ELSEVIER

Physical Therapy in Sport 5 (2004) 109–124

Physical Therapy in sport

www.elsevier.com/locate/yptsp

Masterclass

# Conservative management of shoulder pain in swimming

Peter Blanch*

*Department of Physical Therapies, Australian Institute of Sport, P.O. Box 176, Belconnen ACT 2616, Australia*

Received 15 April 2004; revised 30 April 2004; accepted 3 May 2004

**Abstract**

Swimming fast is a complex skill that requires physical attributes to maximize propulsive force whilst minimizing drag forces. The models that have historically been used to explain the incidence of shoulder pain in swimmers have been very mechanical in nature. The interplay between the requirement of the sport, the shoulder's mechanical restraints, the biomechanical effect of the kinetic chain, and the powerful influence of the neuromuscular system must be appreciated in pathological and rehabilitation models. The interaction between flexibility, strength, fatigue, muscle inhibition, proprioception, muscle patterning and pain is complicated and poorly understood. It is, however, in these complex intertwining relationships that the origin of shoulder pain in swimming must lay and therefore where the conservative management of that pain must have its effect.


*Keywords:* Swimming; Shoulder; Pain; Neuromuscular

## 1. Introduction

Overuse injuries of the shoulder causing pain are the most common cause of time lost to training in swimmers (McMaster & Troup, 1993). The aim of this masterclass paper is to outline several components that create a pathological and therefore a rehabilitation model for the management of shoulder pain in swimmers. Firstly, the biomechanical parameters needed in order to swim fast will be discussed. Next, in order to understand the relationship between the mechanics of swimming and possible causes of shoulder pain, a number of concepts will be illustrated. Following, theories regarding the basis of shoulder pain in swimmers, and the research behind these theories, will be examined. Finally, clinical management procedures and their basis will be outlined.

Throughout this paper appropriate literature will be used where possible to confirm or support statements. Further to this, opinion, conjecture, and argument will be used in order to expand the scope of this paper from being merely a re-statement of the literature to one that attempts to fit the pieces of the puzzle of shoulder pain in swimmers together. A common problem encountered throughout musculoskeletal medicine is that treatment has often revolved around presumed or extrapolated knowledge. Some of those presumptions and extrapolations with regard to swimming shoulder injuries will be questioned whilst undoubtedly others will be made.

To swim fast is an extremely skilful process. High-level swimmers are not faster in the water just because they are fitter and stronger; they are also more adept at moving in water. Swimming athletes compete and train while floating in a fluid medium. They must propel themselves through the viscosity of water by 'grabbing' on to the water as an elusive anchor to then move forward by pulling and then pushing against it. Water offers increasing resistance with velocity to forward motion and gives a relatively poor base for the generation of propulsive motion. For these reasons the laws that govern motion upon ground do not apply in the pool.

## 2. Biomechanics of swimming

A key to being able to understand injuries and rehabilitation in swimming is a thorough knowledge of the biomechanical aspects of swimming.

### 2.1. Propulsive forces

The study of the mechanics of swimming was revolutionised by Counsilman (1971) with his experiment of

* Tel.: +61-2-6214-1728; fax: +61-2-6214-7953.
*E-mail address:* pblanch@ausport.gov.au.

1466-853X/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ptsp.2004.05.002

attaching a flashing light to the end of the third finger of swimmers and having them swim in a darkened pool. The motion of this light was then traced during swimming to give information regarding stroke patterns of different swimmers. The finding that elite level swimmers moved their hands in curved paths across the line of forward movement laid to rest the previously held belief that swimmers pulled in a linear fashion. This information led Counsilman (1971) to propose the theory that propulsion in swimming was achieved using Bernoulli's principles of force generation (i.e. lift and drag) rather than Newtonian principles (Newton's third law-for every action there is an equal and opposite reaction). It was suggested that as the hand moved in a curved linear path, the water flowing over the back of the hand and forearm would move faster than the water on the underside of the hand and arm, causing a pressure differential. This pressure differential is termed lift, and maintains the position of the hand whilst muscle forces pull the body over the hand.

Counsilman's early work was further expanded and supported by Schleihauf (1987a,b) where the pitch and direction of the hand movement was measured. Lift and drag forces were then calculated from these data. The theories of producing lift forces at the hand have come under considerable criticism over the last ten years (Rushall, 2002; Rushall, Sprigings, Holt, & Cappaert, 1994; Sprigings & Koehler, 1990). The hand and arm have limited ability to change shape to accommodate the flow of water and the angles of attack used by swimmers is far greater than that considered viable from a true lift perspective. The curved path of the hand can be explained by Newton's second law (a body in motion will accelerate in proportion to the forces placed upon it). As the swimmer pushes on the water, the mass of water begins to move, decreasing the ability of the swimmer to use this as a base to produce propulsion. This leads to the hand moving to find still water to press on.

Fast swimmers quickly anchor their hand and forearm in the water and pull up to and push past it. What is important to generate this anchoring role of the arm is to get as large of a surface area as possible perpendicular to the line of progression. This can be achieved by what coaches call 'keeping a high elbow' (i.e. that the plane of the elbow is above the plane of the hand) (see Fig. 1).

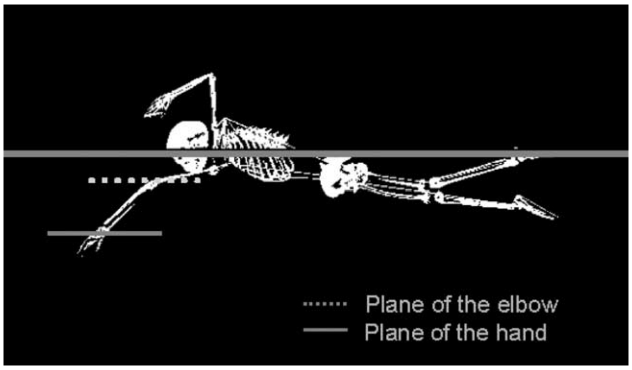


Fig. 1. This picture taken from a three-dimensional representation of an elite freestyle swimmer demonstrates a 'high elbow' where the plane of the elbow is above the plane of the hand.

This position of a 'high elbow' requires considerable flexibility of the shoulder girdle. The swimmer internally rotates the humerus in high levels of elevation whilst flexing the elbow to anchor the hand and forearm.

### 2.2. Drag forces

Whilst creating propulsion is extremely important in generating swimming speed the major difference between elite swimmers and recreational swimmers is in their ability to reduce the drag forces that retard their forward motion. For any given surface area of a hand and forearm there is only so much force that can be applied to the arm before it will move backwards through the water and be a much poorer anchor for the pulling to and the pushing past of the body. The ability to reduce the retarding forces enough so that the body can be pulled over the arm, without backward movement of the arm in the water, is crucial in swimming fast. This point is vital in understanding the trade-off between propulsive and drag forces in swimming. A good example is if you sit in a normal kitchen chair, lift your feet off the ground, grab onto the edge of the kitchen table, and try and pull yourself past the table. In most cases the retarding forces will be too great and you will move the table and not move the chair much. However, if you were to sit in an office chair with wheels on (this reduces your retarding forces) you will be most likely be able to pull yourself past the table.

This concept of drag force becomes interesting when considering the role of strength in swimming fast. If we go back to sitting in the kitchen chair, if the force applied to the table is so much that the table moves and it cannot then use it as a solid base to pull past, applying more force to the table (i.e. get stronger), does not help. The force applied to the table, without it moving, has to be enough to be able to pull past it. This principle applies to swimming: being able to apply more force to the water will not make the water more stable to receive that application. Where strength may become important, is the percentage of overall strength used for each stroke cycle. If, for example, a swimmer uses 20% of their 'total strength' to perform a stroke cycle and they then became stronger so that a stroke cycle required only 15% of their total strength, the swimmer could do more repetitions before fatiguing.

The key to swimming fast is more in reducing the drag than increasing the propulsive forces. There are three types of drag forces involved in swimming biomechanics. First, *friction drag*, which is the retarding force created by the flow of water over a body. This has a proportional relationship to velocity so that if velocity is doubled the friction drag is also doubled (Laughlin, 1996). This can be overcome to a certain extent by shaving body hair and by the use of specialist swim suits. The second type of drag, *form drag*, is the retarding force related to the shape and size of the body to the flow of water (obviously water does not flow in a swimming pool but for a hydrodynamic argument the movement of the body through the water effectively creates a flow). Vertical and lateral movement of the body within the water increases the surface area of the form to the flow of water. Form drag has an exponential relationship to velocity so that if velocity is doubled form drag is quadrupled (Laughlin, 1996). The swimmer attempts to minimize form drag by trying to maintain as streamlined position of the body as possible. This position allows them to try to combat the effects of form drag by interrupting the least amount of the flow of water as possible. The third type of drag, *wave drag*, is the energy lost by forcing up a bow wave against gravity. Wave drag is at its greatest just at water level where most swimming occurs and it drops off dramatically once three body widths under the water (Hertel, 1966). The length of the body has dramatic effects on wave drag (i.e. the longer the body the less drag created). Wave drag has a cubic relationship to velocity (Laughlin, 1996; Videler, 1993).

## 3. Clinical concepts

### *3.1. Performance enhancement, injury prevention, and efficient movement patterns*

Most people are able to swim without experiencing a shoulder injury. However, most people do not swim fast. It is erroneous to equate the swimming action of a recreational swimmer with that of an elite performer and deduce that they do the same thing in the water. The biomechanical analysis of what it takes to swim fast is perhaps not as scientific as it could be when it comes to defining 'good technique'. Different coaches and scientists have their own theories and variations of what the elusive good technique is. The production of hypotheses and then testing the hypotheses by introducing or changing techniques is rarely used. Most commonly the observation of successful swimmers and the gleaning out of similarities between these swimmers is used as a basis for what constitutes the description of good technique.

