non-modifiable risk factors and may affect the relationship between modifiable risk factors and injury (Emery, 2003). The following section shines some light on non-modifiable extrinsic risk factors associated with swimming.

2.7.3.1 Speciality (distance vs. sprint)

According to Puckree and Thomas (2006) it seems evident that distance speciality may play a role. In their study the majority of specialist sprinters (70%), regardless of gender, complained of shoulder injuries compared with long-distance swimmers. Contrary to this, Wolf *et al*. (2009) reported that the risk of suffering an injury was not significantly different between sprinters and distance swimmers.

2.7.4 Inciting Events

Training errors such as overuse, misuse, abuse or disuse may contribute to shoulder pain in swimmers (Tovin, 2006). Following are some training factors that might incite an injury.

2.7.4.1 Excessive Increase in Exercise Volume

Work in other sports suggest that week-on-week increases in load of up to 10% can largely be tolerated, but increases beyond this are associated with a linear increase in injury incidence (van Dorssen *et al*., 2014).

The main factor in the development of a swimmer's shoulder seems to be the high training volume, during growth, in the absence of a well-designed and balanced dryland training program (Bak, 2010). This affects the muscular balance of the core, the scapulothoracic articulation, the rotator cuff, and glenohumeral mobility (Bak, 2010). The author expressed that swimmers often report that their shoulder pain was related to an increase in the amount of training, typically during a training camp or in conjunction with advancement to a higher training level.

Pink and Tibone (2000) suggested that the two factors that appeared to provoke shoulder pain is an increase in the intensity and distance of the workout. In line with the above mentioned, Wolf *et al*. (2009) reported that freshmen had the highest total number of injuries and the highest mean number of injuries per swimmer when compared to the sophomore, junior and senior populations in their study. The authors proposed the high prevalence of injuries during the early college years are likely to be explained by the transition from high school training regimens to that of collegiate level. The increase in swimming yardage and the additional cross-training activities are often substantially greater than what an athlete was accustomed to, and can lead to overuse-type injuries early in a swimmer's college career (Wolf *et al.,* 2009). They further remarked that fewer injuries are experienced as the swimmer becomes accustomed to the yardage and workout routine.

In their study on the cause of shoulder injuries in swimmers, Sein *et al*. (2010) found that the incidence of supraspinatus tendinopathy was related to time spent training (hours swim per week) and distance swim per week. Out of the latter research swimmers who swam more than 15 hours per week were twice as likely to have tendinopathy as those who trained for less time. Swimmers who swam more than 35km per week were four times more likely than those who swam fewer kilometres (Sein *et al.,* 2010).

Besides these findings they further noted that a greater proportion of swimmers competing at a higher level of competition had an increased incidence of supraspinatus tendinopathy than swimmers at lower competitive levels. These findings are supported by the findings of Tate *et al.* (2012) who found that high school swimmers practised on average 16 hours per week and had the highest prevalence (22.6%) of symptomatic shoulders. The latter authors further proposed that shoulder pain, dissatisfaction and disability correlates positively with increased repetitive upper extremity usage in terms of swimming or water polo exposure for mature swimmers.

To conclude, it seems evident that an excessive increase in exercise volume or additional exercise (i.e. dry land training etc.) might play a significant role in the prediction and/or prevention of overuse-type injuries.

2.7.4.2 Taking Time off from the Sport

Abgarov *et al.* (2012) found a negative effect for taking off from the sport of swimming. The expectation was that taking time off would reduce injury risk but found an increased risk of injury Instead. Abgarov *et al.* (2012) further elaborated, that those athletes who took time off placed unrealistic expectations on themselves once they returned to the sport. This attitude of attempting to make up for lost time and/or ‘catch-up’ to familiar swimmers, would increase the risk of injury as time off from the sport puts an athlete/swimmer behind with regards to their development or fitness levels.

2.7.5 Potentially Modifiable Extrinsic Factors

Modifiable risk factors refer to those that have the potential to be altered by injury prevention strategies to reduce injury rates (Meeuwisse, 1991). Risk factors may be intrinsic (age, conditioning etc.) or extrinsic (weather, field, conditions etc.) to the individual participating in the sport (Emery, 2003). The following section defines some modifiable extrinsic risk factors associated with swimming.

2.7.5.1 Paddle Swimming

Hand paddles are used to increase resistance with the arm stroke (McMaster, 1999). This increase in resistance leads to an increase in the load, which often results in shoulder pain (McMaster, 1999). Opposing this, Tate *et al.* (2012) did not find a correlation between hand paddle use in swimming and shoulder injury. According to the authors this might be due to the change in paddle technology, from rectangular and solid in design, to a shape that conforms to the hand with holes to reduce resistance. Paddle use itself might not elicit a shoulder injury, but excessive use of paddles might as seen by work done by Tovin (2006). Abuse is defined as having excessive force going through normal tissues. The example used is one of a swimmer who trains excessively with hand paddles, increasing strain on the shoulder (Tovin, 2006).

2.7.5.2 Technical Errors

McMaster (1996) postulated that many injuries originate from faulty techniques or mechanisms, and an assessment of injured athletes’ biomechanics must be made to identify factors that may contribute to injury. Some specific freestyle technical flaws heavily stress the shoulders and can lead to overuse (Kammer *et al*., 1999). This will be the topic of discussion for the rest of this chapter.

2.8 Freestyle Stroke Biomechanics

McMaster *et al.* (1998) stated that mechanical efficiency is an important factor to excel at the sport of competitive swimming. The swimming technique that produces the greatest distance per stroke at the most efficient energy use will produce the best result (McMaster *et al.,*1998). Stroke mechanics not only seems important in injury prevention, but the energy cost of freestyle swimming (ml/m) appears to be strongly influenced by the swimmers lean body weight and the effective application of force during the arm stroke (Costill *et al.*, 1985).

Swimming is comprised of four different strokes of varying distances, including freestyle (sometimes referred to as the crawl), butterfly, backstroke, and breast stroke (van Dorssen *et al.,* 2014). The sport requires several different shoulder motions, most being performed during circumduction in clockwise and counter-clockwise directions with varying degrees of internal and external rotation and scapular protraction and retraction (Tovin, 2006). Most swimming strokes consist of a pull-through phase that generates speed and a recovery phase where the arm is out of the water (Bak, 2010). One of the methods explaining freestyle stroke biomechanics is stated by Tovin (2006) where the stroke was divided into two primary phases referred to as the pull-through and recovery. The propulsion is achieved during the pull-through which was further subdivided into different phases consisting of the hand entry, the catch, mid-pull, and finish or end pull-through (Tovin, 2006). Figure 2-8 depicts the phases of swimming freestyle (Pink *et al.,* 1991).

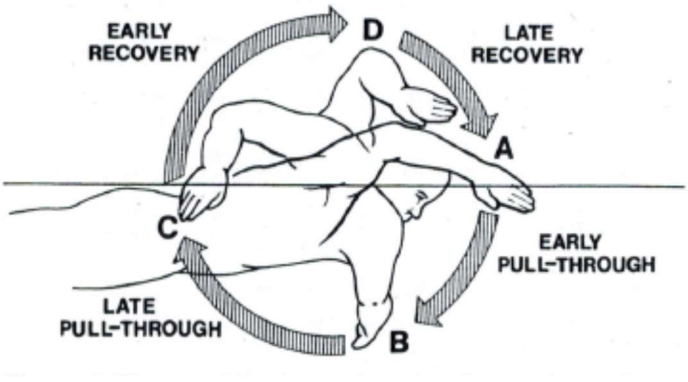


Figure 2-8. Phases of the freestyle swimming cycle

The freestyle stroke pull-cycle can be divided in four phases (Fernándes *et al.*, 2012):

1. Early pull-through: beginning with the hand entry into the water and ending when the humerus is perpendicular to the axis of the torso.
2. Late pull-through: beginning at the completion of early pull-through and ending as the hand leaves the water.
3. Early recovery: beginning at hand exit and ending when the humerus is perpendicular to the water surface.
4. Late recovery: beginning at the completion of early recovery and ending at hand entry.

2.8.1 Hand entry

The hand usually enters the water close to the midline with the elbow above the surface of the water (Tovin, 2006). According to Pink *et al.* (1991) the hand enters forward and lateral to the head, and medial to the shoulder. The elbow is flexed, with the elbow above the hand, so that the fingers are the first to enter the water (Pink *et al.,* 1991). Johnson *et al.* (2003) advances that the hand should enter with the little finger or fingers first, and not the thumb first. This technique will keep the swimmer in the impingement range for as short period as possible by avoiding excessive internal rotation (Johnson *et al.*, 2003). The hand then continues to 'reach' forward, below the surface of the water and towards (but not crossing) the midline of the body (Tovin, 2006). Becker and Havriluk (2012) suggests that at the completion of the arm entry the hand should be below shoulder level to minimise shoulder stress, maximise force generation, and optimise arm synchronisation. This was similar to the work done by Yanai and Hay (1998) who suggested avoiding an impingement position during hand entry by a reduction of the elevation angle, and to resist the forcible elevation of the hand. Figure 2-9 depicts hand entry during freestyle (Van Dorssen *et al.,* 2014)

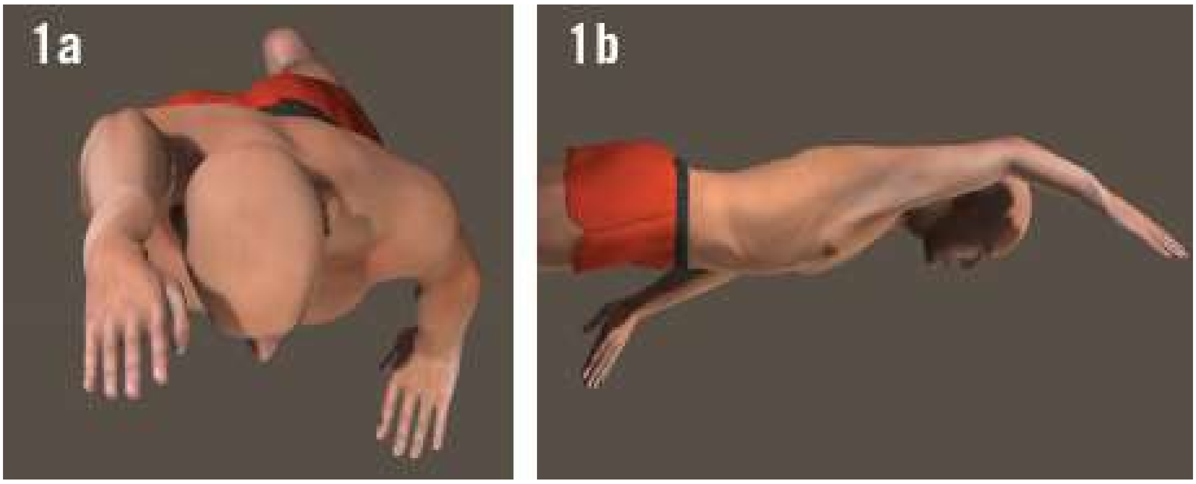


Figure 2-9. Hand entry

2.8.2 The Pull Through

The underwater pull-through starts with the early pull-through phase, which is marked by the initiation of the backward arm movement (Pink *et al.,* 1991). The palm and forearm should face the backward direction with the fingertips pointing down for as long as possible. Thus the shoulder is abducted and internally rotated during this phase (Yanai & Hay, 1998). Johnson *et al.* (2003) suggested that the pull through should be done in a straight line, and not in a S-shape. The point at which the humerus is perpendicular to the body is called the mid pull through (Pink *et al.,* 1991). Following mid pull-through is the late pull through (Pink *et al.,* 1991). During this phase the hand continues back and passes next to the hip until it exits the water, leading with the elbow (Pink *et al.,* 1991).

2.8.3 Recovery

During the recovery phase, the shoulder abducts and rotates externally as the arm is brought forward for arm entry (Yanai & Hay, 1998). After the arm exits the water, the recovery phase begins, when the arm is swung above the water to bring the arm into position to enter once again (Pink *et al.,* 1991). Figure 2-10 illustrates recovery during freestyle swimming (Van Dorssen *et al.,* 2014).

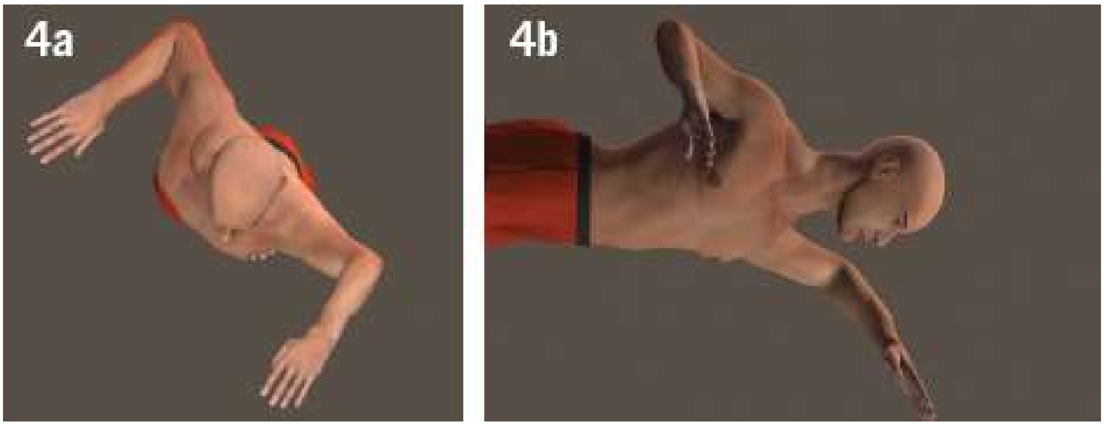


Figure 2-10. The recovery phase

2.9 Functional Anatomy During Freestyle Swimming

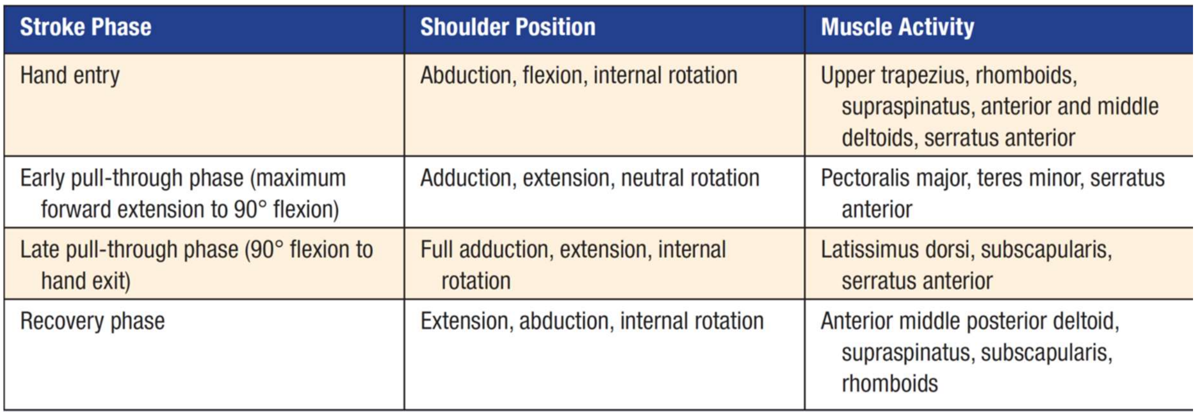
The shoulder complex is designed to achieve the greatest range of motion (ROM) with the most degrees of freedom of any joint system in the body. At the glenohumeral joint, a complex ligamentous system contribute to primary stability and an musculotendinous system serves as secondary stabilisers (Tovin, 2006). The author further noted that this support mechanism allows the shoulder to withstand large external forces, while providing enough mobility for the upper extremity to accomplish complex movement patterns.

Johnson *et al.* (2003) reported the normal freestyle arm stroke with fine-needle electromyography (EMG) as follows:

- The normal "catch" occurs when the forward hand enters the water as the upper trapezius elevates and the rhomboids retract the scapula. The serratus anterior protracts, upward rotates the scapula, and is highly active from this point in the catch and through the pull. These opposing actions hold the scapula in place.
- Just after the catch, the pectoralis major fires and adducts and extends the humerus while internal rotation is balanced by the antagonistic external rotation of the teres minor.
- The latissimus dorsi fires in concert with the subscapularis from the mid pull-through until the beginning of recovery. The deltoid and supraspinatus are the prime movers through recovery.

Wanivenhaus *et al.* (2012) summarized the phases of the freestyle stroke, shoulder position, and muscle activation in the form of Table 2-2 below.

Table 2-2. Functional anatomy during freestyle swimming



Stroke Phase	Shoulder Position	Muscle Activity
Hand entry	Abduction, flexion, internal rotation	Upper trapezius, rhomboids, supraspinatus, anterior and middle deltoids, serratus anterior
Early pull-through phase (maximum forward extension to 90° flexion)	Adduction, extension, neutral rotation	Pectoralis major, teres minor, serratus anterior
Late pull-through phase (90° flexion to hand exit)	Full adduction, extension, internal rotation	Latissimus dorsi, subscapularis, serratus anterior
Recovery phase	Extension, abduction, internal rotation	Anterior middle posterior deltoid, supraspinatus, subscapularis, rhomboids

2.10 Freestyle Pathomechanics

McMaster (1996) postulated that many injuries originate from faulty techniques or mechanisms, and an assessment of injured athletes' biomechanics must be made to identify factors that may contribute to injury. Some specific freestyle technical flaws heavily stress the shoulders and can lead to overuse (Kammer *et al*., 1999).

