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Masters thesis

MPhil (Sports Physiotherapy)

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BCHWEN001

Paddle grip: handgrip size ratio and associated factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in K1 marathon paddlers during the 2006 Berg River Canoe Marathon

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	4
LIST OF TABLES.....	5
LIST OF FIGURES.....	6
ABSTRACT.....	7
1 INTRODUCTION	8
2 LITERATURE REVIEW.....	12
2.1 Epidemiology of upper limb injuries sustained during paddling	12
2.2 The anatomy of the elbow and wrist joints.....	13
2.2.1 The elbow joint.....	13
2.2.2 The wrist joint.....	14
2.3 Biomechanics of the paddling stroke	15
2.3.1 The basic start position	16
2.3.2 Entry and catch	17
2.3.3 The power phase	18
2.3.4 Exit and recovery	19
2.3.5 Forearm muscle activity during the paddling stroke.....	20
2.3.6 The kinetic chain of the upper limb in the paddling stroke	20
2.3.7 Upper limb myofascial meridians in the paddling stroke	22
2.4 Overuse injuries	25
2.4.1 Normal tendon anatomy.....	26
2.4.2 The inflammatory response to acute tendon injury	27
2.4.3 Tendinitis.....	29
2.4.4 Delayed onset muscle soreness (DOMS).....	30
2.4.5 The tendon response to repetitive overloading and overuse	34
2.4.6 Overuse tendinopathy	35
2.5 Predisposing factors to paddling-specific overuse injuries of the elbow and wrist	36
2.5.1 Intrinsic factors	36
2.5.2 Extrinsic factors.....	40
2.6 Chronic overuse tendinopathies affecting the elbow and wrist joints.....	46
2.6.1 Lateral elbow tendinosis.....	46
2.6.2 DeQuervains tenosynovitis	53
3 AIM AND OBJECTIVES.....	58
3.1 Aim.....	58
3.2 Objectives	58
4 METHODS	59
4.1 Study design	59
4.2 Subjects	59
4.2.1 Subject recruitment	59
4.3 Informed consent	60
4.4 Questionnaire.....	60
4.5 Height and body mass measurements	62
4.6 Diagnostic tests.....	62
4.6.1 Diagnostic tests for lateral elbow tendinosis	63
4.6.2 Diagnostic test for DeQuervains tenosynovitis.....	65
4.6.3 Pain assessment using the Visual Analogue Scale (VAS).....	66
4.6.4 Analysis of extrinsic factors involved in upper-limb overuse injuries.....	66
4.7 Testing procedure	68

4.8	Post-race data collection and analysis.....	70
4.9	Statistical analysis.....	70
5	RESULTS	72
5.1	Subject selection.....	72
5.2	Data analysis	73
5.3	Daily subject totals for the symptomatic group	73
5.4	General characteristics of subjects	74
5.5	Previous medical history	75
5.6	Use of medication	75
5.7	Paddling history	76
5.8	Stretching history	76
5.9	Training history	76
5.10	Time-trial speed	79
5.11	Paddling equipment	80
5.12	Race results for the 2006 Berg River Canoe Marathon	81
5.13	Paddle grip: handgrip size ratio	81
5.14	Grip strength	82
5.15	Weather conditions	83
6	DISCUSSION.....	85
6.1	Incidence of injury	85
6.2	Training history	89
6.3	Training factors	90
6.4	Time-trial	91
6.5	Paddling equipment	93
6.6	Handgrip size and the paddle grip: handgrip size ratio.....	93
6.7	Weather and water surface conditions.....	94
7	CONCLUSION.....	95
7.1	Limitations of this study and recommendations for future research.....	96
7.2	Clinical relevance of this study.....	97
8	REFERENCES	98
9	APPENDIX I - Ethical clearance certificate	106
10	APPENDIX II - Recruitment notices.....	108
11	APPENDIX III - Informed consent form	110
12	APPENDIX IV - Questionnaire.....	112
13	APPENDIX V- Pilot study.....	119
14	APPENDIX VI - Summary of results of the Shapiro-Wilkes test for normality.....	120

ACKNOWLEDGEMENTS

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University of Cape Town

LIST OF TABLES

Table 5.1. *Incidence of elbow and wrist pain on days one to four of the 2006 Berg River Canoe Marathon.*

Table 5.2. *General characteristics of subjects in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).*

Table 5.3. *Previous medical history in the symptomatic and asymptomatic groups.*

Table 5.4. *Paddling history of subjects in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).*

Table 5.5. *Race results in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).*

Table 5.6. *Paddle grip size, handgrip size and the paddle grip: handgrip size ratio for the symptomatic and asymptomatic groups. (Mean \pm standard deviation).*

Table 5.7. *Dominant and non-dominant grip strengths for the symptomatic and asymptomatic groups. (Mean \pm standard deviation).*

University of Cape Town

LIST OF FIGURES

Figure 2.1 *Entry and catch*

Figure 2.2 *The power phase*

Figure 2.3 *Exit and recovery*

Figure 4.1 *Passive wrist flexion with full elbow extension and pronation (Reid, 1992; Whaley & Baker, 2004).*

Figure 4.2 *Finkelsteins test (Finkelstein, 1930).*

Figure 4.3 *The Nirschl technique (Nirschl, 1992).*

Figure 4.4 *Testing procedure*

Figure 5.1. *Average number of training days in 12 off-season weeks in the symptomatic (n = 17) and asymptomatic (n = 23) groups. (** p = 0.007)*

Figure 5.2. *The average number of training days in 12 weeks preceding the 2006 Berg River Canoe Marathon in the symptomatic (n = 17) and asymptomatic groups (n = 23). (* p = 0.025)*

Figure 5.3. *The average duration of training sessions in 12 off-season weeks in the symptomatic (n = 17) and asymptomatic (n = 23) groups.*

Figure 5.4. *The average duration of training sessions in 12 weeks preceding the 2006 Berg River Canoe Marathon in the symptomatic (n = 17) and asymptomatic (n = 23) groups.*

Figure 5.5. *The average time-trial speeds recorded within a 6-month period prior to the 2006 Berg River Canoe Marathon in the symptomatic (n = 17) and asymptomatic (n = 23) groups. (* p = 0.034)*

Figure 5.6. *Daily race distances for the 2006 Berg River Canoe Marathon.*

Figure 5.7. *Environmental conditions for days one to four of the 2006 Berg River Canoe Marathon. Daily incidence of injury; day 1 (n = 1), day 2 (n = 11), day 3 (n = 3), and day 4 (n = 2).*

ABSTRACT

Aim: To determine the relationship between the paddle grip: handgrip size ratio and associated factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in K1 marathon paddlers.

Methods: 40 paddlers were recruited from participants in the 2006 Berg River Canoe Marathon. 17 paddlers, who presented with elbow or wrist pain during the 2006 Berg River Canoe Marathon, and who tested positive for lateral elbow tendinosis and/or DeQuervains tenosynovitis, on the diagnostic tests below, were assigned to the symptomatic group. 23 paddlers with no elbow or wrist pain, at the start or the end of the 2006 Berg River Canoe Marathon, and who tested negative for lateral elbow tendinosis and/or DeQuervains tenosynovitis, on the diagnostic tests below, formed the asymptomatic group. Subjects completed a questionnaire to determine previous medical history, medication use, paddling history, stretching history, training history, and paddling equipment. Tests for lateral elbow tendinosis included passive wrist flexion with elbow extension and pronation with an associated VAS for pain, and grip strength. Finkelsteins test was used for diagnosis of DeQuervains tenosynovitis, along with an associated VAS for pain. Handgrip size was measured using the Nirschl technique. The paddle grip: handgrip size ratio was determined. Daily temperature, flow rate, water level, and rainfall were recorded.

Results: The incidence of lateral elbow tendinosis and DeQuervains tenosynovitis on the 2006 Berg River Canoe Marathon was 11.81%. The paddle grip: handgrip size ratios were not significantly different between the symptomatic and asymptomatic groups. The asymptomatic group trained significantly more frequently during 12 off-season weeks (58.43 ± 21.19) than the symptomatic group (43.06 ± 16.46), with $p = 0.007$. The asymptomatic group also trained significantly more frequently during 12 weeks pre-competition (62.61 ± 19.47) than the symptomatic group (52.94 ± 17.52), with $p = 0.025$. The asymptomatic group were also significantly faster over a 10km time-trial (3.43 ± 0.42) than the symptomatic group (3.14 ± 0.35), with $p = 0.034$.

Conclusions: The paddle grip: handgrip size ratio did not contribute to development of lateral elbow tendinosis and DeQuervains tenosynovitis in the paddlers in this study. Possible factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis included the training frequency in preparation for the canoe marathon and time-trial performances.

1 INTRODUCTION

Canoeing and kayaking, two forms within the discipline of paddling, are seeing a worldwide rise in popularity every year (www.canoesa.co.za). In the United States, canoeing and kayaking are among the top ten fastest growing sports, with an estimated 1.4 to 2.8 million whitewater paddlers in 2001. This number is growing by approximately 15% annually (Fiore & Houston, 2001). A similar trend is evident in South Africa, where endurance events such as the Dusi River Canoe Marathon attract a rapidly growing number of paddlers every year (Hagemann *et al.*, 2004). The Dusi River Canoe Marathon started in 1951 with only eight participants, whereas in 2007 the Dusi River Canoe Marathon boasted a field of over 2000 competitors (www.dusi.org.za).

The growth in popularity of paddling as a sport has been paralleled by technology and scientific development, with research focussing on experimental boat and paddle designs (Hagemann *et al.*, 2004).