To a certain extent this is what takes place in identifying the physical requirements for fast swimming without injury. The concepts of performance enhancement and injury prevention are somewhat similar in their goals in that the aim is to produce the most mechanically efficient movement patterns possible.

### *3.2. Kinetic chain*

The concept of the kinetic chain as it relates to the biomechanics of motion has existed for many years. Motion and forces produced (e.g. throwing) or dissipated (e.g. landing from a jump) by the body during athletic activity are the culmination of all segments of the body working together. Throwing is an example where the concept of the kinetic chain has been well applied (Fleisig, Barrentine, Escamilla, & Andrews, 1996). To achieve a good cocking position the thrower needs to achieve a position of external rotation of the shoulder, extension and rotation of the thoracic spine, extension of the lumbar spine and extension of the hip of the trail leg. To accelerate their projectile the thrower needs to have muscle strength across all these areas, and movements must occur in a coordinated fashion. All actions in sport have a component of the transfer of force and/or movement along the kinetic chain. If a component of the kinetic chain does not perform (i.e. it does not have enough range of motion or not enough strength), the motion, production, or dissipation of force will be passed to another link in the chain, therefore overloading that link's role in a particular movement. (Fleisig et al., 1996; Kibler, 1995, 1998; Prichard, 1993).

In swimming, athletes must reach extreme ranges of motion, especially in the shoulder girdle (Yanai and Hay, 2000), and they must also be able to reach these positions without any mechanical cost (i.e. force into the position). Any excessive force will manifest in movement of the body, either lateral or vertical in the water, which will increase the drag the swimmer creates.

### *3.3. Relative flexibility*

Relative flexibility (Sahrmann, 1998) refers to the comparative flexibility of one part of the body to another along the kinetic chain. When there is a breakdown in one link of the kinetic chain (i.e. loss of range of motion), the gross movement of the body will only be slightly affected because excessive compensatory movement will occur at other components of the chain. The body will move in its path of least resistance. This means that if it takes 20 kg of force to move a joint through a particular motion but only 10 kg of force for a component of that movement to occur in the next link of the chain, it will occur at the link that requires only the 10 kg force. A good example is that of the runner with tight calf muscles limiting the amount of dorsiflexion available at the talocrural joint. In normal gait, the leg passes over the foot on the ground by the talocrural joint dorsiflexing, however, if this motion is limited by calf tightness the leg must still pass over the foot and the body can compensate by overpronating at the subtalar joint.

The concept of relative flexibility applies to swimmers in two ways. Firstly, within the body, for example, a swimmer will try to achieve a position of high humeral elevation with internal rotation to initiate their stroke. If there is a limitation of glenohumeral range available this motion requirement can be passed to the scapulothoracic joint or even the spine. Secondly, in swimming the position of the body within the water is also a component of 'relative flexibility'. If the swimmer is trying to achieve a position with the hand above the head in the line of progression, and there is tightness of the shoulder girdle restricting that motion, the body of the swimmer can yaw laterally to achieve the same hand position. This lateral motion will cause an increase in the amount of drag the swimmer creates.

### 3.4. Pathology definitions

Shoulder pain in swimmers was initially referred to as being an 'impingement syndrome' (Hawkins & Kennedy, 1980). The definition of impingement syndrome given by Hawkins and Kennedy (1980) describes the symptoms of swimmers' shoulder as a result of impingement of the long head of biceps and/or supraspinatus tendons against the anterior third of the coracoacromial arch, coupled with recurrent episodes of avascularity of these two tendons. This combination of mechanical irritation and avascularity leads to microtrauma, focal degeneration, and resultant inflammation and was thought to be the basis of shoulder pain in swimmers (Hawkins & Kennedy, 1980).

This definition was based on extrapolation from previous anatomical studies. For example, Rathbun and McNab (1970) investigated the vascular complexities of the shoulder and described an area of avascularity in the supraspinatus tendon in a dependent, adducted, internally rotated position of the shoulder. As this position coincides with the late pull-through/early recovery stage of the swim stroke this constant repetitive avascularisation has been cited by several authors (Hawkins & Kennedy, 1980; Penny & Smith, 1980) as being related to shoulder pain in swimmers.

The work of Neer (1972) has also been used to provide an anatomical explanation of impingement syndromes. He stated that impingement of the supraspinatus and long head of biceps tendons occurs against the anterior edge and the underside of the anterior third of the coracoacromial arch. Ciullo (1986) and Hawkins and Kennedy (1980) suggested that the movement of external to internal rotation during a swim stroke causes abutment of the greater tuberosity against the coracoacromial arch, leading to impingement of the supraspinatus and long head of biceps tendon. All swimmers, however, must go through an internally rotated adducted position in late pull through, and all swimmers move from an externally rotated to an internally rotated position, as these are requirements of the sport, yet not all swimmers develop shoulder impingement problems.

More recently, we have been given a definition of the pathology of impingement that can better explain the phenomena that we see (Belling Sorensen & Jorgensen, 2000). This definition delineates primary from secondary impingement. Primary impingement occurs when the subacromial space is decreased due to anatomical reasons such as os acromiale and osteophytes. Certainly this needs to be a consideration when confronted by the swimmer with shoulder pain, however, there is no evidence to suggest the incidence of primary impingement is greater in the swimming population with comparison to the normal population. Secondary impingement is explained as the impingement that is related to 'instability' of the shoulder.

Instability is another term that then needs further definition. Belling Sorensen and Jorgensen (2000) defined instability of the shoulder as any structural or functional deficit that can cause pathological translation, hyperangulation, or excessive rotation of the glenohumeral joint. Instability has been further defined as a clinical condition in which unwanted translation of the humeral head on the glenoid compromises the comfort and function of the shoulder (Matsen, Harryman, & Sidles, 1991). The combination of these definitions, however, makes the terms of instability and impingement almost interchangeable. Most swimmers with shoulder pain will experience secondary rather than primary impingement. To have secondary impingement there must therefore be instability of the glenohumeral joint. It is important to appreciate this distinction of instability as not only being excessive translation. We know that swimmers are often at the extremes of available shoulder motion during the swim stroke (Yanai & Hay, 2000; Yanai, Hay, & Miller, 2000) and therefore are susceptible to problems of hyperangulation and excessive rotation of the glenohumeral joint.

The contribution of excessive translation, rotation, or hyperangulation to secondary impingement, however, must also be related to some change in the neuromuscular system to allow these motions to begin to occur to create pathology or return to normal in the case of rehabilitation. If we are to accept that this instability is solely a mechanical phenomenon, conservative management can do little to change the mechanical restraints and it should then follow that a swimmer shouldn't get better unless there has been some intervention to the mechanical restraints.

Furthermore, it should be noted that the definition of instability does not include our clinical ability to translate the humeral head on the glenoid. The delineation between laxity and instability needs to be quite plain. Laxity of the shoulder as determined by the various tests designed to ascertain the magnitude of translatory motion are not necessarily related to this present definition of instability (Matsen et al., 1991).

### 3.5. Tightness of the posterior capsule

In early pathological models of the cause of overuse shoulder pain it was suggested that stretching of the anterior capsule, either due to activity (e.g. throwing) or through stretching exercises, caused a laxity of the anterior capsule. It was then surmised that this anterior laxity would cause an anterior migration of the humeral head during activity, leading to impingement and pain (Jobe, Kvitne, & Giangarra, 1989). This purely mechanical theory has not been supported by cadaveric studies, where minimal anterior translation was noted after a simulated Bankart lesion (Speer et al., 1994). What has been shown using cadaveric models is that tightening of the posterior capsule causes anterior migration of the humeral head during motion of the glenohumeral joint (Harryman et al., 1990).

It is now widely accepted that tightness of the posterior capsule can be a contributing cause to overuse shoulder problems. The relationship between tightness of the posterior shoulder, as measured by glenohumeral internal rotation and cross-body adduction, is related to small changes in humeral translations during shoulder elevation of subjects suffering from impingement syndrome (Ludewig & Cook, 2002). Swimmers have been shown to have decreased internal rotation of the glenohumeral joint (Beach, Whitney, & Dickoff Hoffman, 1992) which is assumed to be tightness of the posterior capsule (Weldon & Richardson, 2001) and be possibly related to injury. The defining of decreased range of motion to be solely related to the posterior capsule does, however, disregard the important contribution of the shoulder musculature.

The shoulder capsule has been described by Wilk, Arrigo, and Andrews (1997) as large, loose and redundant, thereby allowing for the large range of glenohumeral motion. It supplies little in the way of mechanical stability of the shoulder. It is also known that the structure of the capsule is predominantly collagen and elastin (Rodeo, Suzuki, Yamauchi, Bhargava, & Warren, 1998) which does not gain length quickly. However, it has been shown that stretching (Johansen, Callis, Potts, & Shall, 1995), joint mobilization, and soft tissue techniques (Blanch, Clews, Popov, & Matley, 1995; Conroy & Hayes, 1998) have immediate effects on shoulder joint ranges of motion which would tend to implicate the contractile neurophysiological restraints rather than the mechanical ones. It has also been demonstrated that low muscle tone is an important contributing factor in shoulder subluxation in stroke patients (Lo et al., 2003), which again implicates the contractile component of the shoulder contributing significantly to the stability of the joint. Given the intimate blending of the rotator cuff musculature to the capsule, the contractile element of the posterior shoulder should be considered an extremely important component of the restrictions of motion occurring at the glenohumeral joint. Perhaps it would be more appropriate to refer to tightness of the posterior shoulder rather than specifically implicating only the capsule.