The impingement of sub-acromial structures has been proposed as a major cause of shoulder problems that often occur among freestyle swimmers (Yanai & Hay, 1998). In their study on 11 male College swimmers, Yanai and Hay (1998) found the mean duration of impingement positioning during freestyle swimming to be up to 24.8%, with 14.4% of this occurring during pulling and 10.4% during recovery. They found a considerable variability in the mean value for the percentage stroke time among subjects, and suggested that certain stroke techniques and/or physiques might be less vulnerable to shoulder impingement than others (Yanai & Hay, 1998).

2.10.1 Hand Entry Pathomechanics

Swimmers with painful shoulders had a different pattern of hand entry than those with normal shoulders (Scovazzo *et al.,* 1991). According to them the hand entered further away from the midline, and the humerus was lower in the water. This position is frequently described as a 'dropped elbow' position (Scovazzo *et al.,* 1991). They further noted that in this position (hand entry further from the midline) the scapula would not need to be upwardly rotated (associated with a weak serratus anterior) nor retracted as much. This position of hand entry avoids the classic impingement position of flexion and internal humeral rotation (Scovazzo *et al.,* 1991).

Johnson *et al.* (2003) suggested that a hand entry that crosses the midline of the long axis, of the body, causes mechanical impingement in the anterior shoulder including the long head of the biceps and supraspinatus. This is exacerbated by a thumb first entry which further stresses the biceps brachii attachment to the anterior glenoïd labrum (Johnson *et al.,* 2003). According to the latter authors, a crossover pull through usually results from a crossover entry, and increases the time in the impingement position.

2.10.2 Hand/Arm Position at the end of the Hand Entry Pathomechanics

Yanai and Hay (1998) reported that the hydrodynamic force exerted on the hand during entry could forcibly elevate the arm beyond normal maximum active flexion, placing the shoulder in a position of hyperflexion, causing impingement. In their study, this mechanism appeared to cause shoulder impingement for approximately 10% of the stroke time (Yanai & Hay, 1998). In an effort to avoid this position Yanai and Hay (1998) suggest a reduction of the elevation angle, and to resist the forcible elevation of the hand. They also remarked that at the point when the hand enters the water, the hydrodynamic force applied on the hand generates a large moment in the shoulder joint, causing elevation of the humeral head and subsequent impingement.

In line with this, Becker and Havriluk (2012) found that an intentional effort to complete the arm entry with the arm parallel to the surface is a technique factor that contributes to an ineffective arm position, increases shoulder stress, minimal force production and gaps in propulsion. Intentional maintenance of the arm in a position parallel to the surface (as in catch-up stroke), causes torso rotation to increase the time of exposure of the shoulder in a hyperflexed position, and exacerbates shoulder stress (Becker & Havriluk, 2012).

2.10.3 Early Pull Through Pathomechanics

Bak (2010) proposed that the anterior capsulolabral complex and the posterior-superior labrum are at risk of injury during the early pull-through. One of the most commonly described technical faults in freestyle swimming is called the “dropped elbow” (Figure 2-11) and occurs during this phase (Yanai and Hay 1998). Dropping the elbow constitutes increasing shoulder external rotation, in an attempt to avoid the painful internal rotation causing impingement (Richardson *et al.,* 1980). This position places the muscles of propulsion at a mechanical disadvantage (Richardson *et al.,* 1980). It is still unknown whether the stroke alterations seen in swimmers with symptomatic shoulders are the cause or the consequence of pain (Heinlein & Cosgarea, 2010).

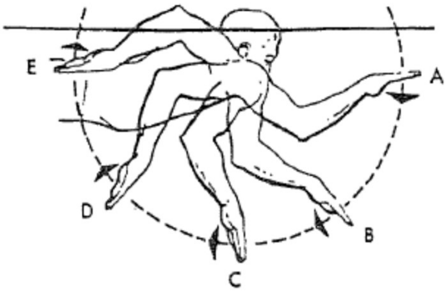


Figure 2-11. Schematics of a dropped elbow

The dropped elbow pull involves a relatively large shoulder external rotation with horizontal adduction.According to Yanai and Hay (1998), Dr. Counsilman presented a sequence of arm positions during the pull phase to define the “dropped elbow” pull and the “correct high-elbow” pull (see Figure 2-11 above and Figure 2-12 below).

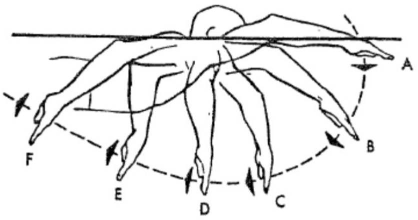


Figure 2-12. Schematics of the high-elbow pull

The high-elbow pull appears to involve a combination of a relatively large shoulder internal rotation with horizontal abduction. The “dropped-elbow” technique involves a combination of relatively large external rotation and horizontal abduction at the shoulder, and the correct “high-elbow” technique involves a combination of a large internal rotation and horizontal abduction). Although the high-elbow technique is known to place the muscles used to generate the propulsive force at a mechanical advantage, it also tends to place the shoulder structures at risk because of impingement (Yanai & Hay, 1998). In the high elbow pull position, the backward pull of the hand (in the early pull through phase) is initiated by the backward motion of the hand relative to the elbow, thus the hand moves backward while the elbow remains almost stationary. This backward motion of the hand relative to the elbow is associated with an increase in the internal rotation angle. Swimmers who executed the pull phase with a large internal rotation angle of the arm had an increased susceptibility to impingement (Yanai & Hay, 1998). Yanai and Hay (1998) recommended that swimmers should adopt the high-elbow technique during the pull phase only within their boundary ROM, so that the advantage of this technique can be obtained safely.

2.10.4 Late Pull Through Pathomechanics

Pink and Tibone (2000) claims that a swimmer with a shoulder injury fails to generate force from that arm during the late pull through phase. Therefore, the swimmer must rely on the contralateral arm to pull the body forward. An increase in training intensity will therefore result in an increase in propulsive forces of the opposite hand during the early pull through phase.

2.10.5 Hand Exit Pathomechanics

Scovazzo *et al.* (1991) reported that an early hand exit was associated with swimmers with painful shoulders. An early exit was defined as an exit that occurred before the palm passed the thigh, with the elbow bent (Scovazzo *et al.,* 1991). They suggest that this is an attempt to avoid the extremes of internal rotation that accompany the more fully flexed elbow (Scovazzo *et al.,* 1991). Bak (2010) concluded that the supraspinatus tendon is at risk of injury during the late pull-through.

2.10.6 Recovery Phase

Yanai and Hay (1998) stated that shoulder impingement was most often found during this phase of freestyle swimming. Swimmers who spend the most stroke time in internal rotation (17 to 19% of their stroke time) had a recovery pattern where the elbow led the wrist and were likely to experience impingement (Yanai & Hay, 1998). The swimmers, who exhibited the least percentage of stroke time in internal rotation (0 to 3% of their stroke time) where the elbow barely preceded the wrist, were unlikely to experience impingement.

A dropped elbow during the recovery phase was also associated with shoulder pain in Scovazzo *et al*. (1991) study on 14 Collegiate and Masters Swimmers. They noted that by keeping the arm lower and shortening the arc of motion, these swimmers were avoiding the painful impingement position (Scovazzo *et al.,* 1991). The latter statement makes sense as a characteristic of the position eliciting subacromial impingement symptoms, is forward flexion and internal rotation of the glenohumeral joint during the recovery phase (above-water portion) of the stroke (Wanivenhaus *et al.*, 2012).

2.10.7 Catch-up Stroke

Becker and Havriluk (2012) avers that when swimming catch-up stroke, where the arm is intentionally maintained in a position parallel to the surface at the end of arm entry, torso rotation increases the time of exposure in a hyperflexed shoulder position (where the hand is higher than the shoulder at the completion of the hand entry) and increases shoulder stress.

3 CHAPTER THREE: Method of Research

3.1 Introduction

This chapter describes the protocol that was designed to investigate the objectives stated in Chapter 1. A description of the instruments and technique/s used for all the measurements will be discussed.

The preparation for this dissertation was performed by reviewing literature from the following electronic databases: Google Scholar, Ebscohost Web, Academic Search Complete, CINAHL with Full Text, Health Source – Consumer Edition, Health Source: Nursing/Academic Edition, MEDLINE with Full Text, MasterFILE Premier, SPORTDiscuss with Full Text, ScienceDirect.

The following key words were used in the search: swimming/swimmer, shoulder, injury/ies, biomechanics, freestyle, sports injury/ies, athletic injury/ies, and prevention, preventive. Various combinations of the key words were used. In addition, the reference lists of retrieved articles and relevant reviews were hand searched.

3.2 Study Design

A cohort-analytical study design was used. Demographic data was obtained using a data sheet. After completing a questionnaire, all participants were subjected to laboratory testing, followed by Aquanex+Video testing.

3.3 Study Participants

The study was conducted on swimmers from the Kovsie Aquatics Swim Club, Bloemfontein, South Africa during the 2014/2015 swimming season (1 May 2014 to 1 May 2015). For this purpose, a convenience sample of sixteen (n=16) swimmers were recruited. All participants were informed about the nature, potential risks and benefits of the study, after which they signed a written informed consent document. Although it is a University swim club, the swimmers are aged from as young as 7 and older. Confidentiality and anonymity of all participants were ensured, and ethical clearance was obtained from the University of the Free State where the study was conducted, with the ethical clearance number UFS-HSD2015/0526 (Appendix C).

3.4 Inclusion and Exclusion Criteria

The target population for this study was the Kovsie Aquatics Swim Club from the University of the Free State.

The following inclusion criteria was used: (1) aged between 10 and 25 years; (2) having trained with a coach for a minimum of 2.5 years; (3) swimming at least 6 hours per week; and (4) qualifying for level 2 and higher. The exclusion criteria were as follow: (1) previous surgery on the involved shoulder; (2) previous fracture of the shoulder; and (3) inability or unwillingness to participate in the testing with Aquanex+Video, participating in the measurement taking (weight, height, shoulder internal and external rotation) or completing the questionnaire.

3.5 Information Document and Informed Consent/Assent

All the participants read and signed an information document (Appendix D) and an informed consent (Appendix E) form. If participants were younger than 18 years of age, their parents/guardians signed the informed consent form and the participant signed an informed assent form (Appendix F). Any information that was acquired during this study, and that can be identified with the participant, remains confidential and will be disclosed only with permission of the participant or as required by law. Confidentiality is maintained by means of allocating numbers to swimmers. Information is being kept with the investigator only, and raw data held under lock and key. All processing of data is governed by a PC password protector. Only the findings were published with the strictest of confidentiality to the individual swimmers. Participation in the study was voluntary. Participants were permitted to withdraw from the study at any time, and without consequences of any kind. The swimmer was not, in any way, affected if he/she chose not to participate in the study.

3.6 Demographic Data

The following demographic data was documented on the day of the Aquanex+Video testing (see Appendix G):

- Date of Birth (Age)
- Gender
- Highest swimming qualification
    - Level 2;

    - Level 3;
    - Senior/Youth Nationals;
    - International Team

Level galas are grading galas for local competition in South Africa. Swimmers must be registered with Swimming South Africa and need to swim qualifying times at qualifying club events. Qualifying times are set by Swimming South Africa. The level ratings are as follows (http://www.nmb-aquatics.co.za/documents/men-galas-explained):

- Level 1: Regional Gala
    - This is the entry level into National galas and gives the swimmer opportunity to compete against other swimmers from around the country. This is swum as a club gala.
- Level 2: Regional Gala
    - Level 2 qualifying times are slightly more difficult to achieve. This is swum as a club event.
- Level 3: National Gala
    - This is the highest level before Senior Nationals. This is also swum as a club event
- Senior/Youth Nationals
    - Once a swimmer has met the qualifying times, a provincial team is selected for Senior/Youth Nationals. This is the highest level of local competition in South Africa.

3.7 Questionnaire

Al the participants completed a brief survey questionnaire titled ‘Sport and Symptom Survey Questionnaire’ (Appendix H). The survey questionnaire is a slightly altered version of the questionnaire used by Harrington *et al*. (2014). It was self-administered under classroom-style supervision obtaining information regarding the 2014/2015 swimming season (1st of May 2014 to the 1st of May 2015). The questionnaire requested the following information:

3.7.1 General Swimming Information

The participants were instructed to indicate the sum of years participating competitively, their stroke preference and their favourite distance. When swimming freestyle, they were asked to specify whether they breathe unilaterally or bilaterally.

3.7.2 Swim Training Variables

3.7.2.1 Frequency

Swimmers were instructed to document the amount of swimming sessions completed on average per week.

3.7.2.2 Time

The questionnaire included reporting the average amount of swimming minutes per session.

3.7.2.3 Distance

Participants were asked to report the kilometres covered on average per session.

3.7.3 Injury Definition

Injuries occur when the energy is transferred to the body in amounts or at rates that exceed the threshold for human tissue damage (Meeuwisse *et al.*, 2007). In the consensus statements for Soccer (Fuller *et al.,* 2006) an injury is defined as:

“Any physical complaint sustained by a player that result from a football match or football training, irrespective of the need for medical attention or time-loss from football activities. An injury that results in a player receiving medical attention is referred to as a ‘‘medical-attention’’ injury, and an injury that results in a player being unable to take a full part in future football training or match play as a ‘‘time-loss’’ injury.”

In this study, a shoulder injury was classified as:

“Any physical complaint, concerning the shoulder, sustained by a swimmer that resulted from swimming or swimming related training (including dry land training), irrespective of the need for medical attention or time-loss from swimming activities. An injury that resulted in a swimmer receiving medical attention is referred to as a ‘‘medical-attention’’ injury, and an injury that resulted in a swimmer being unable to take a full part in future swim training or galas as a ‘‘time-loss’’ injury.

3.7.4 Injury Classification

3.7.4.1 Mechanism and Side of Injury

Injuries were classified by the body side and the mechanism of injury (traumatic or overuse). In this context, a traumatic injury refers to an injury resulting from a specific, identifiable event and an overuse injury to one caused by repeated micro trauma without a single identifiable event responsible for the injury (Fuller *et al.*, 2006).

3.7.4.2 Shoulder Pain/Symptoms and Functional Ability

Shoulder pain and symptoms were assessed using respective subscales of the Penn Shoulder Score (Tate *et al.*, 2012). Pain was rated at rest, with normal activities (eating, dressing, bathing), and with strenuous activities (sports, reaching, lifting) on a scale of 0 (*no pain*) to 10 (*worst pain possible*). The pain subscale total was calculated by subtracting each of the 3 scores from 10 and then adding them for a total of 0 to 30, with 30 indicating no pain.

3.7.4.3 Injury Severity

The severity of the symptoms were categorised according to ability of the swimmer to participate in swim training and competition found in the questionnaire of the study done by Harrington *et al*. (2014).

1. No pain or shoulder symptoms
2. Pain/ache only after heavy workouts
3. Pain/ache (not disabling) during and after workouts
4. Disabling pain during and after workouts that interfered with your athletic performance
5. Shoulder pain preventing competitive sport participation

3.7.4.4 Other Injury Classification Issues

Injuries were classified as to whether these occurred during a gala, training or dry land training.

3.7.4.5 Painful Phases of the Freestyle Stroke

In a survey of 233 competitive swimmers on 17 collegiate teams, Pink and Tibone (2000) found that the part of freestyle stroke most frequently linked to shoulder injury, was the first half of the pull through phase (approximately 70% of symptoms were noted at this time). Another vulnerable point of the stroke appeared to be during the first half of recovery (18% of symptoms were elicited at this point according to the latter authors).

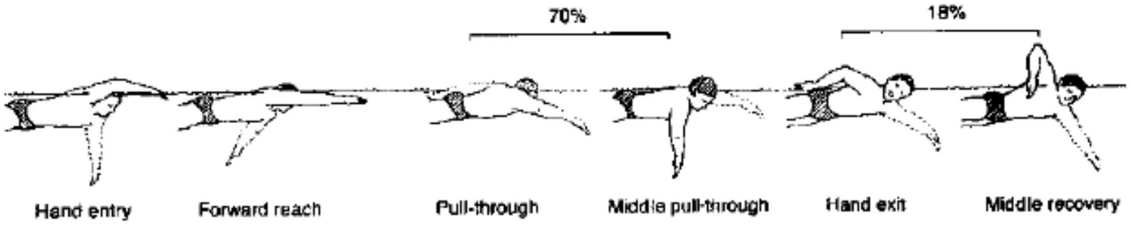


Figure 3-1. Painful phases of the freestyle stroke

Swimmers were asked to indicate during which part of the stroke the symptoms were experienced as seen in Figure 3-1 above (Pink & Tibone, 2000).

3.8 Measurements

3.8.1 Laboratory Testing

3.8.1.1 Height and Weight

The following measurements were documented on the day of the Aquanex+Video testing (Appendix G):

- Height (in centimetres) – using a standard stadiometer
- Weight (in kilograms) – using a calibrated scale

3.8.1.2 Shoulder Range of Movement

Active internal and external shoulder range of movement was measured at 90º of gleno-humeral abduction (Appendix I). This was done with a standard plastic long-armed (12 inch) goniometer with 1º increments, in the supine position (Boon & Smith 2000). Each subject was tested by two Biokineticists.