However, little research has investigated the pathogenesis and the treatment and prevention of paddling injuries (Hagemann *et al.*, 2004). This is especially true in South Africa, where physiotherapy and exercise science have focused the majority of their research efforts on the cycling and running endurance events in the sporting calendar. Worldwide, some studies have attempted to provide descriptive data on paddling injuries. This has provided a starting point, but further studies are needed to determine the specific causes of paddling injuries (Fiore & Houston, 2001).

Paddling is essentially a repetitive motion of the upper body (Kameyama *et al.*, 1999). During the paddling stroke, the upper extremity is involved in force transmission to the paddle and is therefore susceptible to the development of overuse injuries (Fiore & Houston, 2001).

This is evident in the study by Fiore & Houston (2001), who reported the prevalence of injury to the upper limb of whitewater paddlers as 62%, of which overuse injuries accounted for 25%. Du Toit *et al* (1999) found that acute tenosynovitis of the extensor tendons of the forearm was experienced by an average of 23% of long distance paddlers participating in four different canoe marathons in South Africa.

Further, in the Year 2000 Whitewater Injury Survey, 319 paddlers reported injuries to the wrist, forearm, elbow and shoulder more frequently than any other body part (Plumer, 2004). Kameyama *et al* (1999) analysed the results of questionnaires received from 417 competitive paddlers. The results showed that 20.9% of paddlers reported shoulder pain, 10.8% wrist pain and 3.8% elbow pain.

The above research indicates that upper limb injuries may account for one quarter of all paddling injuries. These injuries are mostly overuse injuries that lead to significant time off paddling (Fiore & Houston, 2001). Shuer & Dietrich (1997) equate the psychological effects of chronic-overuse injury of the musculoskeletal system in sportsmen with those experienced by persons who have been traumatised by natural disasters. It is therefore evident that it is important to initiate research to further investigate injuries to the upper limb that may be negatively affecting many paddlers worldwide.

The muscles and tendons of the forearm and their associated joints of the elbow and wrist are collectively the most commonly identified regions of chronic overuse in paddlers (Plumer, 2004). Lateral elbow tendinosis and DeQuervains tenosynovitis are the overuse injuries of interest in this study. The most common cause of lateral elbow tendinosis is repetitive wrist extension, as seen during the paddling stroke (Peters & Baker, 2001). The excessive wrist movements with a closed fist involved in long distance paddling may result in extensor tenosynovitis of the forearm (du Toit *et al.*, 1999). DeQuervains tenosynovitis, also known as paddler's wrist, is the most common form of wrist tenosynovitis in all athletes (Reid, 1992).

There are several factors that may influence the development of an overuse tendinopathy of the muscles and tendons of the elbow and wrist in paddlers. These include training history, weather conditions, and paddling technique (du Toit *et al.*, 1999). Further factors may include previous injury history (Brukner & Khan, 2001), long-term stretching history, and local muscle imbalance (Alizadehkhayat *et al.*, 2007).

When considering paddling technique as a possible cause of an overuse tendinopathy of the elbow and wrist in paddlers, the grip on the paddle shaft may be a contributing factor. An excessively tight grip may contribute to an overuse injury of the forearm (Macleod, 2003). Anecdotally the paddle shaft diameter may also influence grip force.

The appropriate grip size has been identified as an important contributing factor to forearm injuries among tennis players. Furthermore, Nirschl (1992) developed a technique of hand size measurement, the Nirschl technique, which is indicative of the working length of the hand and determines the "correct" diameter size for the tennis racquet handle for each tennis player.

The racquet handle grip: handgrip size ratio should be 1:1 (Nirschl, 1992). In tennis players who present with forearm pain, changing the size of the grip on the tennis racquet has been shown to dramatically reduce forearm stress (Peters & Baker, 2001).

To date, this technique has only been used for correct grip size selection in tennis players. It is unclear as to whether the above ratio may be extrapolated to paddlers, and there is currently no research on whether paddlers may be predisposed to overuse of the forearm if they do not have a paddle grip: handgrip size ratio of 1:1.

The Nirschl technique will be used in this study to measure individualised grip size for each paddler (Nirschl, 1992). This measurement, along with that of individual paddle shaft diameter, will then be converted into a paddle grip: handgrip size ratio for each paddler to establish whether this ratio contributes to the development of lateral elbow tendinosis or DeQuervains tenosynovitis in these paddlers.

The event of choice for this study is the 2006 Berg River Canoe Marathon, a four-day endurance event held in mid-winter conditions (du Toit *et al.*, 1999). The field consists of experienced paddlers who have completed three B-grade races within the past six months (www.canoesa.co.za). The daily distances for the 2006 Berg River Marathon are over 55km for each of the four days.

In summary, paddling is a growing sport with a relatively high incidence of upper limb overuse injuries. However, little is known regarding the possible underlying mechanisms and contributing factors related to these injuries. The purpose of this study is to determine the relationship between the paddle grip: handgrip size ratio and the development of lateral elbow tendinosis and DeQuervains tenosynovitis during the 2006 Berg River Canoe Marathon. In addition other associated factors that may contribute to the development of lateral elbow tendinosis and DeQuervains tenosynovitis are explored.

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2 LITERATURE REVIEW

2.1 Epidemiology of upper limb injuries sustained during paddling

Fiore & Houston (2001) surveyed injuries sustained during whitewater paddling. It was determined that the upper limb was the most common site of injury during paddling, with an injury prevalence of 62%. It was proposed that the high prevalence of upper limb injuries may be due to the fact that the majority of the power and work generated by the trunk is transmitted through the upper limb to the paddle. It was also reported that tendonitis and overuse injuries each accounted for 25% of all injuries sustained. Further, Hagemann *et al* (2004), indicated that paddling injuries are primarily located in the upper body region, with the shoulder accounting for 53%, and the wrist and hand accounting for 13% of all injuries reported.

Du Toit *et al* (1999) established that 23% of long distance paddlers participating in various canoe marathons in South Africa developed acute tenosynovitis of the forearm. In addition, the Year 2000 Whitewater Injury Survey showed that the majority of injuries that were reported occurred above the waist, with injuries to the wrist, forearm, elbow and shoulder occurring more frequently than any other body part (Plumer, 2004). Kameyama *et al* (1999) reported a 20.9% incidence of shoulder pain, a 10.8% incidence of wrist pain and a 3.8% incidence of elbow pain during a medical examination of competitive paddlers.

Although there is much evidence regarding the incidence of injuries in other overhead sports, such as tennis and swimming, the aforementioned studies reflect the lack of evidence regarding injuries in paddling. However, anecdotal reporting also suggests that there is a relatively high incidence of upper limb injuries, particularly in K1 marathon paddlers. Hagemann *et al*. (2004) indicated the need to identify, classify, and profile marathon paddlers that may be at risk of developing upper limb overuse injuries, in order to implement appropriate preventative strategies.

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Therefore, an understanding of the factors that may contribute to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in marathon paddlers is required. The anatomical and biomechanical factors associated with these conditions will now be reviewed.

2.2 The anatomy of the elbow and wrist joints

2.2.1 The elbow joint

The elbow joint is an important anatomical link between the shoulder and the hand, and allows for flexibility in hand placement, and the transmission and absorption of the forces generated by the upper extremity (Steinberg & Plancher, 1995). The elbow joint comprises the articulations between the distal humerus and the proximal radius and ulna. The medial condyle of the distal humerus has a spoon-like trochlea, while the lateral condyle has a capitellum that is spherical in shape (Alcid *et al.*, 2004).

The proximal radius consists of the radial head, which articulates with the capitellum, at the radiohumeral joint. The radiohumeral joint permits flexion and extension of the forearm (Steinberg & Plancher, 1995). The proximal ulna consists of the olecranon, which consists of the sigmoid notch for articulation with the trochlea, and the radial notch of the coronoid process that articulates with the radial head (Alcid *et al.*, 2004). This 'tongue-and-groove' articulation of the humerus and ulna, the ulnarhumeral joint, allows for flexion and extension of the forearm (Steinberg & Plancher, 1995).

The third articulation at the elbow joint is the radioulnar joint which establishes movement between the radius and ulna in pronation and supination. There are two radioulnar articulations, the superior radioulnar joint at the elbow and the inferior radioulnar joint at the wrist (Hamill & Knutzen, 1995).

Two important structural components in the elbow region are the medial and lateral epicondyles. These prominent extensions of the humerus serve as a site of muscular attachment for several of the wrist and hand muscles. These sites of attachment are also potential injury sites from repetitive overuse (Hamill & Knutzen, 1995).

Twenty-four muscles span the elbow region. Some of these muscles act exclusively at the elbow joint, while others act on the wrist and finger joints. The muscles of interest in this review are those attached to the common extensor origin on the anterior aspect of the lateral epicondyle of the humerus. These include extensor carpi ulnaris (ECU), extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB), and these muscles collectively perform wrist extension. The wrist extensors also create movement at the elbow joint and therefore, elbow joint position is important for wrist extensor function (Hamill & Knutzen, 1995).

ECRL and ECRB flex the elbow joint and are therefore enhanced as wrist extensors when the elbow joint is extended. The ECU extends the elbow joint and is enhanced as a wrist extensor in elbow flexion. Wrist extension is important in supporting the gripping action using finger flexion, and the wrist extensors are therefore active in gripping actions. The wrist extensors are also responsible for radial deviation, a position that affords hand stability as it creates the close-packed position at the wrist joint (Hamill & Knutzen, 1995).

ECRB has been identified as the site of overuse in lateral elbow tendinosis. ECRB has its distal attachment at the base of the third metacarpal and effects extension and abduction at the wrist (Lumley *et al.*, 1996).