### *3.6. Plane of the scapula*

The plane of the scapula is often considered to be approximately 30° anterior to the frontal plane and vertical to the horizontal plane (Bagg & Forrest, 1988). However, this is a generalisation for the resting position. The plane of the scapula can be variable due to various muscle tightness (i.e. pectoralis minor) or muscle weaknesses (i.e. serratus anterior).

Changing the plane of the scapula automatically then changes the position of the glenoid and this will affect the type of motion occurring at the shoulder joint. The differentiation between thoracohumeral elevation and glenohumeral elevation must be made. It has been shown that there are varying amounts of isolated glenohumeral elevation available in different planes with respect to the plane of the scapula. The amount of elevation available greatly diminishes once the humerus is elevating in a plane behind that of the scapula (An, Browne, Korinek, Tanaka, & Morrey, 1991).

In the situation where there is limited glenohumeral internal rotation, swimmers will compensate in one of two ways. They can avoid the limits of glenohumeral motion by ‘dropping’ the elbow, which will make them an inefficient swimmer, or they will maintain a ‘high elbow’ and try to achieve more internal rotation of the humerus as it relates to the thorax by internally rotating the position of the scapula. This will normally be by anterior tilt, abduction, and protraction of the scapula. This motion may then allow a desirable thoraco-humeral position but glenohumerally it will lead to the humerus elevating behind the plane of the scapula where there is a decreased range of elevation and be more likely to be impinging at the ends of available glenohumeral range of motion.

## 4. Factors affecting the glenohumeral joint and other links of the kinetic chain

For ease of presentation the clinical approaches and research ideas that have been examined with respect to shoulder injuries in swimmers will be discussed under the following six headings: flexibility/laxity, strength, muscle patterning, proprioceptive feedback, pain, and athletic ability.

### *4.1. Flexibility/laxity*

Recent reviews of shoulder injuries in swimming have indicated that glenohumeral laxity is frequently involved in shoulder pain in swimmers (McMaster, 1999; Weldon & Richardson, 2001). One study featuring highly in these reviews is that of McMaster, Roberts, and Stoddard (1998). This paper suggests a correlation between shoulder pain and laxity in swimmers, however, the methodology of combining both laxity and apprehension scores to singularly describe laxity casts some doubt on this claim and warrants further examination. It has been demonstrated that high level swimmers do have increased laxity of the glenohumeral joint when compared with lesser swimmers and that perhaps this is advantageous in the sport (Zemek & Magee, 1996).

Whilst laxity and flexibility are two different but related physical factors, other studies in their attempt to define possible contributing causes, have examined shoulder flexibility, without finding any relationship to shoulder pain in swimmers (Bak & Magnusson, 1997; Beach et al., 1992; Warner, Micheli, Arslanian, Kennedy,

& Kennedy, 1990). In reporting the laxity or flexibility-injury relationship these studies have mostly used some form of comparative or correlative statistic. Both of these types of analyses are in search of a linear relationship. The question that is being asked is, if subjects are more lax or flexible are they more likely to be injured? What perhaps we need to be asking is; is there a specific amount of laxity and/or flexibility that is optimal, and if there is less or more than this 'optimum window' is a swimmer more likely to be injured? It is my hypothesis that for flexibility measures of the glenohumeral joint, and other components of the kinetic chain, that there is a 'window' of flexibility that is optimal. This concept of a window of flexibility has been raised in previous studies not related to swimmers (Thacker, Gilchrist, Stroup, & Kimsey, 2004). Certainly, if swimmers are not flexible enough in the glenohumeral joint they appear to pass the motion requirements to the scapulothoracic joint or other components of the kinetic chain which can lead to impingement via excessive hyperangulation or rotation at the glenohumeral joint. Conversely, it appears that gross hypermobility also has potential for injury via excessive translation of the humeral head.

Swimmers have greater shoulder ranges of motion than non-swimmers (Beach et al., 1992). Compared to recreational swimmers, it has been shown that elite swimmers have greater general joint hypermobility and glenohumeral joint hyperlaxity (Zemek & Magee, 1996). There is conjecture at whether this is an acquired or inherent condition. However, this flexibility is imperative to attain the extreme shoulder elevation and rotation required to achieve a good catch position required in swimming fast.

Following, is a list of clinical measures that examine flexibility issues as they relate to the swimmers' kinetic chain. The 'windows' of flexibility have been derived only from clinical observation of high-level international swimmers, swimmers with and without injury, and discussions with coaches. These measures are yet to be scientifically validated.

#### *4.1.1. Abduction with internal rotation*

Abduction with internal rotation is an important measure of a swimmer's ability to achieve and maintain a high elbow throughout a stroke cycle. Attention to detail when taking this measure is important as slight changes in the measuring technique can lead to large differences in the result. This measure requires two testers. The swimmer sits on a bench, Tester one abducts the swimmer's arms with the elbows maintained in 90° flexion. By keeping the forearm perpendicular to the plane of abduction this will cause internal rotation as the arms are elevated. Both shoulders should be tested at the same time to avoid lateral flexion of the spine. The angle measured is the line of the humerus to the vertical. An appropriate range for this measure is between 150 and 170°. It is extremely important to be precise in this measuring technique. If the arms are allowed to move forward of the plane of the body, or the arms are in less rotation, a much greater range of elevation will be achieved.

#### *4.1.2. Thoracic rotation*

Measurement of thoracic rotation is performed with the swimmer sitting as tall as possible and the arms elevated to 90° and hands clasped together. Special attention is paid to maintaining the strong shoulder position (i.e. the shoulders should not be rotated forward on one side and back on the other). The swimmer is then asked to rotate one direction and then the other and the angle between the arms and the midline is measured. This range of motion is important in the pull through phases of freestyle and backstroke. An acceptable result is a value between 60 and 90°.

#### *4.1.3. Glenohumeral internal rotation*

Glenohumeral internal rotation is performed with two examiners. The athlete lies in prone on a bench with the arm at 90° to the body, the elbow is bent with the lower arm hanging over the edge of the bench (i.e. elbow in 90° flexion). To measure the athlete's right shoulder, examiner 1 stands at the athlete's right side; the examiner supports the athlete's upper arm with their right fist under the arm. The examiner then holds the shoulder into retraction and depression with their left hand. The athlete is instructed to maintain the contact with the examiner's fist, keep the elbow in 90° flexion, and without pushing into the examiner's left hand, rotate the arm forward (external rotation) and then rotate the arm back (internal rotation). The angle measured by examiner 2 is the line of the lower arm to the vertical (i.e. the vertical is 0° of rotation).

The more important of the two rotations with respect to swimming is internal rotation. This allows the swimmer to have an early catch and maintain a high elbow throughout the stroke. A measure of between 40 and 50° of glenohumeral internal rotation is ideal for freestyle, butterfly, and backstroke swimmers. Breaststroke swimmer's can have a little less as this stroke requires less rotation range. It should be noted that internal rotation of the shoulder can be quite variable from swimmer to swimmer and from day to day depending on training volumes and intensity.

#### *4.1.4. Combined elevation*

Combined elevation is a test of thoracic spine extension (strength and range of motion), shoulder extension, and the ability to draw the shoulder blades back. The athlete lies in prone with both arms elevated above the head. They are asked to lock their thumbs together and maintain their elbows in an extended position. The athlete is then asked to elevate the arms as high as they can while keeping their head, chest, and legs in contact with the bench. The angle measured is the angle between the line of the humerus and the horizontal. This movement is important for achieving a high elbow position at the start of the stroke, recovery and streamlining. A appropriate range for the combined elevation test is between 5 and 15°.

*4.1.5. Hip internal rotation and tibial external rotation*

Hip internal rotation and tibial external rotation are used primarily for breaststroke swimmers. Hip internal rotation is measured with the athlete laying in prone with both knees flexed to 90°. The knees must be kept together and on the bench. The legs are allowed to drop apart out to their limit of hip internal rotation. The measurement is of the angle between the line of the shaft of the tibia and the vertical.

Tibial external rotation is measured with the athlete in sitting with the hips and knees flexed to 90°. The feet are placed on a whiteboard each side of a line that is in the midline of the body. The knees and heels are kept together and keeping the feet flat on the whiteboard the feet are turned out as far as possible. The angle measured is that between the centerline and a line described by the end of the second toe and the center of the heel.

As a general rule, these two angles should add up to approximately 90° so that at the end of recovery of the breaststroke kick the feet are square to the line of progression. This gives the biggest surface area to use to propel in the kick and also allows the knees to be kept closer together reducing form drag.

*4.1.6. Hip extension*

Hip extension is measured with the athlete lying in prone and is notoriously difficult to obtain reliable results. One tester holds the leg to be measured with the knee in 90° of flexion. While monitoring movement in the lower back, tester 1 extends the hip until there is movement in the lumbar spine. The measurement taken is the angle between the line of the shaft of the femur and the horizontal. A range of between 20 and 30° appears to be optimal.

*4.1.7. Ankle plantarflexion*

To measure ankle plantarflexion the swimmer is asked to point their toes and the angle measured is that between the line of the lower leg and the line of the foot. A measure of greater than 160° is desirable.

*4.2. Strength*

Strength and muscle imbalances of the shoulder with particular reference to swimmers and those with impingement pain and/or instability problems have been widely researched offering varying results. Fowler and Regan (1986) found no difference in rotator cuff strength between swimmers with a history of shoulder pain and those without. This was later supported when it was found that there were no major differences in rotator cuff strength between swimmers (some with a history of injury) and other athletes (Reid, Saboe, & Chepeha, 1996).