The investigator described the technique in detail, and demonstrated the procedure, including instruction in positioning seen in Figure 3-2 below (Boon & Smith, 2000). One Biokineticist positioned the arm in internal rotation, and the second Biokineticist measured and recorded the angle. The scapula was stabilized by applying anteropostero-directed force against the coracoid process and clavicle (Boon & Smith, 2000). The first Biokineticist then moved the arm through full range of motion to external rotation and the measurement was taken and recorded (Boon & Smith, 2000). The procedure was repeated for the opposite shoulder.

Figure 3-2. Technique for testing shoulder rotational range of motion

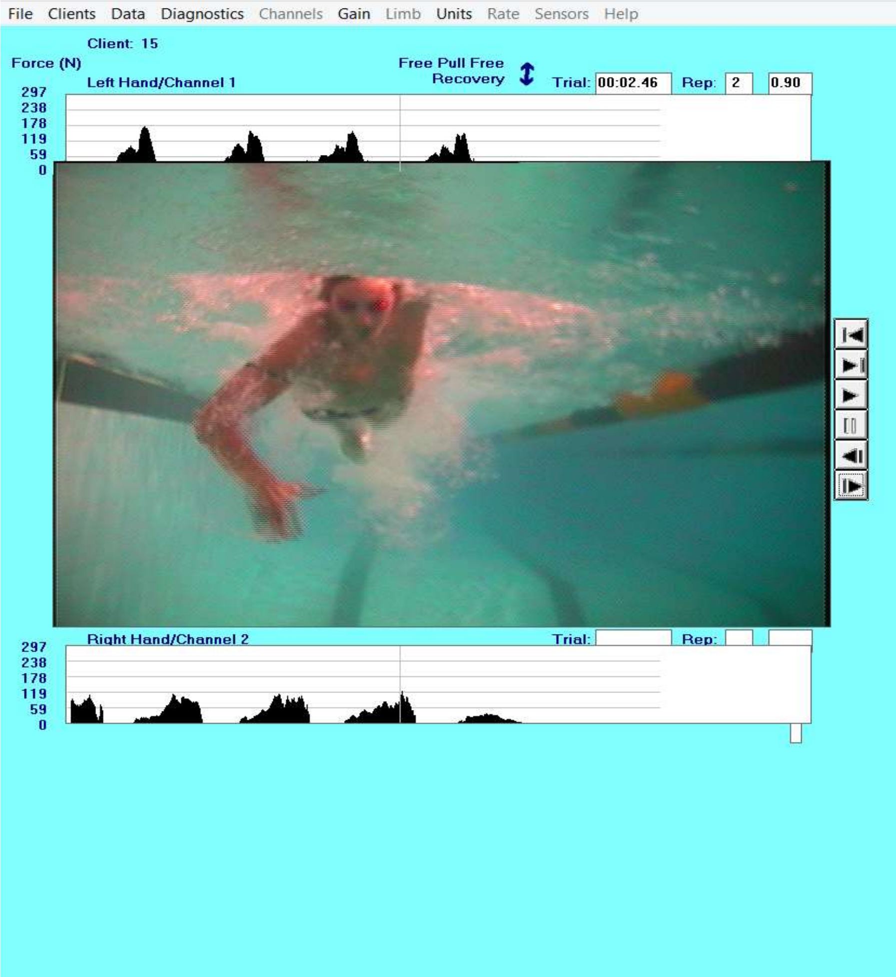
3.8.2 Freestyle Biomechanical Testing using the Aquanex+Video

3.8.2.1 Testing Protocol

Participants were instructed to warm-up with a 100m freestyle swim. The standard Aquanex+Video testing protocol as described by Becker and Havriluk (2010) was used and is described below.

Sensors were positioned at the centre of the swimmer's hands between the third and fourth metacarpals to measure the pressure differential between the palmar and dorsal surfaces. The sensor and video output were connected to a computer via an interface on the pool deck and synchronized the data from the sensors and video. The underwater camera was positioned at 30cm from the water surface at the end of the pool.

Swimmers were instructed to sprint 20m toward the wall where the camera is mounted. Underwater video and hand force data was collected over the last 10 m of each trial. Two trails of each test were performed with 1-minute rest between each trail. Figure 3-3 below illustrates the camera view.



Client: 15
Trial: 00:02.46
Rep: 2
0.90

Figure 3-3. Aquanex+Video camera view

3.8.2.2 Validation

The testing equipment was validated as explained by Havriluk (1988).

3.8.2.3 Freestyle Biomechanical Analysis

The video analysis was done on the video captured during the Aquanex+Video testing. A stroke cycle was considered appropriate for analysis if the cycle was completely within the camera view, with the body centred in the field of view. After an in-depth study on available literature regarding possible freestyle biomechanical errors associated with shoulder pain and advantageous biomechanical positions, a freestyle analysis template was assembled (Appendix J). The first full stroke cycle to enter the camera view that met the criteria was selected for analysis using the latter data sheet. Data captured by the Aquanex+Video hand sensors (i.e. average peak force, stroke velocity, stroke rate, stroke length, and active drag coefficient) were processed and analysed.

3.9 Methodological and Measurement Errors

According to Mouton (2001) the term “research methodology” is the term used to describe the process followed to conduct a scientific study. Thomas *et al*. (2011) describe research as a systematic process of collecting data and logically analysing this data to solve problems and to make significant contributions in the field of science, for example in swimming. Research also involves the application of various techniques, methods, and approaches for investigating a problem or answering a research question.

Errors in any research study is avoided as far as possible. The researcher was available to assist participants in case of any queries or uncertainties. Measurement errors were minimised by making use of a qualified Biokineticist to assist in taking measurements. In order to minimise equipment errors, all the equipment (scale and Aquanex+Video) was calibrated before testing each participant. Errors in the transfer of data into an electronic format was avoided by thorough data checking.

3.10 Pilot Study

Mouton (2014) stated that a pilot study is the extensive collection of data to gain a comprehensive understanding of a single phenomenon on a particular group (ex. swimmers), social setting or event. A pilot study with three swimmers was conducted 6 weeks prior to the present study. It consisted of documenting demographic data, measuring weight, height and shoulder internal and external range of movement. This was followed by filling out the questionnaire under classroom style supervision. Aquanex+Video testing was done in the University of the Free State swimming pool. Additionally, the duration of testing an individual swimmer was evaluated in order to properly plan testing schedules. Data sheets, equipment, and protocols were found to be effective in testing the proposed objectives.

3.11 Ethical Aspects

Marczyk *et al*. (2005) stated that all studies with human participants involve some degree of risk. The author further mentioned that the researcher must be aware that these risks present him with an ethical dilemma. Therefore, conducting research requires integrity, responsibility and honesty in order to protect the rights of the participants. To render the study ethical, the rights to confidentiality, self-determination, anonymity, and informed consent will be observed.

Written permission to conduct this research was obtained from the head coach of Kovsie Aquatics, Marco Markgraaff (Appendix A), the director of Kovsie Sport, Mnr. D.B. Prinsloo (Appendix B) and the Ethics committee of Humanities, University of the Free State (Appendix C).

Basic elements of informed consent include the following:

- A fair explanation of the procedures to be followed;
- A description of the value and benefits of their participation;
- An offer to answer any enquiries concerning the processes;
- An indication that the participant is free to withdraw consent and to discontinue participation on the project or activity at any time.
- The rights of the participant will be considered by the researcher;
- The right to privacy or non-participation;
- The right to remain anonymous;
- The right to confidentiality; and
- The right to expect experimenter responsibility.

3.12 Analysis of the Data

Data was captured electronically in Microsoft Excel (Microsoft Office 2010). The statistical analysis described below was done by a biostatistician (Prof R. Schall of the Department of Statistical Consultation Unit, Department of Mathematical Statistics and Actuarial Science, University of the Free State) using SAS software (SAS; version 9.3 for Windows; Cary, NC).

3.12.1 Descriptive Statistics

Descriptive statistics, namely frequencies and percentages for categorical data and means and standard deviations or medians and percentiles for quantitative data were calculated.

3.12.2 Binary Risk Factors for Injury

The association between binary risk factors for injury, and the binary variable “shoulder injury” (SI 3), was assessed using Fisher’s exact test. A P-value for the null-hypothesis of no association between the risk factor in question and the outcome (shoulder injury) is reported.

Furthermore, both the risk of shoulder injury in presence of the risk factor, and the risk of injury in the absence of the risk factor was presented; finally, the risk ratio “Risk factor present / Risk factor absent” of injury, as well as the exact 95% confidence interval for the risk ratio, are reported.

3.12.3 Quantitative Risk Factors for Injury

The association between the quantitative risk factors and the binary variable “shoulder injury” (SI 3) was assessed using one-way ANOVA. Here the quantitative variable was the dependent variable, and the binary variable “shoulder injury” was the group variable.

P-values associated with the null-hypothesis of zero mean difference between injured and uninjured subjects are reported. Furthermore, the mean difference “Risk factor present - Risk factor absent” of the quantitative variable, as well as a 95% confidence interval for the mean difference, are reported.

4 CHAPTER FOUR: Results

This chapter presents the results obtained from the demographic questionnaire, laboratory testing and freestyle biomechanics analysis. The results are displayed to reflect the demographic information of this cohort of swimmers, followed by the data on the prevalence of shoulder injuries and the data from the freestyle biomechanical analysis.

The results are narrated in this chapter to highlight their significance within the represented profiles. Interpretation and discussion of the findings follow in Chapter 5.

4.1 Participants

The demographic information displayed in this section provides an overview of the cohort of swimmers from Kovsie Aquatics Swimming Club in the 2014/2015 season.

4.1.1 Demographic Data

Descriptive statistics, namely frequencies and percentages for categorical data and means and standard deviations or medians and percentiles for quantitative data were calculated.

Sixteen (n=16) competitive swimmers (6 male, 10 female), adhering to the inclusion criteria, participated in the study. The age of the total sample ranged between 11 and 19 years with a mean age of 15.1 (± 2.78) years. Most of the swimmers fell in the 13 to 14 years age group, totalling to 6 (37.5%) swimmers. This was followed by 4 (25%) in the 17 to 18 years category. The distribution of the rest of the population is depicted in Figure 4-1.

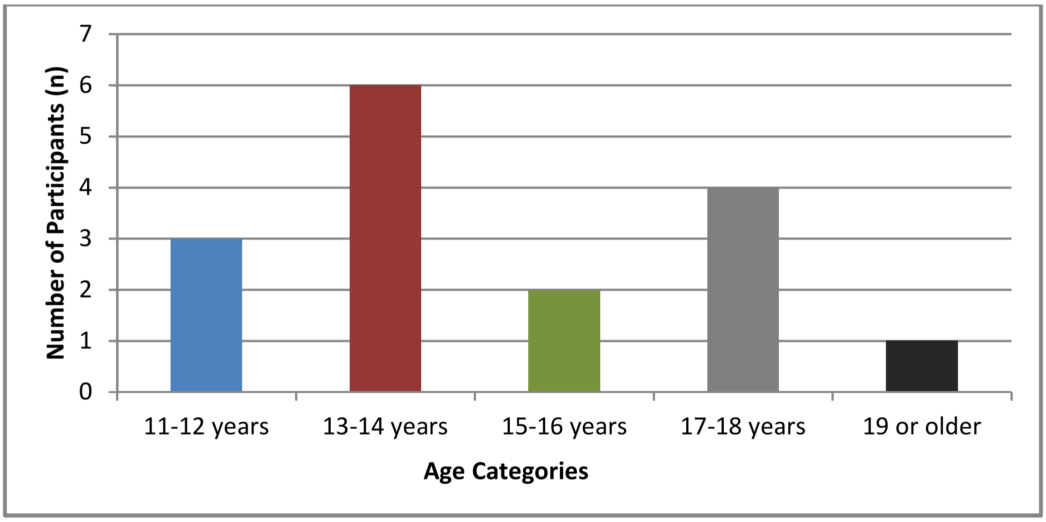


Figure 4-1. Age categories

The mean height was 166.6cm (±11.09), while the mean body mass was 59.4 kg (± 12.03). Nine (56.3%) of the swimmers qualified for Level 2. The swimmers' level of qualification can be observed in Figure 4-2 below.

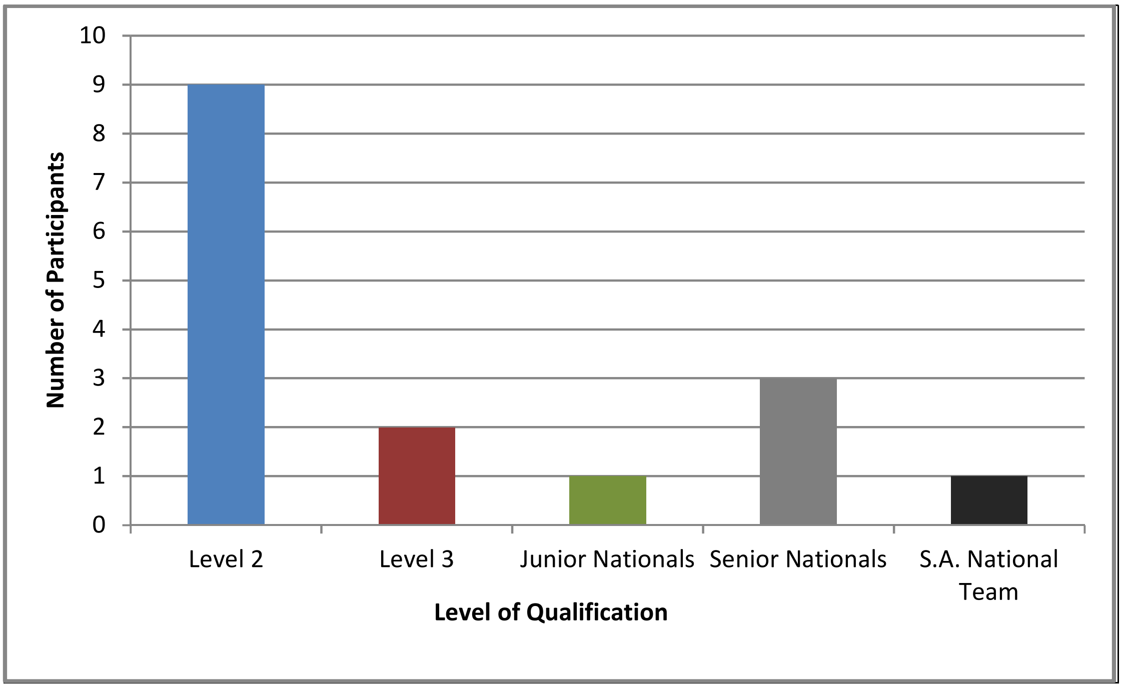


Figure 4-2. Level of qualification

4.2 Questionnaire

Data for 16 study participants were available. The questionnaire collected demographic data, including data on shoulder injuries.

4.2.1 General Swimming Information

4.2.1.1 Years Participating

Fifteen of the participants in this study had been swimming competitively for 5 years or more with one swimmer swimming competitively for 3 to 4 years.

4.2.1.2 Stroke Preference

Freestyle was the most popular stroke with 9 (56.3%) swimmers preferring it. Figure 4-3 illustrates the distribution of stroke preferences.

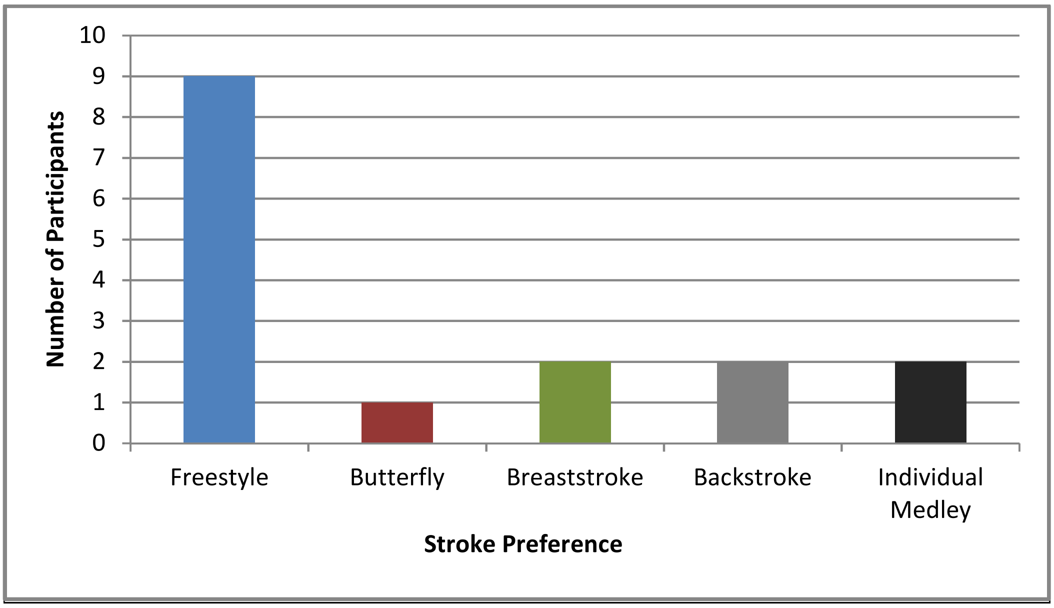


Figure 4-3. Stroke preference

4.2.1.3 Distance Preference

Middle distance was the favourite distance among the participants. Ten (62.5%) of the swimmers favoured 200m-400m while 4 (25%) preferred sprints (50m-100m) and 2 (12.5%) open water events. None of the participants showed an interest in the 800m-1500m category.