2.2.2 The wrist joint

The wrist is the anatomical bridge between the hand and the forearm, and it has an important function in positioning the hand for power and precision activities. The wrist joint or radiocarpal joint is the complex articulation between the distal ends of the radius and the two carpals, the scaphoid and lunate. There is also a minimal amount of contact with a third carpal, the triquetrum. The radiocarpal joint allows for flexion and extension and radial and ulnar deviation. Adjacent to the radiocarpal joint is the distal radioulnar joint. This joint does not participate in any wrist movements but allows for pronation and supination of the forearm (Hamill & Knutzen, 1995).

The ulna has no point of contact with the carpals. It is separated from the carpals by a fibrocartilage disk. This allows the ulna to glide on the disk during pronation and supination without influencing wrist or carpal movements (Hamill & Knutzen, 1995).

There are two rows of carpal bones. The proximal row consists of the three carpals participating in wrist movement (scaphoid, lunate, triquetrum) and the pisiform bone on the medial aspect of the hand. The distal row consists of four carpals, the trapezium that interfaces with the thumb, the trapezoid, the capitate and the hamate. The midcarpal joint is the articulation between the two rows of carpal bones. Translatory movement occurs at the midcarpal joint as the wrist moves (Hamill & Knutzen, 1995).

The wrist contains six synovial sheaths, each of which occupies one of six osseofibrous tunnels deep to the extensor retinaculum, on the dorsal surface of the wrist. These six sheaths contain nine tendons. Abductor pollicis longus (APL) and extensor pollicis brevis (EPB) occupy the first, and most lateral, osseofibrous tunnel (Agur, 1991).

APL attaches proximally to the posterior surface of the radius and the ulna and the intervening interosseous membrane. EPB originates just distal to APL. The tendons of APL and EPB extend laterally and downwards. As the tendons pass distally they form the anterior boundary of the anatomical snuffbox. APL inserts on the radial aspect of the base of the first metacarpal. EPB inserts on the dorsal surface of the base of the proximal phalanx of the thumb. APL acts to abduct and extend the carpometacarpal joint of the thumb. EPB acts to extend the proximal phalanx of the thumb and the metacarpal bone of the thumb (Lumley *et al.*, 1996).

2.3 Biomechanics of the paddling stroke

The paddling stroke is a continuous fluid motion in which the interaction of forces transmitted by the water, the boat and the body occur (Almasi, 2004). There is a lack of scientific evidence regarding the biomechanics of the paddling stroke. Current literature is aimed at the broad paddling community, and therefore does not provide a thorough analysis of paddling biomechanics.

The stroke cycle commences with the basic start position, and consists of a further three key phases. These phases include the entry and catch phase, in which a fixed point is established to pull against; the power phase, in which power is translated into the forward movement of the boat; and the exit and recovery phase, in which the paddler moves into the next stroke (Almasi, 2004).

2.3.1 The basic start position

An effective paddling stroke requires the hands to be correctly positioned on the paddle shaft, in order to facilitate optimal leverage and rotation from the trunk, while maximising stability and power. The hands should be equidistant from the head when the paddle is held with both shoulders abducted to 90° and both elbows flexed to 90°. Correct hand positioning is essential (Macleod, 2003).

The main function of the dominant hand is to hold the paddle through all phases of the paddling stroke. The dominant hand relaxes its grip when the non-dominant hand is in the water, and increases its grip when it is pulling through the water. The rhythm of the stroke determines the timing of the grip and release of the paddle shaft (Macleod, 2003).

The following description of the paddling stroke is based on the right hand acting as the pulling hand, therefore providing the power phase in the water. The paddling stroke commences with trunk rotation of approximately 70° to the left, right scapular protraction, approximately 90° of glenohumeral flexion, 0° of elbow extension, and approximately 30° of wrist extension. The left arm simultaneously performs scapular retraction, glenohumeral horizontal extension and external rotation, elbow flexion, with the wrist maintained in a neutral position. In addition, there is approximately 90° of hip flexion, and approximately 30° of knee flexion (Mann & Kearney, 1980). These movements orientate the face of the paddle blade perpendicular to the boat, therefore providing an optimal position for the blade to enter the water (Almasi, 2004).

2.3.2 Entry and catch

“The catch” describes the paddle blade entering the water. From the basic start position, the right shoulder and the left elbow extend in order to place the paddle in the water (Figure 2.1) (Almasi, 2004). Anecdotally, in this phase the correct paddling stroke should not involve any further movement of the trunk.

The catch assists in generating the forward propulsion of the boat (Almasi, 2004), as large forces are transmitted from the trunk through the upper limb and into the paddle. Therefore, a firm grip on the paddle shaft is essential during this phase of the paddling stroke (Kameyama *et al.*, 1999).



Figure 2.1 *Entry and catch*

2.3.3 The power phase

The boat is then propelled forwards during the power phase of the paddling stroke (Figure 2.2). With the right paddle blade in the water, force is generated by trunk rotation from the starting position of approximately 70° rotation to the left, to a position of approximately 70° rotation to the right. As the trunk rotates, there is approximately 10° of left knee extension, which provides a compressive force through the footrest of the boat, thus further facilitating force generation during this phase. There is associated right scapular retraction, glenohumeral joint extension and internal rotation, elbow flexion, and wrist extension. There is simultaneous left scapular protraction, approximately 90° of glenohumeral joint flexion with internal rotation to neutral, elbow extension, and approximately 30° of wrist flexion (Mann & Kearney, 1980; Almasi, 2004; Hagemann *et al.*, 2004).

Effectively, the combined movement of the right upper limb and trunk rotation provides a "pulling" force, while the combined movement of the left upper limb and trunk rotation provides a counterbalancing "pushing" force (Mann & Kearney, 1980). This coordinated movement of the upper limbs, trunk and lower limbs generates the forward propulsive force that occurs during the power phase. The power phase is complete when the right paddle is aligned with the right hip (Almasi, 2004).

Furthermore, during the power phase there should be no hyperextension of the left wrist, the left hand grip should remain relaxed, and the right hand grip should gradually decrease. Any deviations from the above description may predispose the paddler to forearm overuse injuries (du Toit *et al.*, 1999).



Figure 2.2 *The power phase*

2.3.4 Exit and recovery

The power phase is followed by the exit and recovery phase (Figure 2.3). As the blade reaches the level of the right hip, there is rapid right wrist extension and ulnar deviation, the elbow remains in flexion, and the glenohumeral joint externally rotates (Hagemann *et al.*, 2004). The left arm simultaneously moves into the starting position. This combined movement of the upper limbs allows the paddle blade to be vertically withdrawn from the water. This completes a paddling stroke, and places the left arm in the starting position for the contralateral stroke (Almasi, 2004).



Figure 2.3 *Exit and recovery*

2.3.5 Forearm muscle activity during the paddling stroke

It is theorised that the forearm extensor and pronator muscle groups may be at a mechanical advantage at approximately 90° of elbow flexion. This is therefore advantageous for force generation during the power phase of the paddling stroke (Hamil & Knutzen, 1995; Hagemann *et al.*, 2004). Balanced concentric and eccentric action of the wrist extensors is also required bilaterally during the power phase of the paddling stroke, in order to avoid an increased risk of overuse injuries (Hamil & Knutzen, 1995; du Toit *et al.*, 1999).

It is acknowledged that there is a lack of scientific evidence regarding the muscle activity of the trunk, lower limbs, and shoulder girdle during the paddling stroke. The current theories regarding the interaction of proximal and distal segments and musculature will be discussed briefly in relation to the potential role of muscle activity during the paddling stroke.

2.3.6 The kinetic chain of the upper limb in the paddling stroke

Movement of the upper limb may be described as occurring as part of a kinetic chain. A kinetic chain may be defined as several joints arranged in sequence that act together to produce a complex motor action (Norris, 1999).

It is theorised that the kinetic chain functions to optimise proximal segment activation in order to reduce the requirement for high force generation in the distal segments. Further, as unilateral arm movement is initiated, there is a co-ordinated pattern of muscle activation and force generation from the legs to the arm. These activation patterns, together with the subsequent joint positions lead to anticipatory postural adjustments in the leg and trunk segments. These adjustments facilitate the development of proximal stability, which optimise force generation to the distal segments (Kibler & Sciascia, 2004).

The elbow and wrist are considered as distal segments of the kinetic chain, and are often subjected to high repetitive loads. Injury may result if these loads are not well regulated (Kibler & Sciascia, 2004).

For example, Eliot *et al* (2003), cited in Kibler & Sciascia (2004), evaluated two groups of Olympic tennis players who generated the same ball speed. It was established that a reduction in knee flexion during the cocking phase of the tennis serve was associated with a 21% increase in valgus load at the elbow, with a resultant absolute value of 73.9 Nm. This load was acknowledged to be above the safe level for repetitive loading, and therefore emphasized the importance of efficient proximal activation.

Further, it is proposed that effective kinetic chain interaction may align the bones of the elbow and wrist in order to minimize the load experienced by the supporting ligaments. For example, in the tennis serve, elbow elevation and extension occur before coupled shoulder internal rotation and elbow pronation. It is hypothesised that, if this correct sequence of movement does not occur there may be increased valgus tensile loads at the elbow during the acceleration phase of the tennis serve (Kibler & Sciascia, 2004).

Although the potential role of the kinetic chain has been relatively well described in relation to the tennis stroke, there is a lack of evidence regarding kinetic chain function in paddling. The potential role of the kinetic chain may be of particular importance during the power phase of the paddling stroke, where force generation is facilitated through trunk rotation and knee extension (Mann & Kearney, 1995; Hagemann *et al.*, 2004). It may therefore be speculated that any deviation or inefficiency in activation patterns and energy transfer may lead to a reduction in force generation, with a subsequent increased load at the distal segments of the chain, particularly during the power phase of the paddling stroke.