Warner et al. (1990), in their study comparing the strength tests of normal shoulders with those with impingement and those with instability, suggested a relative weakness in the external rotators of the impingement group, although this was inconsistent. The implication of the external rotators in the involvement of shoulder pain in swimmers was also highlighted by Beach et al. (1992). When researching swimmers with unilateral shoulder pain they found no differences in single test strength but found that the external rotators of the affected side fatigued much more quickly than those of the unaffected side. These findings may fit with the concepts outlined by Post, Jablon, Miller, and Singh (1979) where it was hypothesised that the dysfunctional rotator cuff (in this case the external rotators) loses its ability to apply a depressive force on the humeral head, allowing the fulcrum of rotation of the glenohumeral joint to elevate, possibly increasing the likelihood of impingement.

The findings of Beach et al. (1992) and Post et al. (1979) taken together may provide some explanation to the suggestion by Kennedy Hawkins, and Krissoff (1978) that, in swimmers recovering from swimmers shoulder, isokinetic activities in external rotation should be emphasized as much as possible. They further state that the exact mechanics in which muscle training reduces impingement is a matter of speculation (Kennedy et al., 1978).

Strength is not the sole factor in efficient swimming. Reilly, Kame, Termin, Tedesco, and Pendergast (1990) found no differences in strength measurements of the shoulder between fast and slow swimmers. It was suggested that the skill of the swimmer and speed of muscle contraction are more important than muscular strength in swimming fast.

We are able to ascertain the strength status of the shoulder musculature reasonably well using a combination of clinical and exercise tests. Commonly, as has been shown above, there may be no strength deficits in the shoulder of a swimmer experiencing shoulder pain. Other components of the kinetic chain that should be examined for strength are the thoracoscapula and trunk rotation musculature.

*4.3. Muscle patterning*

As previously discussed, for secondary impingement to occur and be rehabilitated there must be some change in the neuromuscular system. Changes in muscle tightness, amount of muscle activation, and temporal patterning of muscle contraction have all been implicated in shoulder pain.

One of the common misconceptions made regarding muscle imbalances around the shoulder, with regard to shoulder pain in swimmers, relates to the effect of posture and the subsequent effect of this posture on the shoulder musculature. Commonly, in textbooks, the round-shouldered forward-headed posture, which is often seen in swimmers, is interpreted as increased strength and tightness of all the anterior musculature such as the pectorals and subscapularis (Sobel, 1995) and a lengthening and weakness of all the posterior musculature such as the rhomboids and infraspinatus (Ayub, 1991). This is incorrect. If the scapula is brought into a protracted, internally rotated position, there is no doubt that the thoracoscapula (i.e. pectoralis minor, rhomboids) and thoracohumeral (i.e. pectoralis major, latissimus dorsi) muscles will be shortened anteriorly and lengthened posteriorly. However, at the glenohumeral level, as the shoulder girdle internally rotates, the change in scapula position necessitates the glenohumeral joint to externally rotate, to maintain the hands facing the front. This means that the anterior glenohumeral muscles (subscapularis) will be in a lengthened position and the posterior musculature (infraspinatus) will be in a shortened position. The long term effect of this posture then has implications to tightening of the posterior shoulder (not only the capsule) leading to restrictions of glenohumeral internal rotation and possibly causing anterior translations of the humeral head during movement (Ludewig & Cook, 2002).

Initial research by Pink, Perry, Browne, Scovazzo, and Kerrigan (1991) and Scovazzo, Browne, Pink, Jobe, and Kerrigan (1991) has provided valuable information on the EMG activity involved with normal and painful shoulders during freestyle swimming. Their initial papers examined the EMG activity using fine wire electrodes of 12 muscles around the shoulder girdle and calculated their EMG activity as a percentage of maximum muscle test (MMT) at 25 intervals of a complete freestyle stroke cycle. These studies have been widely referred to in more recent studies (Bak & Magnusson, 1997), reviews (Weldon & Richardson, 2001), and have been used as a basis for clinical management (Pink & Tibone, 2000).

The findings of the Pink et al. (1991) and Scovazzo et al. (1991) studies must be considered in light of several methodological and analysis limitations. The use of single line graphs depicting the level of muscle activity in both the Pink et al. and Scovazzo et al. studies has the potential to be quite misleading especially given the huge variation demonstrated by the standard deviations which are apparent in table format. The normalization procedure using MVC has been shown to be fraught with error. Morris, Kemp, Lees, and Frostick (1998) demonstrated a mean coefficient of variation of 53% for the rotator cuff musculature when analysing the MVC normalised data received from three closely co-located electrodes in each muscle for a single test movement of five subjects. Finally if we are to accept the observation in the final summary made by Pink et al. (1991) when they suggest that the subscapularis muscle (which averaged 46.1% MMT through the stroke cycle with a range of 26–71%) and the serratus anterior (average 31.4%, range 18–48%) were active throughout the stroke cycle and were susceptible to fatigue, surely we should also accept the teres minor (average 28.7%, range 15–57%) and the latissimus dorsi (average 32.2%, range 18–75%) in the same category.

Even at the highest levels of swimming, whilst there will be similarities, different athletes will have quite distinctive and different stroke patterns. If there is variation in kinematics there has to be some differences within muscle activity, and therefore perhaps a better way to interpret the muscle activity is to use the standard deviations presented by Pink et al. (1991) to say that the pattern of muscle activity during the freestyle swim stroke can have considerable variation.

Scovazzo et al. (1991) published a comparison with the data of Pink et al. (1991) which shows interesting differences in muscle activity between normal and painful shoulders. The painful shoulders had less activity in the rhomboids, upper trapezius, anterior and middle deltoids at hand entry, the serratus anterior during pulling, anterior and middle deltoid at hand exit, and subscapularis in mid-recovery. There was an increase in muscle activity of the painful shoulders in the rhomboids during pulling and the infraspinatus at hand exit. Even these findings, however, need to be considered with a view of some potential design (previously discussed) and analysis limitations (e.g., type 1 errors). We also must be careful in the interpretation of cross-sectional studies such as these (Scovazzo et al., 1991) where correlative results are often interpreted as causative when they could just as easily be explained as being resultant. Certainly, Scovazzo et al. (1991) noticed kinematic changes (which will of course have corresponding EMG changes) in the stroke pattern of the injured swimmers, which they explained as being as a *result* of those swimmers avoiding the Neer impingement position. However, subsequent reviews have implied that the EMG changes seen between swimmers with and without shoulder pain as being *causative* of the pain (Pink & Tibone, 2000).

The scapula rotators have, however, been further implicated as having a change of pattern with the presence of shoulder pain. In comparing the bilateral shoulder elevation patterns of swimmers with and without shoulder pain, the upper and lower trapezius temporal patterns where found to be more variable and the serratus anterior temporal pattern was more delayed in those subjects with shoulder pain (Wadsworth, 1997). Conversely, when examining a group of ‘overhand athletes’ with impingement syndrome, the middle and upper trapezius showed delayed onset during unexpected motion of the arm (Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003). However, it must be remembered that these results are still correlative and not necessarily causative.

The clinical ability to assess the above mentioned differences is questionable, as often the temporal changes that are being considered as being significant are measured in hundredths of a second. When it comes to examining patients with regard to muscle patterning we tend to rely on observation of elevation patterns often assessing scapulohumeral rhythm. It is my view that examining the shoulder motion of the patient is extremely important but to look for quite obvious changes from side to side as being a small component of the examination. It has been my experience that some clinicians believe they can see a myriad of different things whilst observing the elevation patterns of patients that are supposedly related to shoulder pain. There has been little research to support highly specific observational analysis and it must be questioned in the light of reliability and repeatability before even contemplating the validity. The patterns of scapulohumeral rhythm have quite a wide variation between normal subjects (Bagg & Forrest, 1988) and even small changes in the velocity of movement can cause significant within subject variation (Sugamoto et al., 2002).

#### *4.3.1. Scapula stability*

There appears little doubt that some form of retraining of scapula stability is warranted in the rehabilitation of swimmers with shoulder pain (Jones, 1999; Kibler, 1998; Kibler, McMullen, & Uhl, 2001; McMaster, 1999; Pink & Tibone, 2000; Weldon & Richardson, 2001). Whether the differentiation of that retraining has to be specifically targeted to individual muscles is yet unclear. It is difficult to cogently argue that a training technique used to increase the upward rotation of the scapula is specifically targeting the upper trapezius, for instance, without also affecting the lower serratus anterior. The actual presentation of scapula control dysfunction may be quite variable from subject to subject (Kibler & McMullen, 2003). It would seem logical that any program designed to enhance the role of the scapula will automatically facilitate all those muscles that support the scapula upon the thorax.

### *4.4. Proprioceptive feedback*

Up until this point the discussions regarding the function and examination of the shoulder have been very mechanical in origin. Over the last 10 years there has been an increase in the appreciation of the contribution of the neurophysiological feedback mechanisms involved in the control of movement of the shoulder (Brindle, Nyland, Shapiro, Caborn, & Stine, 1999; Jerosch & Prymka, 1996; Myers & Lephart, 2002; Safran, Borsa, Lephart, Fu, & Warner, 2001). Using standard, supposedly mechanical, clinical laxity tests measured under ultrasound as an outcome measure, it has been demonstrated that an injection of lidocaine into the shoulder capsule will increase the amount of anterior, posterior, and inferior translation, measured at the glenohumeral joint (Jerosch, Castro, Halm, & Drescher, 1993). This led the authors to suggest that the shoulder capsule had significant proprioceptive capability.

The proprioceptive capabilities of the shoulder, whilst measurable in elaborate research settings, are difficult to assess clinically (Alvemalm, Furness, & Wellington, 1996). Most often, shoulder proprioception is broken into two components: (1) kinesthesia, measured by detecting the onset of motion and (2) joint repositioning sense (both active and passive), where a selected joint position is assigned and then re-attained and the difference between the two is measured. (Nyland, Caborn, & Johnson, 1998).