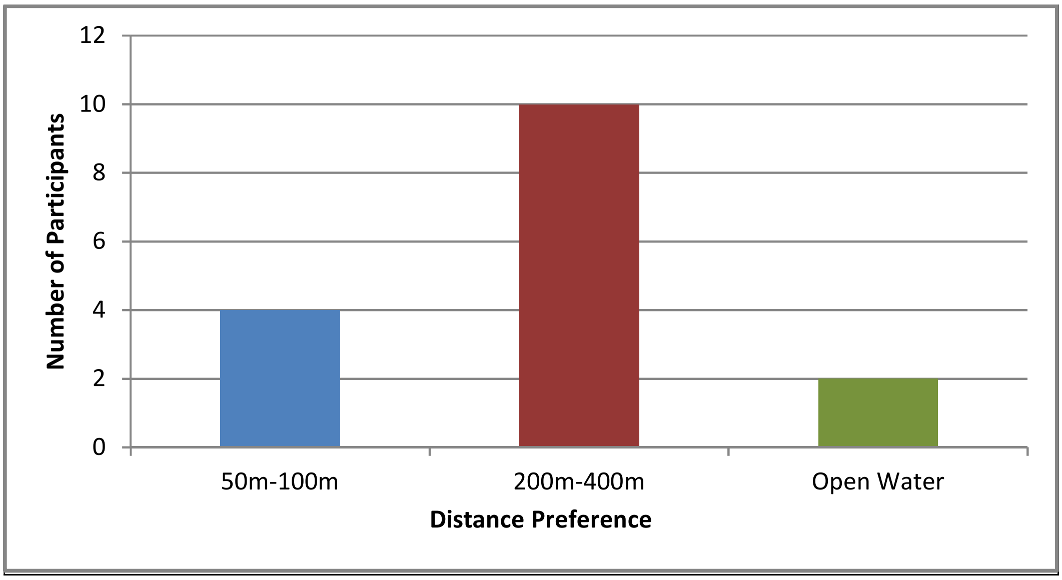


Figure 4-4. Distance preference

4.2.1.4 Breathing Side

Nine (56,3%) of the participants claimed to breath bilaterally while 7 (43.8%) breathed to the right only.

4.2.2 Swim Training Variables

A summary of various questions regarding the swimmers training variables is given in Table 4-1. Eight (50%) of the participants indicated swimming 3 to 4 sessions per week while the other 8 (50%) trained more than 5 sessions per week. Eight (50%) swimmers trained for 90 minutes or more per training session while only 1 (6.25%) indicated swimming 45 to 60 minutes per session. Five (31.3%) participants swim on average 3 to 4 kilometres per session, while the remaining 11 (68.8%) cover more than 4 kilometres per session.

Table 4-1. Training variables

		Frequency(n)	Percentage
Frequency (sessions per week)	1-2	0	0
	2-3	0	0
	3-4	8	50.00
	4-5	0	0
	5 or more	8	50.00
Time (per session)	30-45min	0	0
	45-60min	1	6.25
	60-75min	6	37.50
	75-90min	1	6.25
	90min or more	8	50.00
Distance (per session)	1-2km	0	0
	2-3km	0	0
	3-4km	5	31.25
	4-5km	4	25.00
	5km or more	7	43.75

The sample was stratified into 2 groups. One group reported swimming 5 sessions (or more) per week and 5km (or more) per session. This group consisted of five swimmers. The other group reported swimming less than 5 session per week or less than 5km per session. This group consisted of 11 swimmers. Interestingly it seems that participants with the higher training load were less prone to injury with only one (20%) of the group with the higher training load reporting a shoulder injury. Nine (82%) of the 11 swimmers with a reduced training load reported a shoulder injury (refer to Figure 4-5). This however raises the question of whether participants reduced their training load after injury. Unfortunately, due to the retrospective nature of this study, it is not possible to conclude whether training distance was reduced as a result of injury or if a correlation between a lower training load and shoulder injury exist.

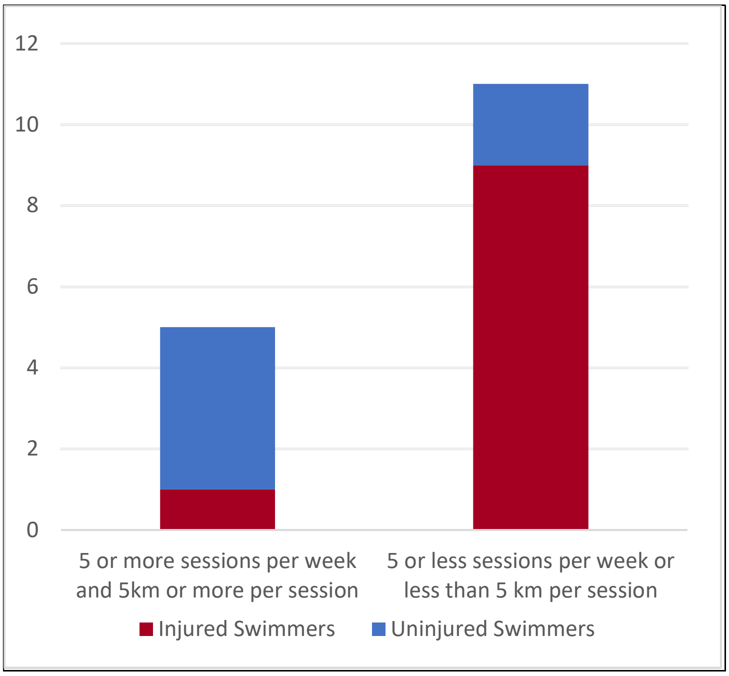


Figure 4-5 Training load and shoulder injuries

4.2.3 Shoulder Injury

4.2.3.1 Prevalence of Shoulder Injuries

In this study 10 (62.5%) of the participants reported having a shoulder injury during the 2014/2015 season. Refer to Figure 4-6.

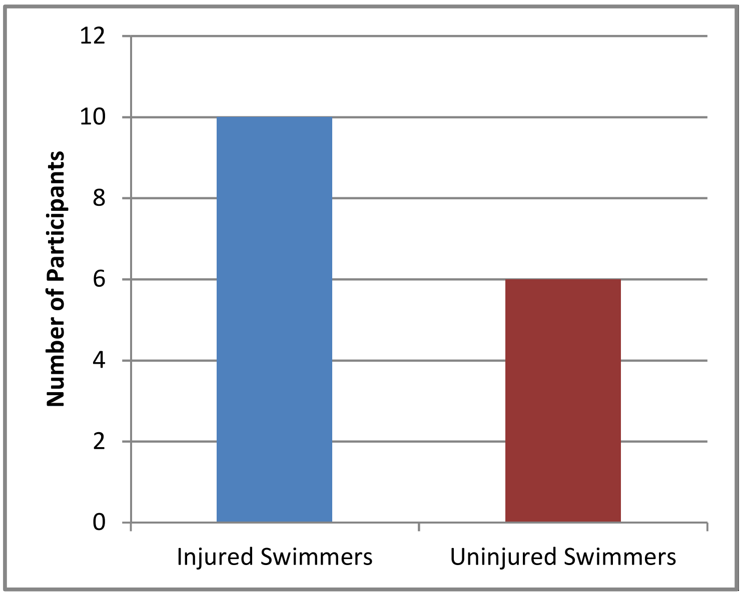


Figure 4-6. Prevalence of shoulder injuries

Eight (80%) of the injured swimmers were female and only 2 (20%) were male. Female swimmers were more prone to injury than their male counterparts. Eight (80%) of the 10 female swimmers presented with a shoulder injury, while only 2 (33%) of the six male participants reporting a shoulder injury.

Three (75%) in the category 17 to 18 years presented with a shoulder injury, while 4 (67%) of the 13 to 14 years category and 2 (67%) of the 11 to 12 years category reported a shoulder injury. One (50%) of the 2 swimmers between 15 and 16 years sustained a shoulder injury.

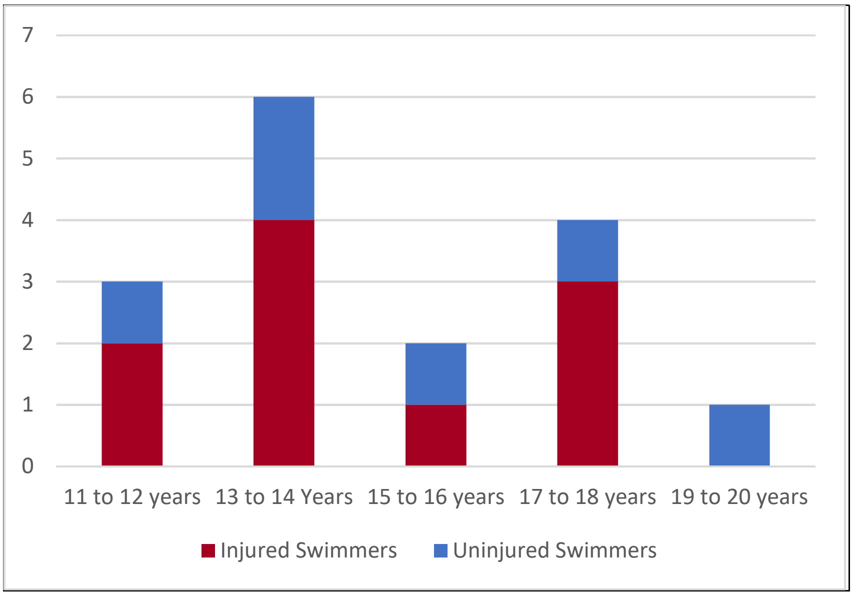


Figure 4-7. Injured vs uninjured swimmers in age category

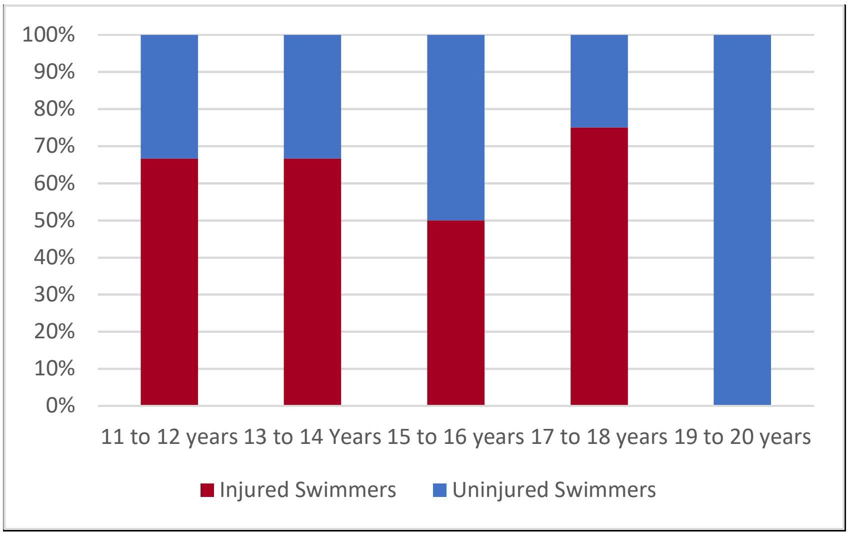


Figure 4-8. Injured and uninjured swimmers represented in percentages

4.2.3.2 Mechanism and Side of Injury

All the injured swimmers indicated that the cause of the shoulder injury was due to overuse during swim training and not due to trauma.

Figure 4-8 shows that 7 (70%) of the injured swimmers experienced bilateral shoulder pain, with 2 (20%) swimmers experiencing symptoms only in the right shoulder and 1 (10%) only in the left shoulder.

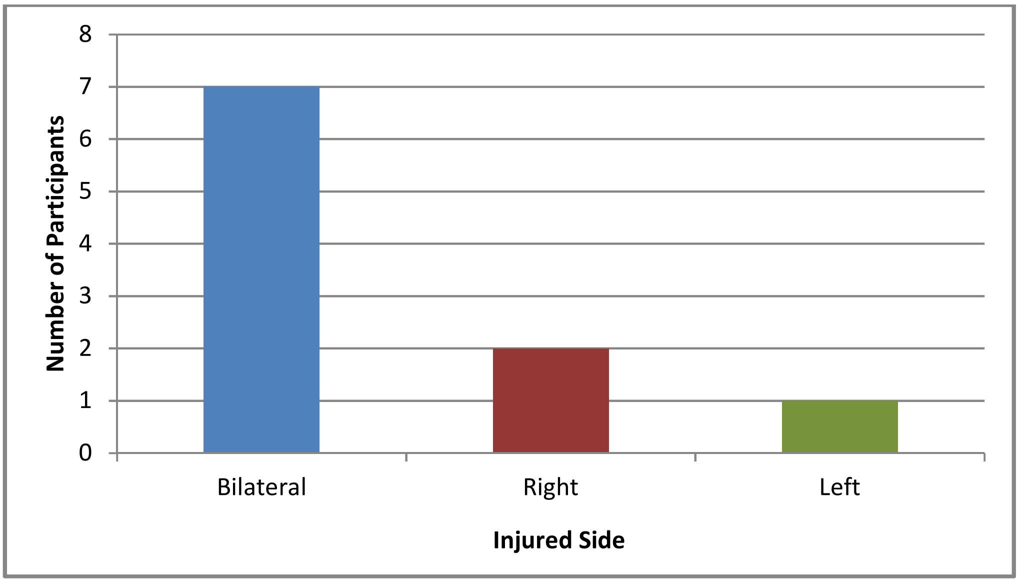


Figure 4-9. Injured side

In total, 56.25% (n=9) of the 16 right shoulders presented with an injury, while 50% (n=8) of the 16 left shoulders were injured.

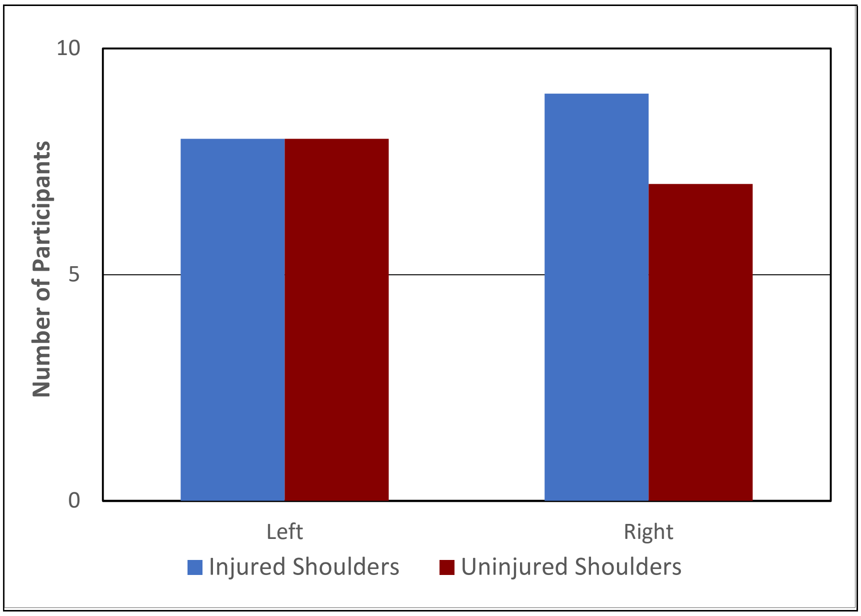


Figure 4-10. Injured side when differentiating between sides

4.2.3.3 Injury Severity

Disabling pain during and after workouts that interfered with the swimmers' performance described 6 (60%) of the participants symptoms. Three (30%) participants experienced pain/ache (not disabling) during and after workouts. Only 1 (10%) swimmer reported pain/ache after heavy workouts.

4.2.3.4 Painful Phases during the Freestyle Stroke

Six (60%) of the injured participants experienced their symptoms only during the early pull through phase with 1 (10%) experiencing symptoms only during the recovery phase. However, 3 (30%) swimmers experienced symptoms during both the early pull through and the recovery phase. Figure 4-11 illustrates the distribution of the painful phases of the freestyle stroke in this population.

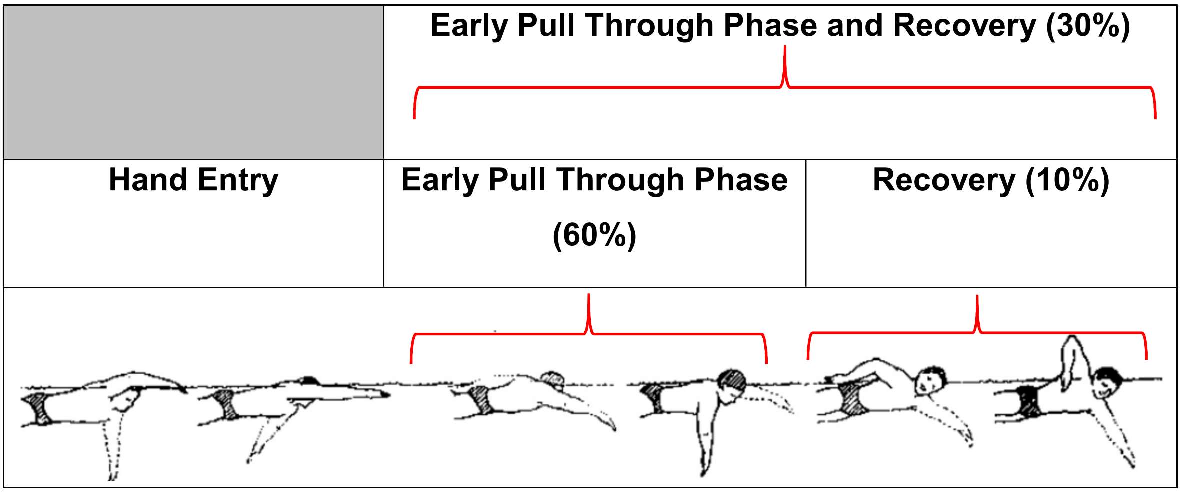


Figure 4-11. Distribution of the painful phases of the freestyle stroke

4.2.4 Freestyle Stroke Biomechanical Analysis Results

The association between binary risk factors for injury, and the binary variable "shoulder injury" (SI 3), was assessed using Fisher's exact test. A P-value for the null-hypothesis of no association between the risk factor in question and the outcome (shoulder injury) is reported.