In addition, Chaitow (2006) proposed that the fascial system may have a role in musculoskeletal dysfunction. Myers (2001) proposed that muscles operate across functionally integrated continuities described as myofascial meridians. This theory may facilitate the understanding of the role of the kinetic chain in musculoskeletal function, and the development of injuries. Myofascial meridians may also have some clinical relevance, in providing an anatomical explanation for the connection between painful symptoms in one area of the body and dysfunction in another, often asymptomatic, area of the body.

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2.3.7 Upper limb myofascial meridians in the paddling stroke.

It is acknowledged that there is a lack of scientific evidence to support the role of myofascial meridians in musculoskeletal dysfunction. Current evidence is limited to case reports and publications with low scientific merit. However, despite the lack of rigorous scientific study, it may be proposed that the theory of myofascial meridians may provide some insight into the complex movement patterns that occur during the paddling stroke.

The myofascial meridians that may be utilized during the paddling stroke include the deep back arm line (DBAL), the deep front arm line (DFAL), the superficial back arm line (SBAL), the back functional line (BFL) and the front functional line (FFL) (Myers, 2001).

2.3.7.1 The arm lines

The connections between the forearm musculature and the axial skeleton are of importance when considering upper limb function during the paddling stroke. Four distinct myofascial meridians run from the axial skeleton and terminate at the thumb, the little finger, the palm and the back of the hand respectively. The arms have a deep and superficial myofascial line along the front of the arm and a deep and superficial myofascial line on the back of the arm. The lines are named for their position as they cross the shoulder (Myers, 2001). The DBAL, DFAL, and the SBAL are of interest for the role they play in the paddling stroke.

(i) The DBAL

The DBAL starts at the spinous processes of C7 and T1. From here passes down and out along with the rhomboid muscles to the vertebral border of the scapula. The DBAL continues along the posterior border of the scapula, and includes infraspinatus and teres minor. The line then tracks down to the posterior aspect of the humerus on the greater tubercle (Myers, 2001).

The second branch of the DBAL starts on the lower surface of the occiput along with rectus capitis lateralis muscle. It continues down from the transverse processes of C1-4 along with levator scapulae. This line terminates on the superior angle of the scapula with its fascial fibres linking to supraspinatus in the supraspinous fossa. The DBAL therefore includes three of the muscles of the rotator cuff. The fourth muscle, subscapularis, is still considered part of this line even though it has no fascial connection to it. It is thought that subscapularis is connected to the line mechanically through the bone of the scapula (Myers, 2001).

The final track of the DBAL continues distally from the shaft of the humerus via the three heads of the triceps muscle. The line extends down to the olecranon of the ulna and then down the whole medial aspect of the arm via the periosteum of the ulna. Once it reaches the ulnar styloid process, the line continues onto the capsule of the wrist and the periosteum and ligaments on the medial border of the hand. The hypothenar muscles also form part of the DBAL (Myers, 2001).

(ii) The DFAL

The DFAL begins with the pectoralis minor muscle and the clavipectoral fascia on the anterior aspect of the 3rd to 5th ribs. It continues to the coracoid process where it passes along the short head of biceps brachii and the coracobrachialis muscle when the arm is in the extended position (as in the upper arm of the paddling stroke). It continues on to attach to the proximal radius and along the periosteum to the distal radial styloid process. The tendons of APL and EPB accompany this line in the forearm. The DFAL terminates over the thumb side of the carpals and onto the thumb itself (Myers, 2001).

(iii) The SBAL

The SBAL begins with the axial attachment of the trapezius muscle from the occipital ridge to the spinous process of T12. It then converges on the spine of the scapula, the acromion and the lateral aspect of the clavicle. The occipital, cervical and thoracic fibres of the trapezius muscle then link to the anterior, middle and posterior fibres of the deltoid muscle respectively. These trapezio-deltoid fibres converge onto the deltoid tubercle and pass via a fascial connection, under the brachialis muscle to blend with the lateral intermuscular septum.

The intermuscular septum continues distally to its attachment on the lateral humeral epicondyle and then directly onto the common extensor origin. From here it joins the common extensor tendon and picks up the longitudinal muscles of the forearm that lie dorsal to the radio-ulnar interosseous membrane. These muscles include ECRL and ECRB. The SBAL terminates on the dorsal surface of the fingers (Myers, 2001).

2.3.7.2 The Functional Lines

The functional lines are extensions of the arm lines that traverse the surface of the trunk and run to the contralateral pelvis and leg. These functional lines come into play when doing athletic activity where one appendicular complex is stabilized or powered by its contralateral complement. The BFL and the FFL are the functional lines that are involved in the action of paddling (Myers, 2001)

(i) The BFL

The BFL starts with the distal attachment of the latissimus dorsi muscle and runs downwards to join to the sacrolumbar fascia. The BFL crosses the midline at the sacrolumbar junction. The line passes through the sacral and sacrotuberal fascia to the contralateral gluteus maximus muscle. From here the line runs under the posterior edge of the iliotibial band to attach to the posterolateral edge of the femur. Fibres from the BFL pass to the vastus lateralis muscle and in turn onto the quadriceps tendon and the tibial tuberosity. The BFL continues via the tibialis anterior muscle and the anterior crural compartment and fascia to the medial arch of the foot (Myers, 2001).

(ii) The FFL

The FFL starts with the distal attachment of the pectoralis muscle on the humerus and continues to the origin of the muscle on ribs five and six. These fibres are continuous with the abdominal aponeurosis. This aponeurosis links the external oblique and rectus abdominus muscles and passes to the pubis. The FFL passes through the pubic bone and the pubic symphysis via a mechanical link to the tendon of the contralateral adductor longus. From here it attaches to the linea aspera on the posterior femur. The FFL then passes via a mechanical link to the short head of the biceps muscle, the peroneal muscles and the lateral crural compartment of the lower leg (Myers, 2001).

In summary, with the right hand acting as the pulling hand, therefore providing the power phase in the water, it may be theorised that during the paddling stroke, the pulling arm connects from the DBAL, pulling from the 5th finger side through to the BFL, and stabilising via the contralateral leg. The pushing arm (left arm) pushes via the DFAL to the thumb, stabilising through the FFL to the contralateral thigh (Myers, 2001).

2.3.7.3 The importance of the myofascial meridians in paddling

A possible example of the role of the myofascial meridians in paddling may be related to the position of the scapula, and the interaction between the lower trapezius and pectoralis minor. Any imbalance between these muscles may be associated with a relative increase in scapular protraction, leading to a potential increase in tension along the SBAL. This may ultimately result in increased tension at the distal components of the line, such as the forearm extensors, and may be linked to the development of overuse injuries (Meyers, 2001).

Furthermore, Chaitow (2006) proposed that the role of myofascial meridians may be described in terms of fascial compensation and decompensation. Fascial compensation refers to beneficial functional adaptations, whereas fascial decompensation describes dysfunctional adaptations of the musculoskeletal system. It may be theorised that training, equipment or technique errors, postural imbalances or previous injuries may be associated with fascial decompensation, and may therefore predispose to injury.

2.4 Overuse injuries

Overuse may be broadly defined as the level of repetitive microtrauma that is sufficient to overwhelm the tissues' ability to adapt. Microtrauma may be produced by a once-off excessive stress, but it usually results from repetitive loading episodes at a force that is well within the physiological range of the musculotendinous unit (Fulcher *et al.*, 1998).

The incidence of overuse syndromes has increased with the general rise in sporting participation. Between 25-50% of all injuries can be directly attributed to overuse, with the upper extremity being commonly involved and the wrist being the most affected site of injury (Fulcher *et al.*, 1998). Overuse injuries of the upper extremity are most frequently identified in sports that require the hand and wrist to take the body weight (for example, gymnastics), act as a tool (for example, volleyball), or transmit force to a tool as seen in paddling and rowing (Rettig, 2001). Fiore & Houston (2001) found that 25% of all injuries sustained in whitewater kayaking were overuse injuries.

In order to fully explore overuse injuries in paddling, normal tendon anatomy and the inflammatory response to acute tendon injury will be discussed. This will be followed by a discussion of delayed onset muscle soreness (DOMS), which may be a differential diagnosis of acute pain experienced during a sporting event. This section will conclude with the tendons reaction to chronic overuse, overuse tendinosis and the tendinopathies of interest in this study, namely lateral elbow tendinosis and DeQuervains tenosynovitis.

2.4.1 Normal tendon anatomy

Tendons are anatomical structures that connect muscle to bone. This allows the force generated within the muscle to be transmitted to the bone, thereby resulting in joint movement (Khan *et al.*, 1999). Normal tendon is made up of sparsely distributed tenocytes within a highly organized extracellular matrix (Cook *et al.*, 2002). The matrix consists of collagen bundles that afford the tendon its tensile strength (Khan *et al.*, 1999); and the ground substance that lies between the collagen bundles, which consists mainly of glycosaminoglycan chains and small proteoglycans (Cook *et al.*, 2002).

Collagen is hierarchically arranged from the smallest unit, tropocollagen, to the collagen fibril, primary, secondary and tertiary fibre bundles, and finally the tendon itself (Khan *et al.*, 1999). Three connective tissue layers reinforce this hierarchical organization. The endotendon lies parallel to the collagen bundles, separating them into tendon fascicles, while the epitendon that lies over the tendon, and the paratendon, which is the outermost layer of connective tissue, join to form the peritendon (Cook *et al.*, 2002).