The classification and distribution of mechanoreceptors in the shoulder capsule have been well described elsewhere (Nyland et al., 1998). What is interesting is that the fast acting quickly adapting receptors tend to be in the mid sections of the capsule where, without the action of the rotator cuff to tension the capsule they would be unable to give feedback in mid ranges of motion. Also, of all the muscles surrounding the shoulder joint the rotator cuff muscles have the lowest muscle spindle density (Nyland et al., 1998). This would suggest a strong feedback relationship between the muscles of the cuff and the receptors of the capsule. Certainly passive repositioning sense (where there is no activity of the rotator cuff) is considerably worse than active repositioning sense (Voight, Hardin, Blackburn, Tippett, & Canner, 1996).

Shoulder proprioception is decreased in subjects who have had a history of shoulder dislocation, and is restored after surgery and rehabilitation (Warner, Lephart, & Fu, 1996). The effect of fatigue has some contradictory results. Most authors have found that muscle fatigue has a significant diminishing effect on proprioceptive acuity of the shoulder (Carpenter, Blasier, & Pellizzon, 1998; Pedersen, Lonn, Hellstrom, Djupsjobacka, & Johansson, 1999; Voight et al., 1996) whilst there has been one study suggesting the change in proprioception is minimal post fatigue (Sterner, Pincivero, & Lephart, 1998). It also appears that pain in the shoulder joint also has a negative effect on shoulder proprioception (Safran et al., 2001). To date there has been no research specifically addressing proprioceptive issues in swimmers with or without shoulder pain. However, given that studies have implicated fatigue and pain in reducing proprioceptive acuity it seems reasonable to expect that these factors will play a role in the dysfunction occurring in swimmers with shoulder pain.

It has been surmised that the mechanoreceptors of the capsule enhance gamma motor neurone efference of the rotator cuff. This increased sensitivity associated with previously learnt motor patterns associated with activity, work together to supply the necessary stiffness of the muscle system to receive and supply force (Nyland et al., 1998). If this feedback loop system is desensitized it can theoretically lead to poor motor patterning. This concept has been well described by the 'functional stability paradigm' incorporating the interaction between the mechanical and neurophysiological restraints, where decreased proprioception leads to decreased neuromuscular control, which complicate the problems of functional instability (Lephart, Pincivero, Giraldo, & Fu, 1997).

Another variation of the clinical hypothesis of functional stability of the glenohumeral joint that I use, is that the total 'level' of functional stability is a combination of the mechanical restraints and the neuromuscular feedback

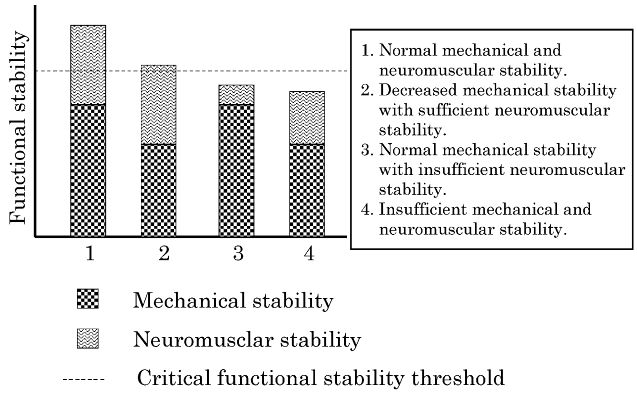


Fig. 2. Functional stability of the shoulder is a combination of the mechanical restraints plus the contribution of the neuromuscular components. If this addition is maintained above a critical threshold the shoulder will function without injury.

mechanisms, and as long as this combination operates above a critical threshold the shoulder will operate without problems (see Fig. 2). Should this combination drop below the critical threshold, the potential for injury is increased. When it comes to conservative management it is only the neuromuscular components of the shoulder functional stability that we can realistically hope to increase.

### 4.5. Pain

Pain is a physical and emotional experience that is specific to an individual. Both aspects of this experience can have powerful effects on the motor system. For a more comprehensive review of the effect of pain on motor activity and control readers are directed elsewhere (Sterling, Jull, & Wright, 2001b).

It has been shown that in subjects with upper limb radiculopathy, pain has the potential to create widespread and multisegmental increases of muscle tone perhaps through the mechanism of increased centralized excitability of both alpha and gamma motor neurons (Hall & Quintner, 1996). Other researchers have more specifically pinpointed the agonists involved in the flexor withdrawal reflexes as being the muscles most likely to have increased activity in the presence of pain (Harris & Clarke, 2003; Woolf, 1984). Previously, pain has been shown to be also involved in reflex inhibition of the quadriceps (an antagonist of the flexor withdrawal reflex) leading to muscle weakness (Stokes & Young, 1984) and this inhibition appears to be also centrally mediated (Graven-Nielsen, Lund, Arendt-Nielsen, Danneskiold-Samsoe, & Bliddal, 2002). It has already been mentioned that pain in the shoulder has the ability to decrease proprioceptive acuity in that joint (Safran et al., 2001). Furthermore, recent clinical hypotheses suggest that pain in the shoulder girdle can lead to non-specific scapula dyskinesis rather than the other way round (Kibler & McMullen, 2003).

It would seem that pain has proven to have a deleterious effect on a number of the factors previously discussed as being involved in shoulder pain in swimmers (proprioception, muscle patterning, strength). It is also probable that changes in muscle tone also have an effect on joint ranges of motion (increased tone of the infraspinatus would limit glenohumeral internal rotation). In examining these previous factors (flexibility, strength, muscle patterning, proprioception) there has always been an underlying perception that dysfunction of these factors are the cause of the pain rather than pain affecting them. Obviously shoulder pain in swimmers does not just appear and it must be related to some dysfunction of the motor system occurring during the high repetition activity they undertake. However, once pain is present in the shoulder it has a powerful influence on the motor system.

The ability to measure pain has always been a frustration to the purely scientific as it must always rely on the subjective assessment of the person experiencing the pain. In research settings the response to pressure or thermal noxious stimuli has been used as a more objective measure to evaluate the effect of different musculoskeletal interventions (Leffler, Hansson, & Kosek, 2002; Vicenzino, Collins, Benson, & Wright, 1998). Clinically it is not viable to use such approaches and we must rely on finding a clinical test that reproduces the patient's pain and use that test or tests to evaluate the value of interventions.

#### 4.5.1. Trigger points

A myofascial trigger point is defined as a hyper-irritable spot usually within a taut band of skeletal muscle or in the muscle's facia. This point is painful on compression and gives rise to referred pain, tenderness and sometimes, autonomic reactions (Simons, Travell, Simons, & Cummings, 1999). All the body's skeletal muscles can be subject to chronic strain and therefore develop such myofascial trigger points. It appears that trigger points may be associated with disorders of specific level spinal reflexes where neural activity sets up a feedback loop, maintaining localized hypertonus (Wheeler, 2004).

There has historically been some reticence in medical circles about the acceptance of trigger points as an entity, due mainly to what is considered a vague diagnostic criteria, and that there are no major independent laboratory or imaging tests to confirm the points (Simons, 2004). Whilst I am in favour of independent tests, if you are able to put pressure on a point and often reproduce what the patient will call, 'my pain', it must at least be implicated as part of the patient's problem. It has been my experience that you will often reproduce a swimmer's shoulder pain through palpation of trigger points.

From a clinical experience perspective the muscles frequently afflicted with trigger points associated with shoulder pain in swimmers are most commonly the infraspinatus, often teres minor and subscapularis, and less commonly supraspinatus, scaleni, subclavius, and triceps. Reproduction of the patient's pain with pressure on the trigger point is enough to assume that it is at least partially responsible for their pain pattern.

### 4.6. Athletic ability

Having considered a list of factors involving the motor system and their possible relationship to swimming injury and performance there is still something elusive about high-level performers that is meekly termed athletic ability for want of a better explanation. However, even in this group occasionally an athlete will develop an aberrant movement habit that may clinically be related to their injury. For instance, insufficient body roll whilst swimming freestyle has been moderately associated with a history of shoulder pain (Beekman & Hay, 1988) but this doesn't appear to be consistent.

If any assessment of a swimmer's technique (e.g. video) is to take place, the clinician must remember a couple of things. Swimming technique is the domain of the swimming coach. Any assessment or recommended change of stroke technique without coach input is doomed for failure. Secondly, a clinician must be aware of their limitations in stroke assessment. To understand what might perhaps be abnormal requires an enormous amount of experience appreciating the range of what is normal.

Whilst there are times when observational biomechanical assessment can be very useful in the management of shoulder pain in a swimmer it is recommended that it be undertaken with the swimmer's coach. The coach can then point out what they believe to be a problem and the clinician can investigate the possible musculoskeletal causes for that problem.

## 5. Examination

The ability to clinically measure the previously outlined factors (flexibility/laxity, strength, muscle patterning, proprioceptive feedback, pain, and athletic skill) has been discussed in those sections. Some aspects such as flexibility and strength are easily measured throughout the kinetic chain. Muscle patterning and scapula control are a little more difficult to quantify accurately. Tests such as Kibler's lateral slide test (Kibler, 1998) may give some indication of scapula control but whether restrictions of glenohumeral motion affect the outcome of this test is still unclear. Using a resisted position mimicking the front end of the stroke can also be used to observe the function of scapula stabilizers. Proprioceptive acuity is quite difficult to measure precisely in a clinical setting and in the presence of pain we may need to accept that proprioception is compromised. A test that reproduces the pain that the swimmer is complaining of, such as the previously mentioned resisted swim action, is useful to gauge the efficacy of interventions. The cervical spine, brachial plexus, and trigger points all have the potential to produce pain in the shoulder girdle and should be examined for possible contributions. Judgments made regarding the involvement of the swimmers technique must be done with caution and with the coaches input even after considerable experience with observing swimming.