Furthermore, both the risk of shoulder injury in presence of the risk factor, and the risk of injury in the absence of the risk factor was presented; finally, the risk ratio "Risk factor present / Risk factor absent" of injury, as well as the exact 95% confidence interval for the risk ratio, are reported.

None of the risk factors that were investigated in this study was statistically significant. It should however be noted that the low power to detect statistically significant risk factors was due to the relatively small sample. Nevertheless, the study results presented below suggest variables which might be associated with an increased risk for shoulder injury, and thus suggest a number of risk factors worthy of further study in future research.

Table 4-2. Potential binary risk factors of right shoulder injury

Risk Factor – Right Hand					
	Risk of injury [%]		Risk Ratio: Risk factor present / Risk factor absent		
Hand Entry Position	**Risk factor present[1] (n/N)**	**Risk factor absent[1] (n/N)**	**Estimate[2]**	**95% Confidence Interval[1]**	**P-value[3]**
Hand crossing the midline	71.4 (5/7)	44.4 (4/9)	1.61	0.67 to 3.83	0.3575
Thumb first hand entry	66.7 (4/6)	50.0 (5/10)	1.34	0.58 to 3.09	0.6329
Hand entering between the body midline and shoulder	42.9 (3/7)	66.7 (6/9)	0.64	0.09 to 1.69	0.6145
Hand entering in line with the shoulder	50.0 (1/2)	57.1 (8/14)	0.88	0.03 to 2.55	1.0000
Hand entering outside of the shoulder	NA	56.3 (9/16)	NA	NA	NA
Hand/Arm Position at the end of the Hand Entry Phase					
Hyperflexed shoulder with fingertips facing upward	100.0 (2/2)	50.0 (7/14)	2.00	0.21 to 4.34	0.4750
Arm Parallel to the water	54.6 (6/11)	60.0 (3/5)	0.90	0.36 to 6.48	1.0000
Fingertips pointing downward towards the bottom of the pool	25.0 (1/4)	66.7 (8/12)	0.37	0.01 to 1.41	0.2615
Early Pull Through Phase – Elbow Position					
Dropped Elbow	54.6 (6/11)	60.0 (3/5)	0.91	0.36 to 6.48	1.0000
High Elbow	60.0 (3/5)	54.6 (6/11)	1.10	0.45 to 2.70	1.000

Early Pull Through Phase – Hand Position					
Hand inside the elbow and crossing the midline of the body	NA	56.3 (9/16)	NA	NA	NA
Hand inside the elbow and not crossing the midline of the body	58.3 (7/12)	50.0 (2/4)	1.17	0.44 to 10.91	1.0000
Hand in line with the elbow	NA	60.0 (9/15)	NA	0.00 to 1.93	0.4375
Hand outside the elbow	66.7 (2/3)	53.9 (7/13)	1.24	0.13 to 3.03	1.0000
Late Pull Through Phase / Push Phase – Force Production					
Drop in force production	63.6 (7/11)	40.0 (2/5)	1.59	0.56 to 14.84	0.5962
Increase in force production	40.0 (2/5)	63.6 (7/11)	0.63	0.07 to 1.77	0.5962
Hand Exit Phase – Hand Position					
Hand exits before the thigh	53.3 (8/15)	100.0 (1/1)	0.53	0.27 to 14.76	1.0000
Elbow bent during hand exit	53.3 (8/15)	100.0 (1/1)	0.53	0.27 to 14.76	1.0000
Catch-up Stroke					
Swimming catch-up stroke	75.0 (3/4)	50.0 (6/12)	1.50	0.67 to 3.34	0.5846

NA: Not applicable; estimate and confidence for risk ratio cannot be calculated because no subjects has the risk factor in question

[1] Percentage of swimmers with injury.

[2] Point estimate and exact 95% confidence interval of the risk ratio “Risk factor present / Risk factor absent” of having a shoulder injury.

[3] P-value from Fisher’s exact test of the null-hypothesis of no association between risk factor and injury.

4.2.4.1 Hand Entry Phase– Right Hand/Arm

The results in Table 4-2 indicate that 71.4% (5 out of 7) of the swimmers with a right hand crossing the midline upon hand entry presented with an injury to the right shoulder, compared to 44.4% (4 out of 9 swimmers) without this risk factor [Risk ratio (RR) =1.61; 95%CI for RR 0.67 to 3.83]. Thus, swimmers with a right hand crossing the midline upon hand entry were 1.6 times more likely to present with a right shoulder injury than swimmers without.

Swimmers with a hand/arm position at the end of the entry phase where the right shoulder was in hyperflexed with the fingertips facing upward were twice as likely to present with a right shoulder injury [Risk ratio (RR) =2.00; 95%CI for RR 0.21 to 4.34].

4.2.4.2 Late Pull Through Phase (Push Phase) – Right Hand/Arm

A risk ratio larger than 1.5 was observed for those swimmers with a drop in force production during the late pull through phase [Risk ratio (RR) =1.59; 95%CI for RR 0.56 to 14.84].

4.2.4.3 Swimming Catch-Up Stroke – Right Hand/Arm

Seventy five percent (3 out of 4) of the swimmers swimming ‘catch-up stroke’ with the right hand/arm presented with a right shoulder injury, compared to 50% (6 out of 12) of the swimmers without this risk factor on the same side [Risk ratio (RR) =1.50; 95%CI for RR 0.67 to 3.34]. Swimmers presenting with this risk factor on the right hand/arm were 1.5 times more likely to present with a right shoulder injury.

Table 4-3. Potential binary risk factors of left shoulder injury

Risk Factor – Left Hand					
	Risk of injury [%]		**Risk Ratio: Risk factor present / Risk factor absent**		
Hand Entry Position	**Risk factor present[1] (n/N)**	**Risk factor absent[1] (n/N)**	**Estimate[2]**	**95% Confidence Interval[1]**	**P-value[3]**
Hand crossing the midline	42.9 (3/7)	55.56 (5/9)	0.77	0.13 to 2.28	1.0000
Thumb first hand entry	66.7 (4/6)	37.50 (3/8)	1.67	0.58 to 3.09	0.6084
Hand entering between the body midline and shoulder	62.5 (5/8)	66.67 (6/9)	1.67	0.57 to 9.43	0.6193
Hand entering in line with the shoulder	0.0 (0/1)	53.33 (8/15)	0.00	0.00 to 2.26	1.0000
Hand entering outside of the shoulder	NA	50.00 (8/16)	NA	NA	NA
Hand/Arm Position at the end of the Hand Entry Phase					
Hyperflexed shoulder with fingertips facing upward	75.0 (3/4)	41.67 (5/12)	1.80	0.33 to 5.00	0.5692
Arm Parallel to the water	28.6 (2/7)	66.67 (6/9)	0.43	0.12 to 1.51	0.3147
Fingertips pointing downward towards the bottom of the pool	60.0 (3/5)	45.45 (5/11)	1.32	0.23 to 3.77	1.0000
Early Pull Through Phase – Elbow Position					
Dropped Elbow	54.6 (6/11)	40.00 (2/5)	1.36	0.43 to 14.84	1.0000
High Elbow	40.0 (2/5)	54.55 (6/11)	0.73	0.22 to 2.44	1.0000

Early Pull Through Phase – Hand Position					
Hand inside the elbow and crossing the midline of the body	NA	56.25(9/16)	NA	NA	NA
Hand inside the elbow and not crossing the midline of the body	40.0 (4/10)	66.67 (4/6)	0.60	0.24 to 0.61	0.6084
Hand in line with the elbow	0.0 (0/2)	57.14 (8/14)	0.00	0.00 to 1.61	0.4667
Hand outside the elbow	100.0 (4/4)	33.33 (4/12)	3.00	1.13 to 10.08	0.0769
Late Pull Through Phase / Push Phase – Force Production					
Drop in force production	50.0 (7/14)	50.00 (1/2)	1.00	0.33 to 27.09	1.0000
Increase in force production	50.0 (1/2)	50.00 (7/14)	1.00	0.23 to 4.40	1.0000
Hand Exit Phase – Hand Position					
Hand exits before the thigh	53.3 (8/15)	0.00 (0/1)	∞	0.44 to ∞	1.0000
Elbow bent during hand exit	53.3 (8/15)	0.00 (0/1)	∞	0.44 to ∞	1.0000
Catch-up Stroke					
Swimming catch up stroke	75.0 (3/4)	43.67 (5/12)	1.80	0.33 to 5.00	0.5692

NA: Not applicable; estimate and confidence for risk ratio cannot be calculated because no subjects has the risk factor in question

[1] Percentage of swimmers with injury.

[2] Point estimate and exact 95% confidence interval of the risk ratio “Risk factor present / Risk factor absent” of having a shoulder injury.

[3] P-value from Fisher’s exact test of the null-hypothesis of no association between risk factor and injury.

4.2.4.4 Hand Entry Phase – Left Hand/Arm

Swimmers with a left thumb first hand entry were 1.67 times more likely to present with a left shoulder injury than those without [Risk ratio (RR) =1.67; 95%CI for RR 0.58 to 3.09].

Swimmers presenting with a left hand entering between the shoulder and the midline of the body were also 1.67 times more likely to present with a left shoulder injury [Risk ratio (RR) =1.67; 95%CI for RR 0.57 to 9.43].

A hyperflexed left shoulder with the fingertips facing upward also seemed to increase the risk of left shoulder injury. Seventy five percent (3 out of 4) of the swimmers with a left hyperflexe shoulder upon hand entry presented with a left shoulder injury, compared with 41.67% (5 out of 12) of swimmers without this biomechanical characteristic [Risk ratio (RR) =1.88; 95%CI for RR 0.58 to 3.09]. The presence of this risk factor increases the risk of injury to the left shoulder by 1.88 times.

4.2.4.5 Early Pull Through Phase – Left Hand/Arm

Interestingly, 100% (4 out of 4) of the swimmers with a left hand position outside the elbow during the early pull through phase had reported an injury to the left shoulder. In contrast, only 33.33% (4 out of 12 swimmers) without this biomechanical characteristic presented with a shoulder injury [Risk ratio (RR) =3.00; 95%CI for RR 1.13 to 10.08]. Swimmers with this risk factor on the left arm were 3 times more likely to sustain a left shoulder injury.

4.2.4.6 Swimming Catch-up Stroke – Left Hand/Arm

In line with the findings for the right shoulder, swimming ‘catch-up stroke’ with the left arm also seems to increase the risk for left shoulder injury by 1.8 times. Seventy five percent (3 out of 4) of the swimmers with this risk factor presented with a left shoulder injury compared to 43.67% (5 out 12 swimmers) without this risk factor [Risk ratio (RR) =1.80; 95%CI for RR 0.33 to 5.00].

4.2.5 Aquanex+Video Quantitative Data Results

The association between the quantitative risk factors and the binary variable “shoulder injury” (SI 3) was assessed using one-way ANOVA. Here the quantitative variable was the dependent variable, and the binary variable “shoulder injury” was the group variable.

P-values associated with the null-hypothesis of zero mean difference between injured and uninjured subjects are reported. Furthermore, the mean difference “Risk factor present - Risk factor absent” of the quantitative variable, as well as a 95% confidence interval for the mean difference, are reported.

Table 4-4. Aquanex+Video quantitative data – bilateral shoulders

Variable	Population (N)	Mean	Standard Deviation	P-Value
Stroke Velocity (meter/sec)	All (16)	1.41	0.20	0.2622
	Injured (10)	1.36	0.14	
	Uninjured (6)	1.48	0.27	
Stroke Rate (cycles/sec)	All (16)	0.70	0.11	0.3002
	Injured (10)	0.67	0.09	
	Uninjured (6)	0.73	0.13	
Stroke Length (meter/cycle)	All (16)	2.04	0.18	0.9247
	Injured (10)	2.04	0.18	
	Uninjured (6)	2.03	0.19	
Active Drag Coefficient	All (16)	0.88	0.12	0.6631
	Injured (10)	0.90	0.11	
	Uninjured (6)	0.87	0.15	

Table 4-4 suggests that the uninjured group outperformed the injured group in all the variables except stroke length, although none of the differences is statistically significant.

Table 4-5. Aquanex+Video quantitative data – left shoulder

Variable	Population (N)	Mean	Standard Deviation	P-Value
Average Peak Force – Left (Newton meter)	All (16)	96.75	32.55	0.8211
	Injured Left Shoulders (8)	94.81	27.50	
	Uninjured Left Shoulders (8)	98.69	38.80	
Stroke Velocity (meter/sec)	All (16)	1.41	0.20	0.3813
	Injured Left Shoulders (8)	1.36	0.16	
	Uninjured Left Shoulders (8)	1.45	0.23	
Stroke Rate (cycles/sec)	All (16)	0.70	0.11	0.3164
	Injured Left Shoulders (8)	0.67	0.09	
	Uninjured Left Shoulders (8)	0.72	0.11	
Stroke Length (meter/cycle)	All (16)	2.04	0.18	0.6536
	Injured Left Shoulders (8)	2.06	0.19	
	Uninjured Left Shoulders (8)	2.02	0.16	
Active Drag Coefficient	All (16)	0.88	0.12	0.2478
	Injured Left Shoulders (8)	0.92	0.10	
	Uninjured Left Shoulders (8)	0.85	0.13	

When isolating left shoulder injuries and comparing all the variables as set out in Table 4-5 it seems that the swimmers with a left shoulder injury had deficits in most of the parameters determining swimming speed. The only variable the injured group did better in was stroke length.

Table 4-6. Aquanex+Video quantitative data – right shoulder

Variable	Population (N)	Mean	Standard Deviation	P-Value
Average Peak Force – Right (Newton meter)	All (16)	90.09	32.82	0.4195
	Injured Right Shoulders (9)	84.01	21.50	
	Uninjured Right Shoulders (7)	97.91	44.16	
Stroke Velocity (meters/sec)	All (16)	1.41	0.20	0.2162
	Injured Right Shoulders (9)	1.35	0.14	
	Uninjured Right Shoulders (7)	1.48	0.27	
Stroke Rate (cycles/sec)	All (16)	0.70	0.11	0.1847
	Injured Right Shoulders (9)	0.66	0.09	
	Uninjured Right Shoulders (7)	0.74	0.12	
Stroke Length (meters/cycle)	All (16)	2.04	0.18	0.7027
	Injured Right Shoulders (9)	2.05	0.18	
	Uninjured Right Shoulders (7)	2.02	0.18	
Active Drag Coefficient	All (16)	0.88	0.12	0.7512
	Injured Right Shoulders (9)	0.88	0.09	
	Uninjured Right Shoulders (7)	0.90	0.16	

5 CHAPTER FIVE: Discussion of Results

Four strokes are recognized in competitive swimming: freestyle, butterfly, backstroke, and breaststroke (Wanivenhaus *et al*., 2012). Regardless of the stroke performed in competition, swimmers spend a considerable time swimming freestyle (Wanivenhaus *et al*., 2012). According to Sein *et al.,* (2010) more than 90% of the swimmers in their study spent more than 50% of their training time on freestyle. Most of the swimming propulsive force is derived from the arms, with the legs adding stabilization as well as propulsive force (McMaster, 1996). King (1995) stated that 80% of the propulsion power is derived from the pull and 20% from the kick during freestyle. In a competitive training program a swimmer can easily log up to a million arm strokes per year (McMaster, 1999) and can exceed 4000 strokes for one shoulder in a single workout, making swimming a common source of shoulder pathology (Tovin, 2006). The monotonous nature and the high volume of training involved in competitive swimming result in cumulative overload injuries (Rodeo, 1999). Shoulder pain is not only the most common complaint for swimmers, it has a high potential to have an impact on a swimmer's ability to compete (McMaster, 1999).

Epidemiologic studies have consistently noted a high incidence and prevalence of shoulder pain and dysfunction in competitive swimmers (Beach *et al.,* 1992; McMaster *et al.,* 1998; Puckree & Thomas, 2006; Bansal *et al*., 2007; Wolf *et al.,* 2009; Sein *et al*., 2010; Tate *et al*., 2012).

Prevention of injuries is an important aspect of athletic training. Our current understanding of injury causation is limited and must be improved to develop effective interventions for modifying injury risk. Identifying risk factors for shoulder injuries associated with certain freestyle pathomechanics therefore might improve incidence and/or prevalence of shoulder injuries under competitive swimmers.