2.4.2 The inflammatory response to acute tendon injury

From the time of injury, the tensile strength of the injured tendon passes through three phases. Each of these phases is discussed below with relevant clinical implications.

2.4.2.1 The inflammatory phase

When the musculotendinous unit is injured, the inflammatory response is initiated and is characterised by the clinical symptoms of heat, swelling and pain. This inflammatory response is essential for healing and usually lasts about four to six days. When acute injury occurs, there is a sudden decrease in the ability of the tendon to withstand tensile stress. This decrease is proportional to the amount of tissue damage.

During this phase, the tensile strength of the lesion is dependent upon fibrin. Fibrin forms a “scaffolding” which holds the wound edges together, but its bonds are very fragile and therefore tension applied to the injury site can easily disrupt these bonds. Disruption of these bonds leads to prolongation of this phase and an increase in the amount of scar tissue post-injury (Hunter, 1994).

The main clinical aims during this phase are therefore to protect the tissue and limit the amount of post-injury oedema. The athlete is therefore removed from the injury causing movement, and the standard formula of rest, ice, compression and elevation (RICE) is used (Kieffhaber & Stern, 1992). Treatment such as ultrasound has been shown to be beneficial in accelerating the inflammatory phase (Hunter, 1994). The range of motion of the affected part is limited to the pain-free range. This is done to protect the disorganised, immature tissues. The restriction of range may be achieved by using suitable bracing, casting or taping. The least restriction of movement that relieves the symptoms should be used (Kieffhaber & Stern, 1992).

2.4.2.2 The regeneration phase

The regeneration phase is the period of the greatest increase in tensile strength of the injury site and lasts from about the fifth day to ten to twelve weeks post-injury. During this phase, fibroblasts lay down collagen in a random orientation that restores structure but hinders function. The maximum rate of collagen deposition occurs between about two and three weeks post-injury. After approximately four weeks tensile strength continues to increase slowly. This increase in tensile strength is a result of cross-linkage formation between existing collagen fibres (Hunter, 1994).

It is during this phase that rest becomes counterproductive as restriction of movement does lead to atrophy, and well-placed and controlled forces increase the strength of healing tissues (Fulcher *et al.*, 1992). The main clinical aim during this phase is therefore to carefully apply tension across the injury site in the appropriate amount, duration and direction to facilitate correct orientation of the collagen fibres (Hunter, 1994).

2.4.2.3 The remodelling phase

The remodelling phase usually begins at about day twenty-one and occurs at the stage when collagen synthesis is matched by collagen lysis. Strength of the tissue increases during this phase via cross-linkage formation between the collagen fibres. These cross-linkages increase the tensile strength of the tissue, but may result in the formation of adhesions. This may restrict the range of motion of the injured tendon and therefore predispose it to re-injury (Hunter, 1994).

The main clinical aim during this phase is to prevent scar tissue contraction by subjecting the healing tissue to appropriate tension on a regular basis to promote extensibility, as tissue contraction may occur for six to twelve months post-injury (Hunter, 1994).

2.4.3 Tendonitis

Tendonitis is a condition in which the substance of the tendon exhibits the cellular reactions consistent with the inflammatory response described above. Knowledgeable tendon physicians understand that the clinical term, tendonitis, refers to a clinical syndrome and not a specific histopathological entity. There is currently no convincing evidence of a distinct histopathology that demonstrates a true tendonitis in humans (Khan *et al.*, 2005).

However, in studies on rabbit Achilles tendons that were divided and then repaired, inflammatory cells were present from days 5 to 18. Clearly, this study does not replicate an overuse tendinopathy, but until studies like the above are done on humans, the possibility of a brief period of true tendonitis cannot be excluded. In clinical practice, by the time that the patient seeks medical attention for pain related to a tendon, most tendinopathies are chronic, i.e. a tendinosis (Khan *et al.*, 2005).

Therefore, an overuse tendonitis is rare, but it is acknowledged that it may occasionally occur in the Achilles tendon in conjunction with a primary tendinosis. Unfortunately, it is difficult clinically to distinguish a tendinosis from the rare tendonitis, but due to the fact that a tendinosis is far more likely, patients presenting with symptoms related to a tendinopathy, should be treated as a tendinosis (Khan *et al.* 2000).

Due to the growing body of literature on the rarity of the true tendonitis and the common prevalence of tendinosis in tendinopathy, it is proposed that paddlers, who present with pain in the tendons of the elbow and wrist during the 2006 Berg River Marathon, are suffering from a tendinosis and not a tendonitis.

It must be acknowledged however, that without a tendon biopsy of the affected tendons of the elbow or wrist of the paddler with symptoms from the 2006 Berg River Marathon, acute pain due to delayed onset muscle soreness (DOMS) cannot be excluded. It is to a discussion of this differential diagnosis that we now turn.

2.4.4 Delayed onset muscle soreness (DOMS)

Eccentric exercise is exercise in which the contracting muscle is forcibly lengthened. An example of this is walking down a steep slope where the quadriceps acts to control knee flexion by contracting against the force of gravity. In the process, the contracting quadriceps muscle is lengthened (Whitehead *et al.*, 2001).

When a bout of unaccustomed eccentric exercise is performed, the body fatigues as it does with other forms of exercise. However eccentric exercise may result in delayed muscle stiffness and soreness (Proske & Morgan, 2001). This is described as delayed onset muscle soreness (DOMS), and is characterized by a dull, aching pain. DOMS peaks between 24 to 48 hours after exercise, and may remain elevated for up to 10 days after exercise (Eston *et al.*, 1995; Schutte & Lambert, 2001; Cleary *et al.*, 2002).

The time course and intensity of DOMS varies according to the nature of the eccentric exercise bout. It may therefore be proposed that the short, intense, exhaustive eccentric exercise used in the laboratory setting to study DOMS produces physiological changes in muscle that are distinct from those produced in sporting activity involving a variety of muscle contractions taking place with lower intensity over a longer period of time (Vickers, 2001).

Furthermore, Vickers (2001) reanalyzed the data from three previous clinical trials on DOMS, in an attempted to determine whether the time course of soreness following a natural exercise, long-distance running, was different from that following a standard laboratory based exercise, bench-stepping. The trials included 400 long-distance runners and 82 untrained volunteers who performed a bench-stepping test. It was found that the time course of soreness developed by subjects in the bench-stepping group was typical of that cited in the literature, with soreness peaking between 24-48 hours after exercise. The soreness in runners following long-distance running generally peaked 8 hours after exercise. The difference between the groups was highly significant.

The results of the above study suggest that research on exercise undertaken in a laboratory setting does not necessarily generalize to exercise undertaken by trained athletes engaging in their chosen sports (Vickers, 2001). There is a paucity of research on DOMS in actual sporting events that take place over several days with exercise bouts on successive days, such as the Berg River Canoe Marathon.

2.4.4.1 Pathophysiology of DOMS

Normal sporting activity occurs in a sequence of active eccentric action followed by active concentric action, known as the stretch-shortening cycle (SSC). Eccentric actions actively contribute to the SSC and muscle damage is therefore a common occurrence during prolonged or intense exercise involving the SSC, such as long distance running. Downhill running for example, increases the contribution of eccentric actions to performance and is therefore an activity more susceptible to DOMS than level or uphill running (Byrne *et al.*, 2004).

Eccentric muscle action is characterized by high tension on the muscle fibres and connective tissue, as the muscle fibres are forcibly lengthened. This loading strains the muscle and results in mechanical disruption of the actomyosin bonds rather than ATP-dependent detachment (Schutte & Lambert, 2001). The sequence of events after a bout of exercise that causes DOMS is consistent with an inflammatory response, including the release of prostaglandins by macrophages, which sensitizes local pain receptors to such an extent that a hyperalgesic state occurs (Byrne *et al.*, 2004).

Pain due to DOMS may be evoked by muscle contraction, stretch and palpation, all of which do not evoke pain in an undamaged muscle (Proske, 2005). The severity and distribution of pain associated with DOMS is related to the type, intensity, and duration of exercise that is performed (Cleary *et al.*, 2002).

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The initial damage is followed by secondary changes such as swelling. Further, there is strong evidence to suggest that overstretching of the sarcomeres is associated with excessive sustained calcium influx into the muscle fibres. This activates a protease system, which digests the structural proteins resulting in muscle damage (Dierking *et al.*, 2000). At a cellular level, structural abnormalities of the damaged muscle include sarcolemmal disruption, myofibrillar distortion, Z-line streaming, cytoskeletal damage and swollen mitochondria. These morphological changes in the contractile machinery of the damaged muscle may lead to the decrements in muscle strength, muscle tenderness and the decrease in range of motion commonly seen in DOMS (Schutte & Lambert, 2001).

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2.4.4.2 Diagnosis of DOMS

Muscle soreness is the most commonly used indicator of DOMS in studies on humans, but shows a poor temporal relationship with histological evidence of muscle damage. Therefore, DOMS should not be used as the only indicator of the extent of muscle damage or functional impairment. Indeed, studies have shown that muscle function is impaired before the onset of DOMS, and that the morphological changes associated with exercise-induced muscle damage continue in the absence of DOMS (Byrne *et al.*, 2004).

Further, although swelling is evident after a bout of eccentric exercise, MRI changes that indicate edema do not occur concurrently with the muscle soreness (Clarkson & Hubal, 2002). Muscle soreness develops several hours post-exercise and peaks at 24-48 hours, while swelling starts gradually at approximately 48 hours and peaks up to 10 days post-exercise (Schutte & Lambert, 2001; Clarkson & Hubal, 2002).