A careful history will help implicate any possible training errors that may be involved in a swimmer's shoulder problem. Questions regarding swimming volume, training intensity, training aids (e.g. paddles), dry land stretching and strengthening activity may offer some clues. The history and behavior of the shoulder pain should help establish it as a musculoskeletal problem, and the differential diagnoses have been well explained elsewhere (McMaster, 1999).

The extensive barrage of available clinical tests that relate to determining pathology of the shoulder has also been covered elsewhere (Tennent, Beach, & Meyers, 2003a,b). However, when evaluating the research on the sensitivity and specificity of the above-mentioned tests, even on the tests that have proven to be of value we must be cognizant of the patient populations that have been used to derive these statistics. Often the subjects used are patients who have failed conservative management and are presenting for an orthopaedic surgical consult. The predictive value of the tests on a group of swimmers who are reporting their first bout of shoulder pain may not be as good. It is uncommon, especially in the early stages of shoulder pain, for the swimmer to have major internal derangement.

## 6. Treatment

Obviously the direction of treatment will be driven by what is discovered in the examination. Basic principles of acute management (i.e. ice application, medical support, anti-inflammatory medication) have not been covered here but it expected the clinician has an appreciation of these principles. Following is a list of possible useful rehabilitative interventions.

### 6.1. Control of training factors

It is imperative not to maintain the pain cycle by trying to 'swim through it'. Possible contributing training errors should be identified from the history and appropriate changes should be made. Total rest, however, is very rarely warranted (nor tolerated by swimmers and coaches) and swimming training may be maintained so long as painful activities are avoided. Using combinations of kick, drill, and swim may allow the swimmer to continue training pain-free during their rehabilitation. Alternative dry land training may be used as a cross-training adjunct. Changes in training should always be done in conjunction with the coach. The input and support of the coach is extremely important in the successful management of shoulder pain in swimmers.

### 6.2. Cervical mobilization/manipulation

There have been no studies examining the efficacy of cervical mobilization on shoulder pain in swimmers. In a single case study, cervical mobilization resulted in decreases in neck and shoulder pain with increases of motion in both areas, however, this was on a patient with neurogenic cervicobrachial pain (Cowell & Phillips, 2002). More convincingly, in well designed and controlled intervention studies on lateral epicondylitis, mobilization of the cervical spine has proven to be effective in creating hypoalgesia and increased muscle function in the upper limb (Vicenzino et al., 1998; Vicenzino, Collins, & Wright, 1996). This analgesia appears to be more pinpointed to the reduction of mechanical pain (Vicenzino et al., 1998). It has been hypothesized that this pain relief is driven by the activation of descending pain inhibitory pathways (Sterling, Jull, & Wright, 2001b). Shoulder pain, as a model, has been avoided in these more scientific examinations due to the difficulties in differentiating the effects of mobilization and manipulation on cervical joints and possible effects on the muscles that have direct attachment from the cervical spine to the shoulder girdle (i.e. levator scapulae, trapezius). However, it would seem that if cervical mobilization can create hypoalgesia at the elbow it is also likely to have the same effect at the shoulder. Cervical mobilization also has further reaching neurophysiological effects including changes in resting muscle activity (Sterling, Jull, & Wright, 2001a).

Whilst it can be argued that creating a state of hypoalgesia will only then mask the damaging effects of mechanical impingement it has been demonstrated in previous sections that shoulder pain is rarely a simple mechanical phenomena. It seems likely that even if there is only a reduction in pain this can lead to improvements in shoulder proprioception and motor patterning. Clinical experience has demonstrated that cervical mobilization can have a powerful effect on shoulder pain and flexibility of swimmers. The lateral glides used as an intervention in the previously mentioned studies (Vicenzino et al., 1996, 1998) and anterior-to-posterior mobilizations (Maitland, Hengeveld, Banks, & English, 2000) have been preferred but the efficacy of any intervention must be gauged from the reassessment of salient tests from the initial examination. It is probable that any improvements gained with these techniques are likely to be acute (Wright, 2000) and need to then be reinforced with rehabilitative exercise.

### 6.3. Trigger points and soft tissue therapy

Initial randomized, but poorly controlled research, has demonstrated soft tissue therapy has benefits in shoulder pain and function in a general outpatient population (van den Dolder & Roberts, 2003). Trigger point therapy and massage of the infraspinatus displays increases of glenohumeral internal rotation range of swimmers at least in the short term (Blanch et al., 1995). It has also been suggested that massage can activate the descending inhibitory pathways to suppress pain in a similar mechanism that has been established in other manual therapies (Goats, 1994b).

Clinically, soft tissue techniques can be used to increase the range of motion of swimmers and also treat their shoulder pain. Again this may then have an influence on shoulder proprioception and muscle patterning. There are a myriad of massage techniques that can be used (Goats, 1994a), and whether one has greater benefit than the other is difficult to ascertain and may only be an intellectual rather than practical argument. Again the efficacy of the intervention must be ascertained by reassessment of initial findings. Improvements in function should be reinforced by the initiation of an appropriate home program.

### 6.4. Stretching

In short, stretching will only be of benefit if you have an identified decreased range of motion. Commonly there will be some tightness of the posterior structures of the glenohumeral joint that will benefit from the appropriate stretches. The mistakes made in stretching programs tend to be that (1) swimmers will stretch areas they are already quite flexible in and (2) swimmers will stretch in areas that are not required for swimming (e.g. strong anterior capsule stretching). Having the appropriate ranges of motion throughout the kinetic chain as mentioned previously is essential to swimming fast but having more than what is required will not help and may potentially be problematic.

### 6.5. Scapula stability

As previously mentioned, there is strong agreement amongst clinical papers that retraining of scapula stability is an integral part of the rehabilitation of the swimmer's shoulder (Jones, 1999; Kibler, 1998; Kibler et al., 2001; McMaster, 1999; Pink & Tibone, 2000; Weldon & Richardson, 2001). There is some debate over which particular section or sections of the scapula stabilizers are the predominate contributors (Kibler & McMullen, 2003; Wadsworth & Bullock Saxton, 1997). This may also tend to be an intellectual rather than practical argument as it is difficult to see how one section of the scapula stabilizers can be trained without also affecting the other components. Finally it may be that scapula control problems will vary from subject to subject (Kibler & McMullen, 2003).

Clinically, from a treatment direction philosophy, scapula stability is approached in four steps. Firstly, facilitating contraction of the scapula stabilizers in static postures encourages *stability*. Secondly, isolated glenohumeral motion is introduced in different positions whilst maintaining stability to support *mobility upon stability*. Thirdly, large range shoulder motions under controlled situations are used to promote *stability through range*. Finally, these exercises can be progressed by adding load via various forms of resistance (weights, bands, pulleys) to achieve *loaded mobility upon stability*.

### 6.6. Proprioceptive exercises

It is very difficult in a clinical setting to ascertain the proprioceptive acuity of the shoulder. However, it has been proven (see the previous section on proprioception) that proprioception of the shoulder is decreased in the presence of pain and/or injury and therefore it should be addressed in a rehabilitation program. A 4-week proprioceptive exercise program has been shown to increase shoulder proprioception and shoulder function, and decrease pain in a group of patients with subacromial impingement (Jerosch & Wustner, 2002). This study did not have the strengthening benefit of a control group, however, it still provides some evidence.

Clinically, the program examined by Jerosch and Wustner (2002), especially the use of the Body Blade (Bodyblade- Hymanson, Inc. Playa del Ray, California, USA) as an exercise tool, is recommended. Other exercises such as ball rolling on a wall (forwards and backwards), push-ups on a wobble board and rhythmic stabilizations may be useful. It is probable that any exercise done in a controlled and concentrated manner will have some proprioceptive retraining effect.

### 6.7. Rotator cuff exercises

Obviously rotator cuff exercises will be of importance if a weakness is detected in the specific muscles of the cuff. This is not generally the case in swimmers. The fact that the exercises are usually done concentrating on maintaining good scapula position and focussing on isolated glenohumeral rotation makes them attractive as both a scapula control and proprioceptive exercise.

### 6.8. Functional strengthening

In the final strengthening component of rehabilitation a number of the factors that have been previously discussed (scapula stability, proprioceptive demand) can be used to help direct the exercise plan. Exercises that attempt to mimic the motions used are beneficial. Performing the exercises with good technique and increasing the intensity of the exercise by increasing the proprioceptive requirements of the exercise will aid in encouraging scapula stability and proprioception.

### 6.9. Electrotherapy

In general, there is little direct or indirect evidence to support the use of electrotherapy in the treatment of shoulder pain in swimmers. The use of TENS and other similar electrical stimulation devices may have a role in the treatment of pain but it is doubtful that these interventions have the same potential to affect the neuromuscular system as powerfully as the described manual therapy techniques.

### 6.10. Plan

It is important to have a treatment plan both short and long term. Initially the program may concentrate on identifying and reducing the aggravating factors plus interventions aimed at decreasing the pain. This may then progress to acquiring the appropriate ranges of motion throughout the kinetic chain. Retraining motor patterning and increasing the proprioceptive input would be followed by a functional strengthening program. This is not to be prescriptive and will need to be tailored to the individual. The emphasis will progress as the swimmer improves.

### 6.11. Surgery

Even after exhaustive rehabilitation there are swimmers who will fail and be faced with surgery as a last option in the treatment of their shoulder pain. Open surgical procedures have historically had poor results in returning swimmers to the highest levels of competition (McMaster, 1999). Anecdotally, in Australia over the last several years there have been several National level swimmers who have had open surgery on the shoulder. Of those, three have made it back to the National team level and only one of those has swam faster times than pre-surgery. The excessive flexibility requirements of fast swimming are in complete contrast to the aims of surgical procedures. The rehabilitation after surgical intervention follows the same guidelines that have been outlined in this paper.