5.1 Participants

Competitive swimmers begin their swimming careers as early as age seven, and most of them train and compete year round (Sein *et al*., 2010). Swimmers start their intensive training early, typically at the age of 8 to 11 years, and the amount of training can be excessive (Bak, 2010). Tate *et al.* (2012) found high school swimmers to be most symptomatic in their study of 236 female swimmers between 8 and 77 years of age.

Sixteen (n=16) competitive swimmers (6 male, 10 female) participated in this study. The age of the total sample ranged between 10 and 19 years with a mean age of 15.05 (± 2.78) years. This was similar to the population studied by Sein *et al.,* (2010) who reported a mean age of 15.9 (± 2.78) years. Ten (62.5%) of the swimmers were female, and 6 (37.5%) were male. In the study done by Sein *et al.,* (2010), 42 (53%) were male and 38 (47%) were female. The mean height was 166.63cm (±11.09), while the mean body mass was 59.44 kg (± 12.03). Nine (56.25%) of the swimmers qualified for Level 2, while two (12.5%) qualified for Level 3, one (6.25%) for Junior Nationals, three (18.75%) for Senior Nationals and one (6.25%) receiving National Colours.

5.2 General Swimming Information

5.2.1 Years Participating

The minimum participant requirements for participating in this study was swimming competitively for at least two and a half years. Most of the swimmers (n=15) in this study have been swimming competitively for 5 or more years with only 1 swimmer competing for 3 to 4 years. All the swimmers included in the study by Sein *et al.,* (2010) had been coached for at least two and a half years.

5.2.2 Stroke Preference

According to Wanivenhaus *et al*. (2012), regardless of the stroke performed in competition, swimmers spend a considerable time swimming freestyle. Kammer *et al*. (1999) avers that most (75% to 90%) of training is done in freestyle, irrespective of the swimmers' speciality. Not only was freestyle the most common stroke in a study by Wolf *et al.* (2009), it was also associated with the highest total number of injuries in their five-year survey of 94 National College Athletic Association (NCAA) Division I swimmers from the University of Iowa. Sein *et al.,* (2010) reported that more than 90% of the swimmers in their study spent more than 50% of their training time on freestyle. They further noted that the swimmers approximately spent 13% of their training time on butterfly, 21% on back stroke and 13% on breaststroke. Considering the swimmers' main event in the latter study, 35% specialised in freestyle, 19% in butterfly, 24% in backstroke and 5% were individual medley swimmers. Puckree and Thomas (2006) found that 69% of the swimmers in their study competed in freestyle.

In accordance with the above findings, freestyle was the most popular stroke in this study with 9 (56.25%) swimmers preferring it. Breaststroke, backstroke and individual medley were respectively preferred by 2 (12.5%) swimmers and only 1 (6.25%) swimmer preferred butterfly. Recent research suggests that most swim training is done in freestyle. Therefore, analysis of freestyle biomechanics might play a role not only in performance, but also in injury prevention.

5.2.3 Distance Preference

Middle distance was the favourite distance among the participants with 10 (62.5%) of the swimmers claimed to favour these distances (200m-400m). Four (25%) preferred sprints (50m-100m) and 2 (12.5%) open water events. None of the participants showed an interest in the 800m-1500m category. These findings were different than the findings by Puckree and Thomas (2006) who found most swimmers (70%) in their study specialising in sprints. Wolf *et al*. (2009) found that the risk of suffering an injury was not significantly different between sprinters and distance swimmers. This seems true as the percentage injured swimmers in this study was in line with that found by Puckree and Thomas (2006), despite the difference in distance preference.

5.2.4 Breathing Side

Nine (56.25%) of the participants claimed to breath bilaterally while 7 (43.75%) breathed to the right only. None of the swimmers breathed to the left when swimming freestyle.

5.3 Swim Training Variables

Tovin (2006) remarked that training errors such as overuse, misuse, abuse or disuse may contribute to shoulder pain in swimmers. In their study on the cause of shoulder injuries in swimmers, Sein *et al*. (2010) found that the incidence of supraspinatus tendinopathy was related to time spent training (hours swim per week) and distance swim per week. From the latter research, swimmers who swam more than 15 hours per week were twice as likely to have tendinopathy as those who trained for less time. Swimmers who swam more than 35km per week were four times more likely than those who swam fewer kilometres (Sein *et al.,* 2010). Besides these findings they further noted that a greater proportion of swimmers competing at a higher level of competition had an increased incidence of supraspinatus tendinopathy than swimmers at lower competitive levels. These findings are supported by the findings of Tate *et al.* (2012) who found that high school swimmers practised on average 16 hours per week and had the highest prevalence (22.6%) of symptomatic shoulders. Tate *et al.* (2012) further proposed that shoulder pain, dissatisfaction, and disability correlates positively with increased repetitive upper extremity usage in terms of swimming or water polo exposure for mature swimmers.

5.3.1 Frequency

The swimmers in the study done by Puckree and Thomas (2006) trained on average 11 sessions per week, which is much higher than the population in this study. In this study 8 (50%) of the participants indicated swimming 3 to 4 sessions per week while the other 8 (50%) trained for more than 5 sessions per week.

5.3.2 Time

Tate *et al.* (2012) found that high school swimmers practised on average 16 hours per week had the highest prevalence (22.6%) of symptomatic shoulders. The average length of the swimmer's training sessions in Puckree and Thomas' (2006) study was 90 minutes. In this study 8 (50%) trained for 90 minutes or more per session, 6 (37.5%) trained 60 to 75 minutes per session while 1 (6.25%) indicated training 45 to 60 minutes per session and 1 (6.25%) indicated training 75 to 90 minutes per session. Sein *et al.,* (2010) reported that the amount of time the swimmers practised in the water varied between 9 and 110 km/week. Time spent in the water training seems to relate to the risk of shoulder injury and should accurately be captured in future studies to determine its relevance to shoulder injury.

5.3.3 Distance

The swimmers in the study by Sein *et al.,* (2010) swam between 9 and 110 km/week with a median distance of 40km/week. In this study 5 (31.25%) swimmers on average covered 3 to 4 kilometres per session, while 11 (68.75%) covered more than 4 kilometres per session.

5.4 Shoulder Injury

Shoulder pain is not only the most common complaint for swimmers it has a high potential to have an impact on a swimmer's ability to compete (McMaster, 1999). It has been suggested that swimmers with interfering shoulder pain might not progress in training and will therefore not compete as effectively (McMaster & Troup, 1993), and injuries to the shoulder can be devastating (McMaster, 1999).

5.4.1 Prevalence of Shoulder Injury

Recent studies reported the prevalence of shoulder injuries ranging from 17% to 91% (McMaster & Troup, 1993; McMaster *et al.,* 1998; Puckree & Thomas, 2006; Bansal *et al*., 2007; Wolf *et al.,* 2009; Sein *et al*., 2010; Tate *et al*., 2012) and an incidence between 10% and 69% (Beach *et al., 1992;* McMaster & Troup, 1993). An alarmingly high prevalence of shoulder injury was found by Sein *et al.* (2010) who reported a 91% of swimmers experienced shoulder pain. This correlated with the work done by Beach *et al.* (1992) who claimed a prevalence of 87% and an incidence of 69%.

In this study 10 (62.5%) of the participants reported having a shoulder injury during the 2014/2015 season. Similar to these results, Puckree and Thomas (2006) reported that 70% of their respondents experienced shoulder pain, while 64% presented with actual shoulder injuries. Conflicting with this, Bansal *et al.* (2007) found a prevalence of 17% of shoulder injuries in their study on 161 male swimmers, which was in line with the findings of Tate *et al.* (2012) who reported a shoulder injury prevalence of about 20%.

The inconsistent findings may be due to the different study designs used (retrospective vs. prospective), and the definition of the severity of the injury. For instance, Wolf *et al.* (2009) defined an injury as: "...any musculoskeletal problem suffered as a consequence of team related activity that resulted in a visit to an athletic trainer or physician", whereas McMaster and Troup (1993) defined a shoulder injury as: "that which interfered with training or progress in training as opposed to post exercise muscle soreness". Notwithstanding, the high incidence and/or prevalence of shoulder injuries in swimmers, the literature is beset with controversy surrounding its aetiology.

5.4.2 Prevalence of Shoulder Injury and Gender

Eight (80%) of the injured swimmers in this study were female, while only 2 (20%) were male. Coincidentally eight (80%) of the 10 female swimmers presented with a shoulder injury and only 2 (30%) of the 6 male swimmers were injured. In line with the above findings, a study done during the 13th FINA World Championships 2009 found female athletes to be at a higher risk of injury than their male counter parts (Mountjoy *et al.,* 2010). Contrary to this finding, neither Ristolainen *et al.* (2009) nor Wolf *et al.* (2009) found a correlation between risk of injury and gender.

Becker (2011) reported that swimmer's shoulder syndromes, under female swimmers, are likely to occur approximately three times over a career span:

- The first occurrence is usually during early to mid-adolescence when the body weight is likely to increase and arm strength is not fully developed while the swimmer is moving to a higher age group.
- The second period is in the later stages of high school competition. Although the body weight is almost settled, the upper body is not sufficiently strong enough to withstand the harder training.
- The third period is during the transition from high school to college swimming. Collegiate swimming often entails dramatic increases in training volume and intensity. In keeping with the latter Wolf *et al.* (2009) reported that the highest total number of injuries and the highest mean number of injuries per swimmer occurred during the freshman year of eligibility. They concluded that this might be due to an increase in swimming yardage and additional cross training activities than at high school level.

Becker (2011) further suggested that in males, two peak times for onset of injury occur:

- First, at the end of the second growth spurt, when the body size increases but shoulder muscles are not yet developed.
- The second time when injury occurs is the high training point of the freshman year, when the yardage exceeds previous distances and these increases occur over a period of a few days.

The results of this study suggest that female swimmers are more at risk of experiencing a shoulder injury. When considering the work done by Becker (2011) it seems that female swimmers are at risk of shoulder injury for most of their competitive swimming careers. Another contributing factor might be that there is probably no differentiation made between the male and female swimmers' training volume and intensity. Female swimmers practising at the same intensity and volume as their male counterparts might be at an increased risk of shoulder injury. This is should be ventured in future research.

5.4.3 Prevalence of Shoulder Injury and Age

Sein *et al.* (2010) found that 100% (8/8) of the swimmers between 17 to 18 in their study presented with supraspinatus tendinopathy. This was in line with the findings in this study where the 17 to 18 years age category also seemed to be the most susceptible to shoulder injury. Three (75%) of the four swimmers in this age category presented with a shoulder injury. This was followed by the 13 to 14 years age category with 67% (4 out of 6 swimmers) injured and 67% (2 out of 3) of the 11 to 12 years age category reported a shoulder injury. Differing results from Puckree and Thomas (2006) was reported, where swimmers between 15 to 16 years of age seemed to have a higher risk of shoulder injuries. It is inconclusive whether certain age categories are more at risk for experiencing shoulder injuries/pain than others.

5.4.4 Mechanism of Injury

All the injured swimmers in this study averred that the cause was overuse during swim training not due to trauma. Opposing these findings, Puckree and Thomas (2006) reported 65% of injuries due to overuse, and 25% traumatic injuries. Wolf *et al.* (2009) reported that nearly 60% of the injuries in their study was training/practice related, while 38% was due to team activities out of the pool, including strength training and dryland workouts.

5.4.5 Side of Injury

Bilateral shoulder injuries were experienced by 7 (70%) of the injured swimmers in this study, while 2 (20%) experienced symptoms right only, and 1 (10%) left only. The prevalence of bilateral shoulder pain was higher than that found by Sein *et al.* (2010). In their cross-sectional study on a group of 80 elite swimmers, 43 (54%) reported unilateral shoulder pain, and 30 (37%) others reported bilateral shoulder pain.

5.4.6 Injury Severity

Disabling pain during and after workouts that interfered with the swimmers' performance described 6 (60%) of the participants in this study's symptoms. Three (30%) swimmers experienced pain/ache (not disabling) during and after workouts. Only 1 (10%) reported pain/ache after heavy workouts. Beach *et al.* (1992) found that 31% of their participants had a shoulder injury affecting their swimming ability.

None of the participants in this study stopped swimming as a result of shoulder pain or injury, whereas Puckree and Thomas (2006) reported that 75% of the swimmers in their study who complained of a shoulder injury, had to stop swimming temporarily for 2 to 3 weeks. Interestingly Abgarov *et al.* (2012) found a negative effect for taking off from the sport of swimming. The expectation was that taking time off would reduce injury risk but found an increased risk of injury instead. They further elaborated, that those athletes who took time off placed unrealistic expectations on themselves once they returned to the sport. This attitude of attempting to make up for lost time and/or 'catch up' to familiar swimmers, would increase the risk of injury as time off from the sport puts an athlete/swimmer behind with regards to their development or fitness levels (Abgarov *et al.,* 2012).

5.4.7 Painful Phases during the Freestyle Stroke

Swim training involves repetitive overhead movement (Sein *et al*., 2010). In a competitive training program a swimmer can easily log up to a million arm strokes per year (McMaster, 1999) and can exceed 4000 strokes for one shoulder in a single workout, making swimming a common source of shoulder pathology (Tovin, 2006). Swimming requires several different shoulder motions, most being performed during circumduction in clockwise and counter-clockwise directions with varying degrees of internal and external rotation and scapular protraction and retraction (Tovin, 2006).

In their study on 11 male College swimmers, Yanai and Hay (1998) found the mean duration of impingement positioning during freestyle swimming to be up to 24.8%, with 14.4% of this occurring during pulling and 10.4% during recovery. The latter is in line with the findings by Pink and Tibone (2000) who explained that the first half of the pull through is the most frequently identified painful phase. According to them, approximately 70% of the symptoms noted when swimming freestyle occur during this phase. They further acknowledged that the first half of the recovery is another vulnerable point where 18% of symptoms are experienced.

In accordance to the above, 6 (60%) of the injured participants in this study only experienced their symptoms during the early pull through phase while 1 (10%) swimmer only experienced symptoms during the recovery phase. However, 3 (30%) experienced symptoms during both the early pull through and recovery phase. This is probably due to the to the arm being in the vulnerable impingement position (shoulder in abduction and internal rotation) during both these phases. Swimming drills advancing increased time spent in these positions should be avoided in an attempt to decrease the risk of shoulder injury.

5.4.8 Freestyle Pathomechanics and Shoulder Injuries

McMaster (1996) mentioned that many injuries originate from faulty techniques or mechanisms, and an assessment of injured athletes' biomechanics must be made to identify factors that may contribute to injury. Some specific freestyle technical flaws heavily stress the shoulders and can lead to overuse (Kammer *et al.*, 1999). Yanai and Hay (1998) suggested that certain stroke techniques and/or physiques might be less vulnerable to shoulder impingement than others. Stroke mechanics not only seems important in injury prevention, but the energy cost of freestyle swimming (ml/m) appears to be strongly influenced by the swimmers lean body weight and the effective application of force during the arm stroke (Costill *et al.*, 1985). Tovin (2006) suggested that the treatment of competitive swimmers should focus on prevention and early treatment, addressing the impairments associated with the condition, and analysing training methods and stroke mechanics.

The freestyle stroke pull-cycle can be divided in four phases (José *et al.*, 2012):

1. Early pull-through: beginning with the hand entry into the water and ending when the humerus is perpendicular to the axis of the torso.
2. Late pull-through: beginning at the completion of early pull-through and ending as the hand leaves the water.
3. Early recovery: beginning at hand exit and ending when the humerus is perpendicular to the water surface.
4. Late recovery: beginning at the completion of early recovery and ending at hand entry.

Underwater video analysis was done on the 16 study participants to evaluate if certain freestyle biomechanics or pathomechanics was associated with an increased risk of shoulder injury. The presence of the following freestyle pathomechanics increased the risk of shoulder injury (observed risk ratio 1.5 or higher).

5.4.8.1 Hand Entry

Scovazzo *et al*. (1991) found that swimmers with painful shoulders had a different pattern of hand entry than those with normal shoulders. According to them the hand entered further away from the midline. None of the swimmers in this study presented with this risk factor. Contrary to this, Johnson *et al.* (2003) suggested that a hand entry that crosses the midline of the long axis of the body, causes mechanical impingement in the anterior shoulder, including the long head of the biceps and supraspinatus. This is exacerbated by a thumb first entry which further stresses the biceps attachment to the anterior labrum (Johnson *et al.,* 2003). According to the latter authors, a crossover pull through usually results from a crossover entry, and increases the time in the impingement position.

In this study swimmers with a right hand crossing the midline upon hand entry were 1.6 times more likely to present with a right shoulder injury than swimmers without this risk factor. This finding was inconsistent with the corresponding data for the left shoulder. For swimmers with a left hand crossing the midline upon hand entry the risk ratio of injury to the left shoulder was only 0.77. However, swimmers entering with the left hand between the midline of the body and the shoulder were 1.6 times more likely to present with a left shoulder injury. It is not clear whether entering with the hand crossing the midline or entering with the hand between the midline of the body and the shoulder increases the risk of shoulder injury due to the inconsistent findings between right and left shoulders.

Interestingly, the analysis of the left shoulder revealed that swimmers entering with the left thumb first had a 1.6 times higher risk of left shoulder injury than the swimmers without this risk factor. Swimmers with the same risk factor on the right side had a moderately increased risk of presenting with a shoulder injury, and were 1.3 times more likely to experience symptoms. Although this is below the observed risk ratio of 1.5 it increases the risk of injury moderately.