Numerous methods have been used to assess the symptoms of DOMS. These include goniometry to assess muscle shortening, limb circumference measurements to assess edema, plasma creatine kinase activity as an indicator of increased permeability of the damaged muscle cell membranes, and pain ratings (Dierking *et al.*, 2000).

2.4.4.3 The repeated bout effect

The effects of DOMS may be reduced when a DOMS-producing exercise bout is preceded by a similar exercise bout. This adaptive response is termed the "repeated bout effect", and results in significantly lower levels of serum creatine kinase and enhanced recovery of muscle strength and joint range of motion after the second bout of exercise (Schutte & Lambert, 2001).

The time frame of this adaptation remains unclear (Cleary *et al.*, 2002). Pierrynowski *et al* (1987), cited in Eston *et al* (1995), found that as little as two 12 minute bouts of downhill running at a 10% gradient, were enough to protect against the occurrence of DOMS in a downhill run 3 days later, which had produced DOMS in the asymptomatic group.

Further, Cleary *et al* (2002) used a dynamometer to actively resist wrist flexion, producing eccentric tension; to produce DOMS in 31 untrained subjects in a laboratory setting. Dependent variables were perceived pain as measured by a visual analog scale and muscular tenderness as measured by a punctuate tenderness gauge. The study showed that perceived pain and muscular tenderness associated with the eccentric exercise bout may be reduced by performing a similar exercise bout 6, 7, 8, or 9 weeks before beginning an exercise programme.

It was therefore concluded that pre-season conditioning may begin up to 2 months prior to intense physical activity, and result in decreased symptoms of DOMS during the first weeks of a competitive sports season (Cleary *et al.*, 2002).

The mechanism responsible for the repeated bout effect has not been established. It has been proposed that the initial bout of exercise may destroy degenerative fibres or fibres that are susceptible to stress, leaving healthy, strong fibres behind that are able to tolerate the effects of repeated bouts of exercise. Conversely, Newham *et al* (1987), as cited in Schutte & Lambert (2001), propose that damage caused by the initial bout of exercise acts as a stimulus for new collagen synthesis, which subsequently strengthens and protects the muscle from further damage.

Lastly, It has also been proposed that adaptation to the initial bout of exercise may occur partly due to an alteration in motor-unit recruitment patterns. These neural adaptations protect the muscle from further damage by limiting the level of excessive force generation or by more efficient distribution of the workload among the muscle fibres (Schutte & Lambert, 2001).

The majority of the participants in the 2006 Berg River Canoe Marathon are well-trained competitive paddlers. It may be proposed that these paddlers may have a reduced risk of developing DOMS, as a consequence of the repeated bout effect associated with regular exercise training.

Further, there are currently no studies that investigate the role of exercise-induced muscle damage in the development of a chronic overuse-type injury. It is therefore difficult to ascertain the role of DOMS in the aetiology and pathophysiology of elbow and wrist overuse injuries during K1 marathon paddling.

2.4.5 The tendon response to repetitive overloading and overuse

According to Wolffes law, most musculotendinous units will attempt to adapt to applied loads. The load-bearing ability of bone will increase, and muscle fibres will hypertrophy in response to applied loads. In addition, the collagen and ground substance content and the number of collagen cross-linkages of tendons and ligaments will increase in order to improve tensile strength. However, a rapid or excessive increase in applied load may not allow the process of adaptation to occur, leading to subsequent failure of the musculotendinous unit (Kiefhaber & Stern, 1992).

Tendons classically react poorly to repetitive loading and overuse. The healing of tendons is slow, incomplete and may lack in suitable extracellular organization (Cook *et al.*, 2002). Overuse injuries generally result when repetitive microtrauma is of a sufficient level to overwhelm the musculotendinous units' ability to adapt.

Tendon failure occurs at the molecular level due to the stretching of its collagen. Collagen elongation of up to 4% is well tolerated, while elongation of 4-8% results in rupture of the cross-links and allows the fibres to slide past one another. Complete macroscopic failure occurs when tendon elongation is greater than 8% (Fulcher *et al.*, 1998). The overload injury may occur in the tendon, at the tendon attachment to the bone, in the muscle, or at the musculotendinous junction (Rettig, 2001).

Meeuwisse (1994), as cited in Kibler (1995), describes a multifactorial model of the factors involved in repetitive microtrauma overload in sport. In this model, an athlete may be predisposed to injury, by intrinsic risk factors such as age, flexibility, previous injuries, and strength. The subsequent interaction with extrinsic risk factors associated with exercise participation, such as equipment and environmental conditions, may increase the risk of injury. A sporting event that may involve different athletic exposure or more intense athletic exposure, may lead to overt clinical injury, symptom production, and a decrement in athletic performance.

2.4.6 Overuse tendinopathy

The response to an acute tendon injury (tendonitis) is the typical triphasic response of inflammation, proliferation and maturation, in which the tendon slowly returns to pre-injury organization and strength. However, overuse tendinopathy does not follow the typical response to injury (Cook *et al.*, 2002).

The reasons for this altered healing response are still unclear. Instead, following overuse, a pathological tendon remains with distinct characteristics of tendinosis. These include large increases in the amount of ground substance and disruption of the hierarchical organization of collagen (Cook *et al.*, 2002). There is also production of immature and disorganised collagen, which is structurally weaker, leading to a reduction in the tensile strength of the tendon (Kraushaar & Nirschl, 1999).

An increased vascularity of the tendon is observed, yet this does not lead to the expected advance in the repair process. What is most significant however, is the almost complete lack of either acute or chronic inflammatory cells (Cook *et al.*, 2002).

Collectively, the above histopathological observations have led to the conclusion that chronic overuse conditions result in a tendinosis, not a tendonitis; which is a degenerative condition of unknown aetiology (Khan *et al.*, 1999).

The net result of the above deleterious effects due to chronic overuse is a tenocyte that is unable to produce matrix of normal quality and quantity. On a tissue level, these deficits may be expressed clinically as muscle weakness or inflexibility, due to the tendons inability to withstand applied loads. These deficits do not necessarily produce clinical symptoms, but they have been implicated as risk factors in producing injuries of the upper limb (Kibler, 1995).

2.5 Predisposing factors to paddling-specific overuse injuries of the elbow and wrist

Predisposing factors to upper limb injuries in K1 marathon paddlers may include both intrinsic risk factors, such as previous injury, post-injury flexibility, local muscle imbalance, and extrinsic risk factors, such as paddling technique, training history, paddle shaft grip modifications, diameter and length, race distance and conditions (Kibler, 1995; Brukner & Khan, 2001).

The intrinsic and extrinsic factors that may contribute to the development of the overuse injuries of interest in this study, lateral elbow tendinosis and DeQuervains tenosynovitis, during paddling will now be discussed in further detail.

2.5.1 Intrinsic factors

2.5.1.1 Previous injury history

Previous injury history is an important intrinsic risk factor that may be associated with the development of upper-limb overuse injuries in paddlers (Kibler, 1995; Brukner & Khan, 2001).

For example, anecdotal evidence suggests that a paddler with an incompletely rehabilitated rotator cuff injury may be unable to achieve 90° of glenohumeral flexion and fully extend the elbow of the right arm at the start of the “catch phase” of the paddle stroke due to the inability of the scapula to fully retract and correctly position and hold the arm. This inability to fully extend the elbow joint would place the ECRL and ECRB at a mechanical disadvantage, as ECRL and ECRB require full elbow extension to place these muscles in an optimal position for maximal power transfer from the trunk to the paddle via the wrist. If ECRL and ECRB were forced to contract repetitively in this position of mechanical disadvantage, the wrist extensors could be predisposed to the development of an overuse injury.

Proprioception, the sensation of joint movement and joint position, is often disrupted during an injury. If the re-education of proprioception is neglected during the rehabilitation of an injury there may be an increased risk of re-injury (Lephart *et al.*, 1997).

2.5.1.2 Post-injury flexibility

A further intrinsic factor to consider post-injury is flexibility around the injured joint. Although Shrier *et al* (2000), as cited in Schweltnus (2006), concluded that there is insufficient evidence linking increased flexibility to injury reduction, it is still good practice to restore pre-injury flexibility. Due to the ongoing nature of the overuse-type injury, it would seem that a long-term stretching programme might be of use to maintain optimal range of movement around the injured joint (Hunter, 1994).

It may be proposed that a flexibility restriction in the latissimus dorsi muscle for example, will not allow the full extension of the leading arm during the “push phase” of the paddle stroke. Therefore the elbow is unable to fully extend, thereby setting the stage for an overuse injury of the wrist extensors, which require elbow extension to maximize wrist extension. This is essential in the paddling stroke where muscles readily fatigue if they are not operating from a position of mechanical advantage. This theory is speculative and requires further investigation.

2.5.1.3 Local muscle imbalance

Muscle imbalance is defined as the failure of the agonist-antagonist functional relationship or as the predominance of one of a synergistic pair of muscles during a particular movement. Muscle imbalance changes joint loading and alignment. The muscles around an injured joint respond by becoming overactive or underactive, both of which may result in tissue pathology (Alizadehkhayat *et al.*, 2007, Eygendaal *et al.*, 2007).

Alizadehkhayat *et al* (2007) studied the strength, fatigability, and activity of the upper limb musculature to demonstrate the role of muscular imbalance in the pathophysiology of lateral elbow tendinosis. Muscle strength was measured for the metacarpophalangeal joints (MCP), wrist joints (flexion and extension), shoulder joints (abduction, internal and external rotation) and grip bilaterally. Electromyographic (EMG) activity was measured in muscles that contribute to the extensor and flexor torque at the wrist. These include ECR, extensor digitorum communis (EDC), flexor carpi ulnaris (FCU), and flexor digitorum superficialis (FDS).