## 7. Conclusion

The development and the consequent rehabilitation of shoulder pain in swimmers can be multifactorial. The interplay between the requirement of the sport, the shoulder's mechanical restraints, the biomechanical effect of the kinetic chain, and the powerful influence of the neuromuscular system must be appreciated in pathological and therefore rehabilitation models. The interaction between flexibility, strength, muscle facilitation, muscle inhibition, proprioception, muscle patterning, and pain is complicated and poorly understood. It is, however, in these neuromuscular areas that conservative management has its greatest influence.

## References

Alvemalm, A., Furness, A., & Wellington, L. (1996). Measurement of shoulder joint kinaesthesia. *Manual Therapy*, *1*, 140–145.

An, K. N., Browne, A. O., Korinek, S., Tanaka, S., & Morrey, B. F. (1991). Three-dimensional kinematics of glenohumeral elevation. *Journal of Orthopaedic Research*, *9*, 143–149.

Ayub, E. (1991). Posture and the upper quarter. In R. A. Donatelli (Ed.), *Clinics in physical therapy: physical therapy of the shoulder* (2nd ed). New York: Churchill Livingstone.

Bagg, S. D., & Forrest, W. J. (1988). A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *American Journal of Physical Medicine and Rehabilitation*, *67*, 238–245.

Bak, K., & Magnusson, S. P. (1997). Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *American Journal of Sports Medicine*, *25*, 454–459.

Beach, M. L., Whitney, S. L., & Dickoff Hoffman, S. A. (1992). Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *Journal of Orthopaedic & Sports Physical Therapy*, *16*, 262–268.

Beekman, K. M., & Hay, J. G. (1988). Characteristics of the front crawl techniques of swimmers with shoulder impingement syndrome. *Journal of Swimming Research*, *4*(3), 15–21.

Belling Sorensen, A. K., & Jorgensen, U. (2000). Secondary impingement in the shoulder. An improved terminology in impingement. *Scandinavian Journal of Medicine and Science in Sports*, *10*, 266–278.

Blanch, P. D., Clews, W., Popov, V., Matley, K., (1995). *The effect of massage on the isolated glenohumeral internal rotation range of swimmers*. Proceedings of the 1995 Australian Conference of Science and Medicine in Sport, Hobart, Australia: Sports Medicine Australia.

Brindle, T. J., Nyland, J., Shapiro, R., Caborn, D. N., & Stine, R. (1999). Shoulder proprioception: latent muscle reaction times. *Medicine and Science in Sports and Exercise*, *31*, 1394–1398.

Carpenter, J. E., Blasier, R. B., & Pellizzon, G. G. (1998). The effects of muscle fatigue on shoulder joint position sense. *American Journal of Sports Medicine*, *26*, 262–265.

Ciullo, J. V. (1986). Swimmer's shoulder. *Clinics in Sports Medicine*, *5*, 115–137.

Conroy, D. E., & Hayes, K. W. (1998). The effect of joint mobilization as a component of comprehensive treatment for primary shoulder impingement syndrome. *Journal of Orthopaedic & Sports Physical Therapy*, *28*, 3–14.

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Danneels, L. A., & Cambier, D. C. (2003). Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. *American Journal of Sports Medicine*, *31*, 542–549.

Counsilman, J. E., (1971). *Application of Bernoulli's principle to human propulsion in water*. Paper presented at the International Symposium on Biomechanics in Swimming, Waterpolo and Diving, Brussels.

Cowell, I. M., & Phillips, D. R. (2002). Effectiveness of manipulative physiotherapy for the treatment of a neurogenic cervicobrachial pain syndrome: a single case study-experimental design. *Manual Therapy*, *7*, 31–38.

Fleisig, G. S., Barrentine, S. W., Escamilla, R. F., & Andrews, J. R. (1996). Biomechanics of overhand throwing with implications for injuries. *Sports Medicine*, *21*, 421–437.

Fowler, P. J., & Regan, W. D. (1986). Swimming injuries of the knee, foot and ankle, elbow, and back. *Clinics in Sports Medicine*, *5*, 139–148.

Goats, G. C. (1994a). Massage-the scientific basis of an ancient art: Part 1. The techniques. *British Journal of Sports Medicine*, *28*, 149–152.

Goats, G. C. (1994b). Massage-the scientific basis of an ancient art: Part 2. Physiological and therapeutic effects. *British Journal of Sports Medicine*, *28*, 153–156.

Graven-Nielsen, T., Lund, H., Arendt-Nielsen, L., Danneskiold-Samsoe, B., & Bliddal, H. (2002). Inhibition of maximal voluntary contraction force by experimental muscle pain: a centrally mediated mechanism. *Muscle and Nerve*, *26*, 708–712.

Hall, T., & Quintner, J. (1996). Responses to mechanical stimulation of the upper limb in painful cervical radiculopathy. *Australian Journal of Physiotherapy*, *42*, 277–285.

Harris, J., & Clarke, R. W. (2003). Organisation of sensitisation of hind limb withdrawal reflexes from acute noxious stimuli in the rabbit. *Journal of Physiology*, *546*(Pt 2), 251–265.

Harryman, D. T., Sidles, J. A., Clark, J. M., McQuade, K. J., Gibb, T. D., & Matsen, F. A. (1990). Translation of the humeral head on the glenoid with passive glenohumeral motion. *Journal of Bone and Joint Surgery (Am)*, *72A*, 1334–1343.

Hawkins, R. J., & Kennedy, J. C. (1980). Impingement syndrome in athletes. *American Journal of Sports Medicine*, *8*, 151–158.

Hertel, H. (1966). *Structure-form-movement*. New York: Reinhold Publishing.

Jerosch, J., Castro, W. H., Halm, H., & Drescher, H. (1993). Does the glenohumeral joint capsule have proprioceptive capability? *Knee Surgery, Sports Traumatology, Arthroscopy*, *1*, 80–84.

Jerosch, J., & Prymka, M. (1996). Proprioception and joint stability. *Knee Surgery, Sports Traumatology, Arthroscopy*, *4*, 171–179.

Jerosch, J., & Wustner, P. (2002). Effect of a sensorimotor training program on patients with subacromial pain syndrome. *Unfallchirurg*, *105*(1), 36–43.

Jobe, F. W., Kvitne, R. S., & Giangarra, C. E. (1989). Shoulder pain in the overhand or throwing athlete. The relationship of anterior instability and rotator cuff impingement. *Orthopaedic Review*, *18*, 963–975.

Johansen, R. L., Callis, M., Potts, J., & Shall, L. M. (1995). A modified internal rotation stretching technique for overhand and throwing athletes. *Journal of Orthopaedic & Sports Physical Therapy*, *21*, 216–219.

Jones, J. H. (1999). Swimming overuse injuries. *Physical Medicine and Rehabilitation Clinics of North America*, *10*, 77–94.

Kennedy, J. C., Hawkins, R., & Krissoff, W. B. (1978). Orthopaedic manifestations of swimming. *American Journal of Sports Medicine*, *6*, 309–322.

Kibler, W. B. (1995). Biomechanical analysis of the shoulder during tennis activities. *Clinics in Sports Medicine*, *14*, 79–85.

Kibler, W. B. (1998). The role of the scapula in athletic shoulder function. *American Journal of Sports Medicine*, *26*, 325–337.

Kibler, W. B., & McMullen, J. (2003). Scapular dyskinesis and its relation to shoulder pain. *Journal of the American Academy of Orthopaedic Surgeons*, *11*, 142–151.

Kibler, W. B., McMullen, J., & Uhl, T. (2001). Shoulder rehabilitation strategies, guidelines, and practice. *Orthopaedic Clinics of North America*, *32*, 527–538.

Laughlin, T. (1996). *Total immersion: the revolutionary way to swim better, faster and easier*. New York: Simon and Shuster.

Leffler, A. S., Hansson, P., & Kosek, E. (2002). Somatosensory perception in a remote pain-free area and function of diffuse noxious inhibitory controls (DNIC) in patients suffering from long-term trapezius myalgia. *European Journal of Pain*, *6*, 149–159.

Lephart, S. M., Pincivero, D. M., Giraldo, J. L., & Fu, F. H. (1997). The role of proprioception in the management and rehabilitation of athletic injuries. *American Journal of Sports Medicine*, *25*, 130–137.

Lo, S. F., Chen, S. Y., Lin, H. C., Jim, Y. F., Meng, N. H., & Kao, M. J. (2003). Arthrographic and clinical findings in patients with hemiplegic shoulder pain. *Archives of Physical Medicine and Rehabilitation*, *84*, 1786–1791.

Ludewig, P. M., & Cook, T. M. (2002). Translations of the humerus in persons with shoulder impingement symptoms. *Journal of Orthopaedic & Sports Physical Therapy*, *32*, 248–259.

Maitland, G. D., Hengeveld, E., Banks, K., & English, K. (2000). *Maitland's vertebral manipulation*. Oxford: Butterworth-Heinemann.

Matsen, F. A., Harryman, D. T., & Sidles, J. A. (1991). Mechanics of glenohumeral instability. *Clinics in Sports Medicine*, *10*, 783–788.

McMaster, W. C. (1999). Shoulder injuries in competitive swimmers. *Clinics in Sports Medicine*, *18*, 349–359.

McMaster, W. C., Roberts, A., & Stoddard, T. (1998). A correlation between shoulder laxity and interfering pain in competitive swimmers. *American Journal of Sports Medicine*, *26*, 83–86.

McMaster, W. C., & Troup, J. (1993). A survey of interfering shoulder pain in United States competitive swimmers. *American Journal of Sports Medicine*, *21*, 67–70.