It seems that entering with the thumb first during hand entry increases the risk for shoulder injury. This is probably due to the fact that this position increases internal rotation of the humerus, thus increasing the pressure on the subacromial structures and producing symptoms. We note again, however, that none of these biomechanical variables correlated statistically significantly with an injury of the shoulder,

5.4.8.2 Hand/Arm Position at the end of the Hand Entry Phase

Yanai and Hay (1998) reported that the hydrodynamic force exerted on the hand during entry could forcibly elevate the arm beyond normal maximum active flexion, placing the shoulder in a position of hyperflexion, causing impingement. In accordance with this, Becker and Havriluk (2012) found that an intentional effort to complete the arm entry with the arm parallel to the surface is a technique factor that contributes to an ineffective arm position, increased shoulder stress, minimal force production and breaks in propulsion. This was consistent with the findings of this study. Both swimmers (2 out of 2;100%) with a hand/arm position where the shoulder is in hyperflexion with the fingers facing upward on the right arm, presented with a right shoulder injury (2/2; 100%), while 75% (3 out of 4) of swimmers with this risk factor in the left arm reported a shoulder injury. Swimmers had a risk ratio of 2.00 and 1.80 on the right and left arm respectively, in the presence of this risk factor. Although this is not statistically significant due to the small sample size, this might be a risk factor to consider in future studies.

5.4.8.3 Early Pull Through Phase– Elbow Position

According to Yanai and Hay (1998) the shoulder is abducted and internally rotated during the pull phase. One of the most commonly described technical faults in freestyle swimming is called the “dropped elbow” (Figure 2-11) and occurs during this phase (Yanai & Hay 1998). Dropping the elbow constitutes increasing shoulder external rotation, in an attempt to avoid the painful internal rotation causing impingement (Richardson *et al.,* 1980). This position places the muscles of propulsion at a mechanical disadvantage (Richardson *et al.,* 1980). It is still unknown whether the stroke alterations seen in swimmers with symptomatic shoulders are the cause or the consequence of pain (Heinlein & Cosgarea, 2010).

In this study, neither swimming with a high elbow, nor a dropped elbow seemed to increase risk for a shoulder injury. None of these biomechanical variables correlated significantly with an injury of the right shoulder, which can be attributed to the relatively small sample size.

5.4.8.4 Early Pull Through Phase– Hand Position

In this study, it seemed that a left-hand position outside the elbow during the early pull through phase increased the risk of injury to the left shoulder. All (4 out of 4) swimmers with this risk factor on the left arm presented with a left shoulder injury, compared to 33% (4 out of 12) injured swimmers without it. Swimmers with this risk factor on the left hand were 3 times more likely to sustain a shoulder injury. Comparing this to the findings of the right shoulder, in the presence of this risk factor swimmers were 1.24 times more likely to sustain a right shoulder injury. Although this is below the observed risk ratio of 1.5 it increases the risk of injury moderately.

It appears that swimming with a hand position outside the elbow during the early pull through phase increases the risk of shoulder injury and should therefore be considered for future research. None of these biomechanical variables correlated statistically significantly with an injury of the shoulder, which can be attributed to the relatively small sample size.

5.4.8.5 Catch-up Stroke

Intentional maintenance of the arm in a position parallel to the surface (as in catch up stroke), causes torso rotation to increase the time of exposure of the shoulder in a hyperflexed position, and exacerbates shoulder stress (Becker & Havriluk, 2012).

In line with the above notion 75% (3 out of 4) of the swimmers swimming catch up stroke with the right hand/arm had a right shoulder injury, compared with 50% (6 out of 12) of the swimmers without this risk factor on the same side. Swimmers presenting with this risk factor in the right arm/hand were 1.5 times more likely to sustain a right shoulder injury. In line with the findings for the right shoulder, swimming ‘catch-up stroke’ with the left arm also increases the risk for left shoulder injury. Seventy five percent (3 out of 4) of the swimmers with this risk factor left presented with a left shoulder injury compared to 43.67% (5 out of 12) without this risk factor. Swimmers presenting with this risk factor in the left arm/hand were 1.8 times more likely to present with a shoulder injury on the left shoulder.

Although this is not statistically significant due to the small sample size, this might be a risk factor to consider in future studies.

5.5 Aquanex+Video Quantitative Data Analysis and Shoulder Injuries

When considering the Aquanex+Video data as outlined in Table 6 (Chapter 4) it becomes apparent that the uninjured swimmers outperformed injured swimmers in all the variables except stroke length. The injured swimmers had an average stroke velocity (meter per second travelled at the completion of one stroke cycle) of 1.36m/s, while the uninjured swimmers had an average stroke velocity of 1.48m/s. To calculate the time to complete an event, the following equation can be used

$$\text{Time} = \text{Distance (m)} \div \text{Stroke Velocity (m/s)}$$

This in turn means that the uninjured swimmers can, on average, do a 50m freestyle sprint in 33.78s and the injured swimmers in 36.76s. Swimmers with overuse injuries seldom stop swimming, but the injury has a detrimental effect on performance. Although these findings are to be expected, this data outlines the importance of injury prevention.

6 Conclusion and Recommendations

This study focused on a specific, small population. The small sample size implied that the study had low power to detect statistically significant risk factors. Nevertheless, the study results suggest that some freestyle bio- or pathomechanics might increase the risk for shoulder injury and are therefore worthy of further research.

Objective 1: Determine the shoulder injury prevalence at the University of the Free State's swimming club (Kovsie Aquatics), during the 2014/2015 swimming season.

The prevalence of shoulder injuries in this study was 62.5%. All the injured swimmers indicated that their injuries were caused by overuse during swim training. Interestingly, in this study, the female swimmers seem to be at a higher risk for shoulder injuries than their male counterparts. Eighty percent (8 out of 10) of the female swimmers in this population presented with a shoulder injury, compared to 30% (2 out of 6) of the male swimmers. The 17 to18 age category seemed to be most susceptible to injury, with 75% (3 out of 4) of the swimmers in this age category presenting with a shoulder injury. Bilateral shoulder injuries were experienced by 70% of the injured swimmers in this study, while 20% experienced symptoms right only, and 10% left only.

Objective 2: Investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries amongst swimmers from the swimming club exist.

In this study, 6 (60%) of the injured participants only experienced their symptoms during the early pull through phase while 1 (10%) swimmer only experienced symptoms during the recovery phase. However, 3 (30%) experienced symptoms during both the early pull through and recovery phase. This is probably due to the to the arm being in the vulnerable impingement position (shoulder abduction and internal rotation) during both these phases. Swimming drills advancing increased time spent in these positions should be avoided in an attempt to decrease the risk of shoulder injury. Although none of the risk factors investigated in this study was statistically significant, the presence of the following freestyle pathomechanics increased the risk of shoulder injury (observed risk ratio 1.5 or higher), and should be considered in future research of this problem:

1. A right hand that crosses the midline upon hand entry (RR 1.61; 95% CI 0.67 to 3.83)
2. Thumb first hand entry (Right: RR 1.34; 95% CI 0.58 to 3.09; Left: RR 1.67; 95% CI 0.58 to 3.09)
3. A left hand entering between the midline of the body and the shoulder (RR 1.67; 95% CI 0.57 to 9.43)
4. Hand/Arm position where the shoulder is in hyperflexion with the fingers facing upward at the end of the entry phase (Right: RR 2.00; 95% CI 0.21 to 4.34; Left: RR 1.80; 95% CI 0.33 to 5.00)
5. Hand position outside the elbow during the early pull through phase (Right: RR 1.24; 95% CI 0.13 to 3.03; Left: RR 3.00; 95% CI 1.13 to 10.08)
6. Swimming ‘catch-up’ stroke (Right: RR 1.50; 95% CI 0.67 to 3.34; Left: RR 1.80; 95% CI 0.33 to 5.00)

6.1 Conclusion

In the current study the prevalence of shoulder injuries is alarmingly high at 62.5%. Female swimmers seem to be at a higher risk for shoulder injuries than their male counterparts. A relationship between certain freestyle pathomechanics and shoulder injuries in this population might exist, and some potential risk factors were identified. Due to the relatively small sample size none of the risk factors for shoulder injury, based on freestyle pathomechanics, was statistically significant. Only indications and directions for future research can be suggested.

6.2 Recommendations

This study was done retrospectively and some data recorded using questionnaires are subjected to the memory of the participants. An obvious shortcoming is the relatively small sample size (16 participants) resulting that none of the findings were statistically significant, which makes drawing conclusions difficult.

It is recommended that future research should be focused on injury prevention through the development of consensus statements for swimming injuries. This would further our understanding of swimming related injuries and injury prevention.

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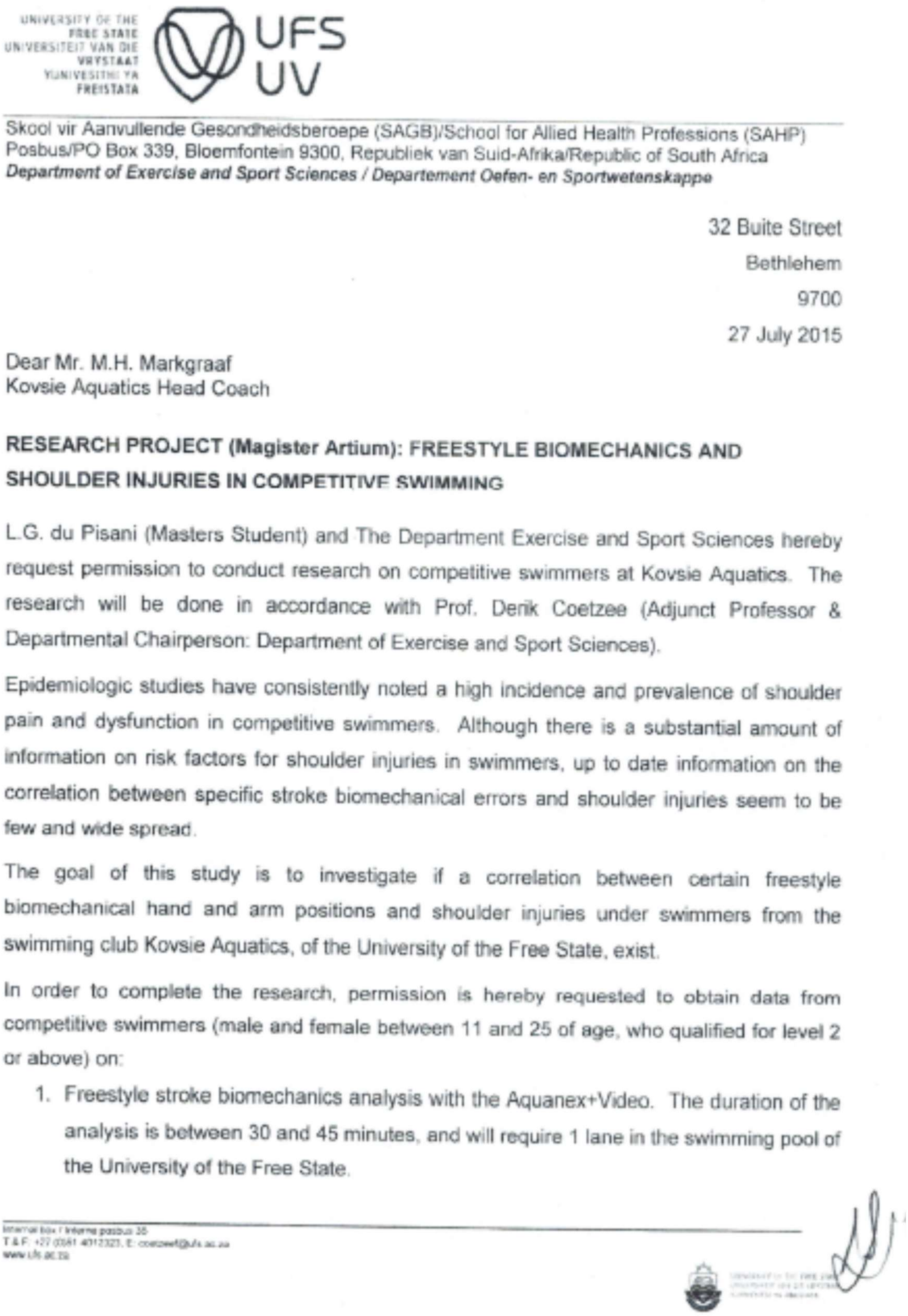
8 Appendices

8.1 Appendix A - Permission Letter (Mr. M. Markgraaff)



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Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

32 Buite Street
Bethlehem
9700
27 July 2015

Dear Mr. M.H. Markgraaf
Kovsie Aquatics Head Coach

RESEARCH PROJECT (Magister Artium): FREESTYLE BIOMECHANICS AND SHOULDER INJURIES IN COMPETITIVE SWIMMING

L.G. du Pisani (Masters Student) and The Department Exercise and Sport Sciences hereby request permission to conduct research on competitive swimmers at Kovsie Aquatics. The research will be done in accordance with Prof. Derik Coetzee (Adjunct Professor & Departmental Chairperson: Department of Exercise and Sport Sciences).

Epidemiologic studies have consistently noted a high incidence and prevalence of shoulder pain and dysfunction in competitive swimmers. Although there is a substantial amount of information on risk factors for shoulder injuries in swimmers, up to date information on the correlation between specific stroke biomechanical errors and shoulder injuries seem to be few and wide spread.

The goal of this study is to investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries under swimmers from the swimming club Kovsie Aquatics, of the University of the Free State, exist.

In order to complete the research, permission is hereby requested to obtain data from competitive swimmers (male and female between 11 and 25 of age, who qualified for level 2 or above) on:

1. Freestyle stroke biomechanics analysis with the Aquanex+Video. The duration of the analysis is between 30 and 45 minutes, and will require 1 lane in the swimming pool of the University of the Free State.

Internal box / Interne posbus 35
T & F: +27 (0)51 4012323, E: coetzeet@ufs.ac.za
www.ufs.ac.za

2. Measurements including height, weight and shoulder internal and external rotation.
3. Medical and training history through a survey questionnaire, self-administered under classroom-style supervision obtaining information regarding the 2014/2015 swimming season (1st of May 2104 to the 30 of April 2015).

Your assistance in this matter will be greatly appreciated.

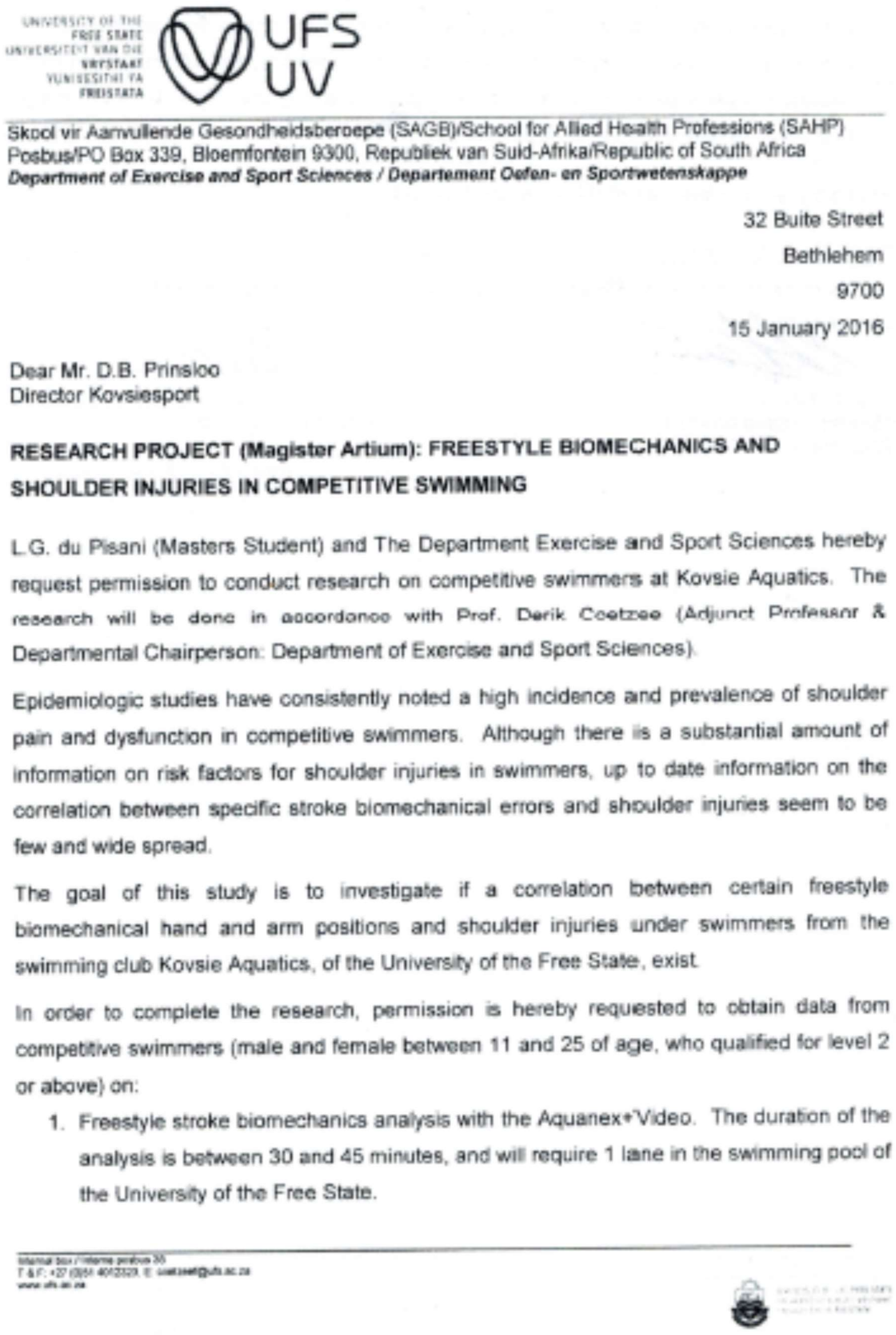
I, Marco Markgraaff, ID nr. 8005185038081 hereby give permission to L.G. du Pisani to collect data from the swimmers, meeting the criteria, affiliated with Kovsie Aquatics

L.G. du Pisani
Masters Degree Student
(Student nr. 2005000977)

Mr M.H. Markgraaff
(Head Coach – Kovsie Aquatics)

28/7/2015 Date

8.2 Appendix B - Permission Letter (Mr. D.B. Prinsloo)



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Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

32 Buite Street
Bethlehem
9700
15 January 2016

Dear Mr. D.B. Prinsloo
Director Kovsiesport

RESEARCH PROJECT (Magister Artium): FREESTYLE BIOMECHANICS AND SHOULDER INJURIES IN COMPETITIVE SWIMMING

L.G. du Pisani (Masters Student) and The Department Exercise and Sport Sciences hereby request permission to conduct research on competitive swimmers at Kovsie Aquatics. The research will be done in accordance with Prof. Derik Coetzee (Adjunct Professor & Departmental Chairperson: Department of Exercise and Sport Sciences).