Results showed that grip strength was 25% weaker in the lateral elbow tendinosis group than in the asymptomatic group. For wrist strength, wrist flexion was 25% stronger than wrist extension bilaterally for both the control and lateral elbow tendinosis groups. However, wrist extension and flexion were 30% weaker in the lateral elbow tendinosis group than in the asymptomatic group. For MCP strength, MCP flexion was 36% weaker in the lateral elbow tendinosis group than in the asymptomatic group. These results may indicate that lateral elbow tendinosis subjects increase the strength of the finger extensors to compensate for the weakness of the wrist extensors (Alizadehkhayat *et al.*, 2007).

For shoulder strength, all shoulder movements studied were 25-35% weaker in the lateral elbow tendinosis group than in the asymptomatic group. Strength or motion deficits at particular segments in the upper limb kinetic chain may be masked in the short term by compensation at other segments. However, with repetition, these compensations are exposed by a decrease in performance at the shoulder or elbow. With time, these compensations may lead to a global muscular imbalance along the upper limb kinetic chain that may in turn predispose to the development of an overuse tendinosis (Alizadehkhayat *et al.*, 2007).

The EMG results showed markedly reduced activity in ECR in the lateral elbow tendinosis group compared to the asymptomatic group. It is suggested that a smaller contribution by ECR may decrease the load on the muscle and consequently decrease fatigue. Further, increased activity or tension of the wrist flexors may have led to the inhibition of the antagonistic wrist extensors. If this imbalance in the relationship between the agonist and the antagonist is not corrected, then joint motion and eventually entire movement patterns may be altered, potentially resulting in muscle imbalances throughout the upper limb kinetic chain (Alizadehkhayat *et al.*, 2007).

The wide spread upper limb weakness found by Alizadehkhayat *et al* (2007), suggests a need to address the whole upper limb in the rehabilitation of lateral elbow tendinosis. Further, restoration of normal ECR activity is paramount in the rehabilitation of lateral elbow tendinosis.

It is proposed that a paddler, who had experienced a bout of lateral elbow tendinosis prior to the 2006 Berg River Canoe Marathon, may not have restored the muscle balance in the upper limb kinetic chain post-injury. This may have predisposed the paddler to the development of an overuse tendinosis. The same theory of muscle imbalance post-injury would apply to a paddler who had DeQuervains tenosynovitis pre-marathon.

2.5.2 Extrinsic factors

2.5.2.1 Paddling technique

Factors such as fatigue and rough water conditions may result in a non-optimal paddling stroke that may predispose the paddler to injury. The classic adjustment in paddle stroke that may be linked to the development of an overuse injury of the forearm musculature during paddling is gripping the paddle too hard (Macleod, 2003). An overly tight grip will influence the paddling technique, as this does not allow the blade to swivel normally in the non-dominant hand forcing the dominant hand into hyperextension (du Toit *et al.*, 1999). The forearm musculature will then be forced to operate in a position of mechanical disadvantage predisposing the musculature to injury (Hamill & Knutzen, 1995).

Functional range of movement in the elbow and wrist joints is also important during the paddling stroke. Wrist flexion range of movement is reduced if the fingers are also flexed, as in the paddle grip, due to the resistance offered by the finger extensors (Hamill & Knutzen, 1995). Similarly, wrist extension will be reduced if the fingers are extended at the same time. During the power phase, the wrist should not hyperextend and the fingers should extend to reduce excessive loading of the joint (Hamill & Knutzen, 1995; du Toit *et al.*, 1999).

Deviations from the optimal proximal to distal segmental activation of the kinetic chain during the paddle stroke may predispose the paddler to injury. It may be proposed that a paddler with poor technique may be predisposed to an overuse injury of the forearm due to the increased valgus load placed on the elbow (Hagemann *et al.*, 2004).

2.5.2.2 Training history

Training history may also be an important predisposing factor to upper limb overuse injuries. Du Toit *et al.* (1999) theorise that increased weekly training distances may be associated with improvements in fitness, and the ability to maintain an optimal paddling stroke for a longer duration. An increased training distance may also improve the skill level of the paddler. The paddler may therefore avoid compensatory actions such as gripping the paddle too hard, resulting in a decreased risk of injury to the elbow and the wrist.

2.5.2.3 Grip modifications and paddle diameter

There is much variability in inter- and intra-paddler grip types. The range of grip modifications are varied, and may include no modification, adhesive tape, or "padded" tape to pad the grip position on the dominant side (Macleod, 2003).

A further paddle shaft modification is to slightly roughen the shaft of a paddle in order to improve grip. Another modification seen is the use of moulded plastic handles, which are favoured by K1 marathon paddlers. In this case, the handle is set on the dominant hand side to keep the shaft in the correct position (Macleod, 2003).

All of the above grip modifications would effectively increase the diameter of the paddle shaft. Anecdotally, it is reported that some elite K1 marathon paddlers utilise a thin paddle, in which there is a reduction in the paddle shaft diameter. These shafts are prone to damage in rough waters, where the paddle may be too thin to withstand direct hard contact with rocks or trees and may possibly break (Macleod, 2003). The use of the thin paddle appears to be limited to elite flat-water paddlers, and the researcher did not expect that too many would appear at the 2006 Berg River Canoe Marathon with its rough water and numerous tree-blocks.

It is theorised that a grip modification may become important if the modification alters the paddle shaft diameter. Nirschl (1992) proposed that a grip that is too large or too small may increase the likelihood of developing an overuse injury of the elbow or wrist. There is a lack of scientific evidence regarding the optimal grip diameter for a paddle shaft.

2.5.2.4 The paddle grip: handgrip size ratio

Nirschl (1992) describes a technique of handgrip size measurement in tennis players called the Nirschl technique. In this technique, the length of the racquet hand (mm) is measured from the distal palmar crease along the radial border of the ring finger to its tip. This measurement is taken using a solid ruler, and is indicative of "the working length" of the racquet hand.

This individualised handgrip measurement determines the "correct" diameter size for the tennis racquet handle for each tennis player. The tennis racquet handle grip: handgrip size ratio for each tennis player should therefore be 1:1 (Nirschl, 1992). In tennis players who present with forearm pain, changing the size of the grip on the tennis racquet has been shown to dramatically reduce forearm stress (Peters & Baker, 2001).

It is unclear as to whether the above ratio may be extrapolated to paddlers, and there is currently no research on whether paddlers may be predisposed to overuse of the forearm if they do not have a paddle grip: handgrip size ratio of 1:1.

2.5.2.5 The paddle length

Watson (2007) states that the arbitrary cut-off point between a long and a short paddle is 220 cm, with a long paddle being described as greater than 220 cm. Anecdotally, Almasi (2004) advised South African paddlers to base the selection of the paddle length on the traditional method of reaching up with the dominant hand while standing next to the paddle. The fingers should then comfortably flex over the top of the blade. This height represents the maximum paddle length.

Wyatt (2007) acknowledges that the current selection of paddle length is primarily based on personal preference. A very short paddle (215 cm or less), allows the paddler to use a more vertical stroke that affords speed and power with each stroke.

A longer paddle (greater than 220 cm) allows the paddle to enter the water at a more acute angle, as apposed to the vertical entry of the short paddle. However, high winds and rough waters may make a longer paddle much more cumbersome to use (Watson, 2007).

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Another disadvantage of the longer paddle is the tendency to spread the hands further apart on the shaft. This results in a deviation away from the optimal 90° angle between the elbow and the shoulder. The paddling stroke becomes more inefficient as the distance between the hands on the paddle shaft widens (Watson, 2007).

The final disadvantage of a longer paddle is that it may negatively influence the optimal rotation of the trunk during the paddling stroke, because the paddler may reach out and pull the paddle back using only the arms. This may influence the transfer of energy along the kinetic chain, and result in an increased load on the distal parts of the kinetic chain. Conversely, a shorter paddle encourages rotation of the trunk in order for the paddle to enter the water, thereby enhancing force transmission along the kinetic chain (Watson, 2007).

2.5.2.6 Race distance

Du Toit *et al* (1999) found that the incidence of forearm tenosynovitis increased in paddling marathons in which the daily distance was greater than 38km. This was particularly evident if the paddler had undergone at least one previous bout of paddling.

2.5.2.7 Race conditions

The fluid in which the sport takes place affects human motion during sport. Air and water are the fluids that affect the motion of the paddler and canoe. Density and viscosity are the two most important properties of the air and the water that need to be considered. Density of a fluid is defined as the mass per unit volume. The more dense the fluid, the more resistance it provides to the object. The density of air is affected by humidity, pressure and temperature (Hamill & Knutzen, 1995).

Viscosity is a measure of resistance of the fluid to flow. The more viscous a fluid, the more resistance it provides to the flow. Air is less viscous than water and therefore provides less resistance to flow (Hamill & Knutzen, 1995). Air becomes less viscous, and therefore provides less resistance to flow, as air temperature decreases (Hamill & Knutzen, 1995).

As the paddler and canoe pass through the air and water, it disturbs the air and water. The degree to which the air and water is disturbed is dependent on the density and viscosity of the air and water. The greater the disturbance, the greater the amount of energy that is transmitted from the paddler and canoe to the air and water. This transfer of energy is called fluid resistance, which may be divided into two components, lift and drag (Hamill & Knutzen, 1995).