Morris, A. D., Kemp, G. J., Lees, A., & Frostick, S. P. (1998). A study of the reproducibility of three different normalisation methods in intramuscular dual fine wire electromyography of the shoulder. *Journal of Electromyography and Kinesiology*, *8*, 317–322.

Myers, J. B., & Lephart, S. M. (2002). Sensorimotor deficits contributing to glenohumeral instability. *Clinical Orthopaedics*, *400*, 98–104.

Neer, C. S. (1972). Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *Journal of Bone and Joint Surgery (Am)*, *54A*, 41–50.

Nyland, J. A., Caborn, D. N., & Johnson, D. L. (1998). The human glenohumeral joint. A proprioceptive and stability alliance. *Knee Surgery, Sports Traumatology Arthroscopy*, *6*, 50–61.

Pedersen, J., Lonn, J., Hellstrom, F., Djupsjobacka, M., & Johansson, H. (1999). Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. *Medicine and Science in Sports and Exercise*, *31*, 1047–1052.

Penny, J. N., & Smith, C. (1980). The prevention and treatment of swimmer's shoulder. *Canadian Journal of Applied Sport Science*, *5*, 195–202.

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

Pink, M. M., & Tibone, J. E. (2000). The painful shoulder in the swimming athlete. *Orthopaedic Clinics of North America*, *31*, 247–261.

Post, M., Jablon, M., Miller, H., & Singh, M. (1979). Constrained total shoulder joint replacement: a critical review. *Clinics in Orthopaedics*, *144*, 135–150.

Prichard, B. (1993). A new swim paradigm (Un nouveau paradigme en natation: les nageurs se propulsent a partir du bassin). *Swimming technique ETATS UNIS D'AMERIQUE*, *30*(1), 17–23.

Rathbun, J. B., & Macnab, I. (1970). The microvascular pattern of the rotator cuff. *Journal of Bone and Joint Surgery (Br)*, *52B*, 540–553.

Reid, D. C., Saboe, L. A., & Chepeha, J. C. (1996). Anterior shoulder instability in athletes: comparison of isokinetic resistance exercises and an electromyographic biofeedback re-education program—a pilot program. *Physiotherapy Canada*, *48*, 251–256.

Reilly, M. F., Kame, V. D., Termin, B., Tedesco, M. E., & Pendergast, D. (1990). Relation between freestyle swimming speed and stroke mechanics to isokinetic muscle function (Relation entre la vitesse nage libre et la mecanique du mouvement par rapport a la fonction musculaire isocinetique). *Journal of swimming research ETATS UNIS D'AMERIQUE*, *6*(3), 16–21.

Rodeo, S. A., Suzuki, K., Yamauchi, M., Bhargava, M., & Warren, R. F. (1998). Analysis of collagen and elastic fibers in shoulder capsule in patients with shoulder instability. *American Journal of Sports Medicine*, *26*, 634–643.

Rushall, B. S. (2002). Lift is not an important force in swimming propulsion. *American Swim Coaches Association Newsletter*, 6.

Rushall, B. S., Sprigings, E. J., Holt, L. E., & Cappaert, J. M. (1994). A re-evaluation of forces in swimming. *Journal of Swimming Research*, *10*, 6–30.

Safran, M. R., Borsa, P. A., Lephart, S. M., Fu, F. H., & Warner, J. J. (2001). Shoulder proprioception in baseball pitchers. *Journal of Shoulder and Elbow Surgery*, *10*, 438–444.

Sahrmann, S. A. (1998). The twenty-ninth Mary McMillan lecture: Moving precisely? Or taking the path of least resistance? *Physical Therapy*, *78*, 1208–1218.

Schleihauf, R. (1987). Swimming skill: a review of a basic theory. *Swimming Times*, *64*(7), 3–8.

Schleihauf, R. (1987). Swimming skill: a review of a basic theory (Part 2). *Swimming Times*, *64*(8), 1–6.

Scovazzo, M. L., Browne, A., Pink, M., Jobe, F. W., & Kerrigan, J. (1991). The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. *American Journal of Sports Medicine*, *19*, 577–582.

Simons, D. G. (2004). Review of enigmatic MTrPs as a common cause of enigmatic musculoskeletal pain and dysfunction. *Journal of Electromyography and Kinesiology*, *14*, 95–107.

Simons, D. G., Travell, J. G., Simons, L. S., & Cummings, B. D. (1999). *Travell and Simons Myofascial pain and dysfunction: The trigger point manual*. Baltimore: Williams and Wilkins.

Sobel, J. (1995). Shoulder rehabilitation—Rotator cuff disease. In F. A. Pettrone (Ed.), *Athletic injuries of the shoulder* (pp. 245–270). New York: McGraw-Hill.

Speer, K. P., Deng, X., Borrero, S., Torzilli, P. A., Altchek, D. A., & Warren, R. F. (1994). Biomechanical evaluation of a simulated Bankart lesion. *Journal of Bone and Joint Surgery (Am)*, *76A*, 1819–1826.

Sprigings, E. J., & Koehler, J. A. (1990). The choice between Bernoulli's or Newton's model in predicting dynamic lift. *International Journal of Sport Biomechanics*, *6*, 235–245.

Sterling, M., Jull, G., & Wright, A. (2001). Cervical mobilisation: concurrent effects on pain, sympathetic nervous system activity and motor activity. *Manual Therapy*, *6*, 72–81.

Sterling, M., Jull, G., & Wright, A. (2001). The effect of musculoskeletal pain on motor activity and control. *Journal of Pain*, *2*, 135–145.

Sterner, R. L., Pincivero, D. M., & Lephart, S. M. (1998). The effects of muscular fatigue on shoulder proprioception. *Clinical Journal of Sport Medicine*, *8*, 96–101.

Stokes, M., & Young, A. (1984). The contribution of reflex inhibition to arthrogenous muscle weakness. *Clinical Science*, *67*, 7–14.

Sugamoto, K., Harada, T., Machida, A., Inui, H., Miyamoto, T., Takeuchi, E., & etal, . (2002). Scapulohumeral rhythm: relationship between motion velocity and rhythm. *Clinical Orthopaedics*, *401*, 119–124.

Tennent, T. D., Beach, W. R., & Meyers, J. F. (2003a). A review of the special tests associated with shoulder examination. Part I: the rotator cuff tests. *American Journal of Sports Medicine*, *31*, 154–160.

Tennent, T. D., Beach, W. R., & Meyers, J. F. (2003b). A review of the special tests associated with shoulder examination. Part II: laxity, instability, and superior labral anterior and posterior (SLAP) lesions. *American Journal of Sports Medicine*, *31*, 301–307.

Thacker, S. B., Gilchrist, J., Stroup, D. F., & Kimsey, C. D., Jr (2004). The impact of stretching on sports injury risk: a systematic review of the literature. *Medicine and Science in Sports and Exercise*, *36*, 371–378.

van den Dolder, P. A., & Roberts, D. L. (2003). A trial into the effectiveness of soft tissue massage in the treatment of shoulder pain. *Australian Journal of Physiotherapy*, *49*, 183–188.

Vicenzino, B., Collins, D., Benson, H., & Wright, A. (1998). An investigation of the interrelationship between manipulative therapy-induced hypoalgesia and sympathoexcitation. *Journal of Manipulative and Physiological Therapeutics*, *21*, 448–453.

Vicenzino, B., Collins, D., & Wright, A. (1996). The initial effects of a cervical spine manipulative physiotherapy treatment on the pain and dysfunction of lateral epicondylalgia. *Pain*, *68*, 69–74.

Videler, J. J. (1993). *Fish swimming*. London: Chapman & Hall.

Voight, M. L., Hardin, J. A., Blackburn, T. A., Tippett, S., & Canner, G. C. (1996). The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. *Journal of Orthopaedic & Sports Physical Therapy*, *23*, 348–352.

Wadsworth, D. J., & Bullock Saxton, J. E. (1997). Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. *International Journal of Sports Medicine*, *18*, 618–624.

Warner, J. J., Lephart, S., & Fu, F. H. (1996). Role of proprioception in pathoetiology of shoulder instability. *Clinical Orthopaedics*, *330*, 35–39.

Warner, J. J., Micheli, L. J., Arslanian, L. E., Kennedy, J., & Kennedy, R. (1990). Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *American Journal of Sports Medicine*, *18*, 366–375.

Weldon, E. J., & Richardson, A. B. (2001). Upper extremity overuse injuries in swimming. *Clinics in Sports Medicine*, *20*, 423–438.

Wheeler, A. H. (2004). Myofascial pain disorders: theory to therapy. *Drugs*, *64*, 45–62.

Wilk, K. E., Arrigo, C. A., & Andrews, J. R. (1997). Current concepts: the stabilizing structures of the glenohumeral joint. *Journal of Orthopaedic and Sports Physical Therapy*, *25*, 364–379.

Woolf, C. J. (1984). Long term alterations in the excitability of the flexion reflex produced by peripheral tissue injury in the chronic decerebrate rat. *Pain*, *18*, 325–343.

Wright, A. (2000). Hypoalgesia post-manipulative therapy: a review of a potential neurophysiological mechanism. *Manual Therapy*, *1*, 11–16.

Yanai, T., & Hay, J. G. (2000). Shoulder impingement in front-crawl swimming: II. Analysis of stroking technique. *Medicine and Science in Sports and Exercise*, *32*, 30–40.

Yanai, T., Hay, J. G., & Miller, G. F. (2000). Shoulder impingement in front-crawl swimming: I. A method to identify impingement. *Medicine and Science in Sports and Exercise*, *32*, 21–29.

Zemek, M. J., & Magee, D. J. (1996). Comparison of glenohumeral joint laxity in elite and recreational swimmers. *Clinical Journal of Sport Medicine*, *6*, 40–47.