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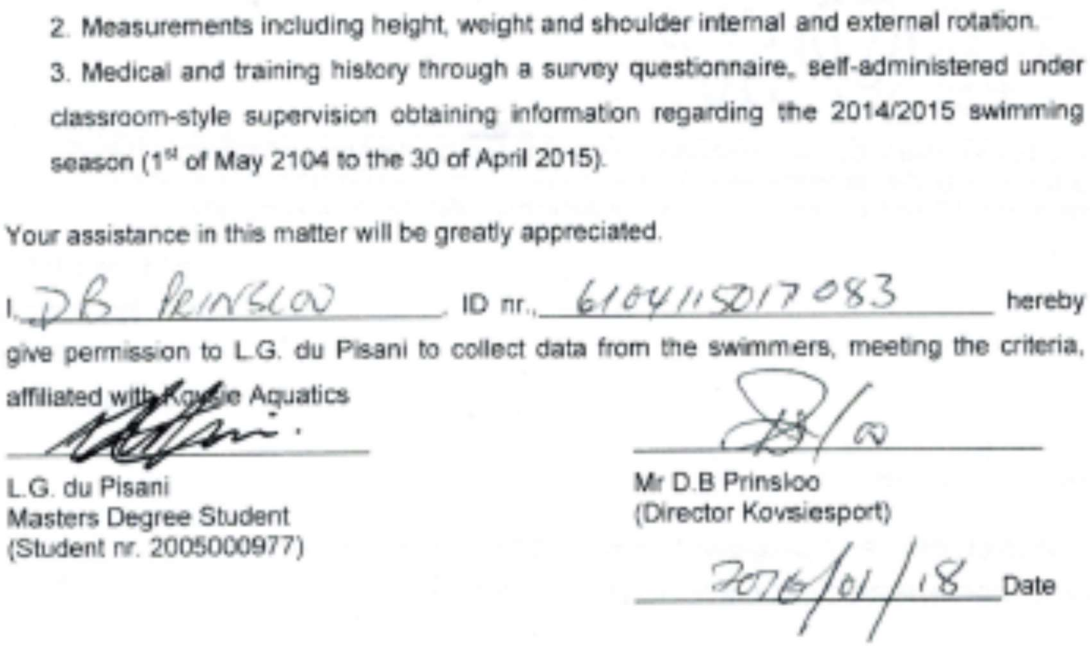
The goal of this study is to investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries under swimmers from the swimming club Kovsie Aquatics, of the University of the Free State, exist.

In order to complete the research, permission is hereby requested to obtain data from competitive swimmers (male and female between 11 and 25 of age, who qualified for level 2 or above) on:

1. Freestyle stroke biomechanics analysis with the Aquanex+Video. The duration of the analysis is between 30 and 45 minutes, and will require 1 lane in the swimming pool of the University of the Free State.



2. Measurements including height, weight and shoulder internal and external rotation.

3. Medical and training history through a survey questionnaire, self-administered under classroom-style supervision obtaining information regarding the 2014/2015 swimming season (1st of May 2104 to the 30 of April 2015).

Your assistance in this matter will be greatly appreciated.

I, DB PRINSLOO, ID nr., 6104115017083 hereby give permission to L.G. du Pisani to collect data from the swimmers, meeting the criteria, affiliated with Kovsie Aquatics

L.G. du Pisani
Masters Degree Student
(Student nr. 2005000977)

Mr D.B Prinsloo
(Director Kovsiesport)

2016/01/18 Date

8.3 Appendix C - Ethical Clearance

Faculty of the Humanities

08-Oct-2015

Dear Mr **Du Pisani**

Ethics Clearance: **Freestyle biomechanics and shoulder injuries in competitive swimming**

Principal Investigator: Mr **Louis Du Pisani**

Department: **Exercise and Sport Sciences (Bloemfontein Campus)**

APPLICATION APPROVED

With reference to your application for ethical clearance with the Faculty of the Humanities. I am pleased to inform you on behalf of the Research Ethics Committee of the faculty that you have been granted ethical clearance for your research.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2015/0526**

This ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the ethics office to ensure we are kept up to date with your progress and any ethical implications that may arise.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely

Prof. Stephen Walker
Chairperson: Research Ethics Committee
Faculty of the Humanities

8.5 Appendix D - Information Document

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Skool vir Aanvullende Gesondheidsberoepe (SAGB)/School for Allied Health Professions (SAHP)
Posbus/PO Box 339, Bloemfontein 9300, Republiek van Suid-Afrika/Republic of South Africa
Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

Freestyle Biomechanics and Shoulder Injuries in Competitive Swimming

Epidemiologic studies have consistently noted a high incidence and prevalence of shoulder pain and dysfunction in competitive swimmers. Although there is a substantial amount of information on risk factors for shoulder injuries in swimmers, up to date information on the correlation between specific stroke biomechanical errors and shoulder injuries seem to be few and wide spread.

The goal of this study is to investigate if a correlation between certain freestyle biomechanical hand and arm positions and shoulder injuries under swimmers from the swimming club Kovsie Aquatics, of the University of the Free State, exist.

Data on freestyle biomechanics will be gathered through a freestyle stroke biomechanics analysis with the Aquanex+Video (underwater camera system). The duration of the analysis is between 30 and 45 minutes, and will be done at swimming pool of the University of the Free State. The following measurements will be taken: weight, height, shoulder internal and external rotation. Medical and training history data will be gathered through a survey questionnaire, self-administered under classroom-style supervision obtaining information regarding the 2014/2015 swimming season *(1st of May 2104 to the 30 of April 2015)*.

Your participation in this research project will be greatly appreciated. Your participation is voluntary. The researcher undertakes to handle all personal information in a confidential manner.

The results of the research study may be used by L.G. du Pisani and/or the Department of Exercise and Sport Sciences of the University of the Free State for presentations at national / international congresses and for articles published in health journals.

Contact detail of researcher:

L.G. du Pisani	083 657 7568

Contact detail of Study Leader:

Prof. Derik Coetzee:	051 401 2944

8.6 Appendix E - Informed Consent

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Freestyle Biomechanics and Shoulder Injuries in Competitive Swimming

Research is the process to learn the answer to a question. L.G. du Pisani and the Department of Exercise and Sport Sciences are conducting research on competitive swimming at Kovsie Aquatics. This research is done to improve the understanding of the correlation between freestyle biomechanics and shoulder injuries under swimmers affiliated with Free State Aquatics.

Data collected from each participant enrolled in this study will include:

- A Freestyle Stroke Biomechanics analysis with the Aquanex+Video (an underwater camera system). This will be done at the University of the Free State swimming pool.
- The following measurements will be taken: weight, height, shoulder internal and external rotation.
- Medical and training history through a survey questionnaire, self-administered under classroom-style supervision obtaining information regarding the 2014/2015 swimming season (1st of May 2014 to the 30 of April 2015).

Participation is voluntary and refusal to participate will involve no penalty or loss of benefits to which the participant is otherwise entitled; the participant may discontinue participation at any time without penalty or loss of benefits to which the participant is otherwise entitled.

I have read the above and understand the nature of this study. I understand that by participating or allowing my child to participate in this study I may contact the researchers at the University of the Free State at any time. I voluntary agree to participate or let my child participate in this study. I understand that I may refuse that me or my child participate and may withdraw from the study at any time without prejudice.

I, ____________________________, parent/guardian of ______________________, hereby give permission to participate in this study.

Parent/guardian's Signature: ____________________ Date: ___________________

I, ____________________________, the participant, hereby give permission to participate in this study.

Participant's Signature: ________________________ Date: ___________________

Researcher's Signature: _______________________ Date: ___________________

8.7 Appendix F - Under Aged Informed Assent

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Department of Exercise and Sport Sciences / Departement Oefen- en Sportwetenskappe

Freestyle Biomechanics and Shoulder Injuries in Competitive Swimming

You are being asked to participate in a research study. Research is the process to learn the answer to a question. L.G. du Pisani and the Department of Exercise and Sport Sciences are doing research on competitive swimming at Kovsie Aquatics and is inviting you to participate. In this study we are interested in finding out what in your freestyle stroke might cause a shoulder injury.

If you decide to take part in this study, the following will be expected from you:

- An underwater video of you swimming freestyle will be recorded for analysis. When doing this, sensors will be placed between your fingers, which will give the researcher feedback on how much force you are generating while swimming. This will be done at the University of the Free State swimming pool.
- The following measurements will be taken: weight, height, shoulder range of motion.
- You will be asked fill out a questionnaire collecting information on possible shoulder injuries, as well your training history, during the last year.

By signing this you are showing that you understand what is going to be happening and have asked any questions you may have about the research. You can also ask questions later if you cannot think of them now. Signing this form does not mean you have to finish the study – you withdraw from this study at any time without giving reasons for doing so.

- Child’s Signature: ___________________________ Date: ___________________

8.8 Appendix G - Aquanex Testing Sheet

Aquanex Testing Sheet

Code	Swimmer	Date of Birth (dd/mm/yy)	Test Date (dd/mm/yy)	Sex (M/F)	Length (cm)	Weight (kg)	Highest Qualifying Level
1							
2							
3							
4							
5							
6							
8							
9							
10							
11							
12							
13							
14							
15							
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22							
23							
24							
25							
26							
27							
28							
29							
30							

8.9 Appendix H - Sport and Symptom Survey Questionnaire

Swimmer Code: _______

General Swimming Information

1. **What is your preferred stroke (please mark with *X*)?**
   - Freestyle ☐
   - Fly ☐
   - Breaststroke ☐
   - Backstroke ☐
   - IM (Individual Medley) ☐

2. **How many years have you been swimming competitively?**
   - 1-2 ☐
   - 3-4 ☐
   - 5 or more ☐

3. **When swimming Freestyle, what side do you normally turn to breath?**
   - Right ☐
   - Left ☐
   - Both ☐

4. **What is your favourite distance?**
   - 50-100m ☐
   - 200-400m ☐
   - 800-1500m ☐
   - Open water (>1500m) ☐

Swim Training Variables

1. **How many sessions do you train on average per week?**
   - 1-2 ☐
   - 3-4 ☐
   - 5 or more ☐

2. **How many minutes do you train on average per session?**
   - 30-45min ☐
   - 45min-60min ☐
   - 60-75min ☐
   - 75min-90min ☐
   - 90min or more ☐

3. **How many kilometres do you cover on average per session?**
   - 1-2 ☐
   - 3-4 ☐
   - 4-5 ☐
   - 5 or more ☐

Shoulder Injury

1. **Have you had previous surgery done on either one/both your shoulders?**
   YES ☐
   NO ☐

2. **Have you ever had a shoulder fracture?**
   YES ☐
   NO ☐

3. **Did you experience a shoulder injury (as a direct result of swimming or swimming related activities – including dry land training) in the 2014/2015 season?**
   YES ☐
   NO ☐
   If **YES**, please answer the following questions:

4. **Did the injury occur during a gala, swim training or dry land training?**
   Gala ☐
   Swim Training ☐
   Dry Land Training ☐

5. **Injured side?**
   Left ☐
   Right ☐
   Both ☐

6. **Did you receive medical attention (Doctor's visit, Physiotherapy, Biokinetic Rehabilitation) for the injury?**
   YES ☐
   NO ☐

7. **Have you experience an injury of the same type and at the same site before the 2014/2015 season?**
   YES ☐
   NO ☐

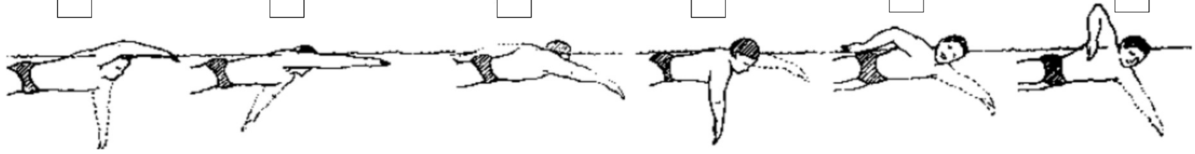
8. **Was the injury caused by overuse or trauma?**
   Overuse ☐
   Trauma ☐

9. **Did you experience the injury during Freestyle swimming?**
   YES ☐
   NO ☐

If **YES**:

10. **Where in the stroke?** (mark appropriate phase in the stroke with *X-if more than one is applicable please mark them as well)*

☐ ☐ ☐ ☐ ☐ ☐



For the questions below, please circle the number closest to your level of pain or dissatisfaction. <u>If both shoulders are painful, please circle a number for each side and use R for right and L for left above the number:</u>

EXAMPLE

L R

0 1 [✓ 2] 3 4 5 6 7 [✓ 8] 9 10

No Pain ... Worst Pain Possible

11. **Pain <u>at rest</u> with your arm/s by your side:**

0 1 2 3 4 5 6 7 8 9 10

No Pain ... Worst Pain Possible

12. **Pain with <u>normal activities:</u>**
<u>(eating, dressing, bathing)</u>

0 1 2 3 4 5 6 7 8 9 10

No Pain ... Worst Pain Possible

13. **Pain with <u>strenuous</u> activities:**
(sports, reaching, lifting)

0 1 2 3 4 5 6 7 8 9 10

No Pain ... Worst Pain Possible

14. **How would you describe your shoulder related symptoms? (Check only one)**
    a. I had no pain or shoulder symptoms ☐
    b. Pain/ache only after heavy workouts ☐
    c. Pain/ache (not disabling) during and after workouts ☐
    d. Disabling pain during and after workouts that interfered with your athletic performance ☐
    e. Shoulder pain preventing competitive sport participation ☐

8.10 Appendix I - Shoulder Range of Movement Sheet

Swimmer Code: ____________________

	Shoulder Internal Rotation	**Shoulder External Rotation**
Right		
Left		

8.11 Appendix J - Freestyle Biomechanical Analysis Sheet

Swimmer Code: ____________

Hand Entry Phase

Hand Entry Position	Right		Left	
1. Hand crossing the midline on entry	YES	NO	YES	NO
2. Thumb first entry (arm internally rotated)	YES	NO	YES	NO
3. Hand entering between the midline of the body and shoulder	YES	NO	YES	NO
4. Hand entering in line with the shoulder	YES	NO	YES	NO
5. Hand entering outside the shoulder	YES	NO	YES	NO

Hand Position at the end of the Hand Entry Phase	Right		Left	
1. Fingertips pointing upward towards the water surface With the shoulder in a hyperflexed position	YES	NO	YES	NO
2. Arm parallel to the water surface	YES	NO	YES	NO
3. Fingertips pointing downward towards the bottom of the pool	YES	NO	YES	NO

Early Pull Through Phase

Elbow Position	Right		Left	
1. Dropped Elbow	YES	NO	YES	NO
2. High Elbow	YES	NO	YES	NO

Hand Position	Right		Left	
1. Hand inside the Elbow and crossing the midline of the body	YES	NO	YES	NO
2. Hand inside the Elbow not crossing the midline of the body	YES	NO	YES	NO
3. Hand in line with the Elbow	YES	NO	YES	NO
4. Hand outside the Elbow	YES	NO	YES	NO

Late Pull Through Phase

Force Production	Right		Left	
1. Drop in Force production	YES	NO	YES	NO
2. Increase in Force Production	YES	NO	YES	NO

Hand Exit Phase

Hand Position	Right		Left	
1. Hand exits before thigh	YES	NO	YES	NO
2. Elbow bent during hand exit	YES	NO	YES	NO

Catch Up Stroke

Swimming Catch Up Stroke	Right		Left	
1. Swimming catch up stroke	YES	NO	YES	NO