Drag always acts to oppose the motion of the paddler and canoe through the air and water. The magnitude of the drag is a function of the nature of the fluid, the nature and shape of the paddler and canoe, and the velocity of the paddler and canoe through the fluid. Drag increases as a function of velocity squared. Therefore, the greater the velocity of the paddler and canoe through the air and water, the greater the drag (Hamill & Knutzen, 1995). Low water levels and hence low flow rates that are characteristic of the Berg River Canoe Marathon increase the amount of effort required by the paddler to move forward. Increased effort may predispose the paddler to an overuse tendinopathy of the upper limb.

Flow rate is defined as the measure of the volume of water passing a point within the system per unit time. The flow rate is calculated as the product of the cross-sectional area (A) for flow and the average flow velocity (v) and is measured in $\text{m}^3 \cdot \text{s}^{-1}$ (www.engineersedge.com). The lower the water level, the smaller the volume of the water and hence the slower the flow rate. The slower the flow rate, the harder the paddler has to work to get to the end of the race. This increased effort may predispose the paddler to injury.

2.5.2.8 The Isuzu Berg River Canoe Marathon

The Berg River Canoe Marathon is the longest canoe race in South Africa. The race extends over four days and covers 220 kilometres from Paarl to Velddrift in the Cape Province, South Africa. Approximately 250 canoeists attempt the race each year (www.southafrica.info).

The Berg River Canoe Marathon incorporates excessive water level fluctuations, extreme weather, forests, channels that are dangerously narrow, low level bridges, and challenging eddies. Paddlers are required to have a moderate level of paddling proficiency to qualify for the race (www.menshealth.co.za).

The literature presented in this review highlights the lack of knowledge regarding the mechanisms of the paddling stroke. There is also a paucity of evidence regarding factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in K1 marathon paddlers. Although a previous study has examined the incidence of forearm tenosynovitis in K1 marathon paddlers during a multi-day event as well as some of the possible contributing factors to injury (du Toit *et al.*, 1999), further investigation of the topic is warranted.

Furthermore, the paddle grip: handgrip size ratio may be an important contributing factor to the development of upper limb overuse injuries. However, there is a lack of scientific evidence regarding the role of this ratio as a predisposing factor to injury in paddlers. Accordingly, the aim of this study was to determine the relationship between the paddle grip: handgrip size ratio and associated factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in K1 marathon paddlers.

2.6 Chronic overuse tendinopathies affecting the elbow and wrist joints.

2.6.1 Lateral elbow tendinosis

Lateral elbow pain is a common problem experienced by sports people and manual workers alike. The incidence of lateral elbow pain in recreational athletes is 47%, with a 45% incidence in world-class athletes. In the non-sporting population, the incidence of lateral elbow pain is associated with middle age, with the largest incidence between 35-50 years of age (Rettig, 2001). There is however a paucity of literature regarding the effect of age in the incidence of lateral elbow pain in the sporting population.

The terms "tennis elbow" and "lateral epicondylitis" have both been used to describe the pathological condition characterised by an area of degeneration within the extensor carpi radialis brevis (ECRB) tendon, usually located within 1-2cm of the muscle's attachment to the lateral epicondyle of the humerus (Brukner & Khan, 2001). The ECRB tendon is the site of pathology in 100% of the cases of tennis elbow (Kraushaar & Nirschl, 1999). Lateral elbow tendinosis has become the preferred term to describe "tennis elbow", as inflammation is only present, if at all, in the initial stages of the disease (Nirschl, 1992; Whaley & Baker, 2004).

The disease process involved in lateral elbow tendinosis is really a degenerative tendinopathy that is the result of failed tendon healing (Kraushaar & Nirschl, 1999). Nirschl (1992), describes an "angiofibroblastic tendinosis", after histological examination of the affected part of the tendon in subjects diagnosed with lateral elbow tendinosis revealed grey, friable, oedematous tissue with disorganized collagen bundles, numerous fibroblasts and granulation-like tissue.

In over 600 surgeries on patients with lateral tennis elbow, acute inflammatory cells were almost always absent from the ECRB tendon. There was however a minimal amount of chronic inflammatory cells in supportive or adjacent tissues, but these were present due to the repair of partial tears within the tendon itself (Nirschl, 1992).

2.6.1.1 Aetiology and pathophysiology of lateral elbow tendinosis

Chronic microtrauma within the ECRB tendon, at stress and strain levels below those required to cause overt symptoms, have been shown to lead to lateral elbow tendinosis (Kibler, 1995). The mechanism of microtrauma may be due to a considerable shearing stress being placed on the ECRB tendon during wrist movements, especially wrist extension. The head of the radius also applies additional stress as it rotates anteriorly during pronation of the forearm and compresses the ECRB tendon (Brukner & Khan, 2001).

The microtrauma may result in an excessively stretched tendon, or may further compromise the already poor blood supply to the area. With excessive use, these stresses may lead to degenerative changes in the ECRB tendon. If the excessive use is continued, these degenerative changes may result in microscopic tears and fibrosis within the ECRB tendon. A degenerative tendinosis is the result (Brukner & Khan, 2001).

Pathologic specimens from lateral elbow tendinosis surgery reveal a characteristic picture of the process of injury. Evidence of a failed healing response due to chronic low-grade injury includes the presence of numerous blood vessels and a large amount of unorganised fibrotic tissue. This immature tissue lacks the ability to mature. The absence of inflammatory cells indicates that this process of injury is not acute, and that the repair process is significantly impaired (Kibler, 1995, Kraushaar *et al.*, 1999), resulting in angiofibroblastic tendinosis (Nirschl, 1992).

It is thought that repetitive eccentric and concentric overloading of the extensor muscle mass of the forearm may be the primary cause of the angiofibroblastic tendinosis of the lateral tendons of the elbow (Whaley & Baker, 2004). The extensor mass of the forearm is involved in the eccentric and concentric control of the repetitive wrist movements involved in long distance paddling (du Toit *et al.*, 1999). It may therefore be proposed that paddlers are predisposed to developing lateral elbow tendinosis due to increased repetitive strain at the distal end of the kinetic chain of the upper limb, particularly at the tendons of the elbow and wrist.

2.6.1.2 Clinical features of lateral elbow tendinosis

Lateral elbow tendinosis may result from a specific localised injury to the extensor origin, but it is most often described as pain of gradual insidious onset that results due to repetitive overuse of the lateral elbow structures. Symptoms of lateral elbow tendinosis include point tenderness at the insertion of the ECRB tendon onto the lateral epicondyle, which is worsened by activities that involve gripping or manipulating an object (Peters & Baker, 2001, Ashe *et al.*, 2004). Pain may radiate down the forearm, and there may be a reduction in grip strength (Vincenzino, 2003; Whaley & Baker, 2004). Palpation over the lateral epicondyle and extensor mass typically produces localised tenderness (Reid, 1992).

It is acknowledged that it is difficult to distinguish between the clinical presentation of lateral elbow tendinosis and muscle pain due to DOMS in the lateral elbow region. It is proposed that the diagnostic tests described below may be able to selectively identify the presence of lateral elbow tendinosis.

2.6.1.3 Diagnostic tests for lateral elbow tendinosis

The cardinal physical signs of lateral elbow tendinosis are pain on direct palpation over the lateral epicondyle at the area of insertion of the extensor muscle mass, and the reproduction of pain and weakness during grip strength testing. Commonly, resisted contractions of the extensor muscles of the forearm, via wrist or finger extension with the elbow in full extension and pronation of the forearm may also reproduce pain in the region of the lateral epicondyle (Vincenzino, 2003). The above resisted wrist or finger extension tests evaluate ECRB and reproduce pain in the origin of the muscle in the subject with lateral elbow tendinosis (Whaley & Baker, 2004).

A maximal passive stretch test may also be diagnostic for lateral elbow tendinosis. The passive stretch test is diagnostic of lateral elbow tendinosis if maximal passive wrist flexion with the elbow in full extension and forearm pronation reproduces pain at the origin of the ECRB (Reid, 1992; Whaley & Baker, 2004).

There is a lack of evidence regarding the validity or reliability of the aforementioned tests in the diagnosis of lateral elbow tendinosis. Current practice involves the use of two or more tests to strengthen the diagnosis (Reid, 1992; Peters & Baker, 2001; Vincenzino, 2003; Whaley & Baker, 2004).

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Smidt *et al* (2003) evaluated the reliability of tests commonly used to diagnose lateral elbow tendinosis. The interobserver reproducibility of the assessment of severity of complaints, grip strength, and pressure pain threshold was evaluated in patients with lateral elbow tendinosis. It was determined that the assessment of severity of complaints and grip strength are both reliable methods in the assessment of lateral elbow tendinosis. However, pressure pain threshold testing has unsatisfactory reliability in the assessment of lateral elbow tendinosis.

Rompe *et al* (2007) investigated the reliability, validity, and sensitivity of the visual analogue scale (VAS) for pain, the disabilities of the arm, shoulder, and hand (DASH) questionnaire, the Roles and Maudsley score, the upper extremity function scale, and the patient-rated tennis elbow evaluation questionnaire (PRTEE) in subjects with lateral elbow tendinosis. It was concluded that the VAS for pain, the DASH and the PRTEE were reliable, reproducible, and sensitive instruments for assessment of lateral elbow tendinosis.

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The tests selected to diagnose lateral elbow tendinosis in this study were passive wrist flexion with the elbow in full extension and pronation (Reid, 1992; Whaley & Baker, 2004), a standard VAS to document lateral elbow pain elicited during the passive test (Brunton, 2004), and grip strength testing (Vincenzino, 2003). These tests will now be described in further detail.

2.6.1.3.1 Passive wrist flexion with the elbow in full extension and pronation

This is a passive test, which is easy to administer in a standardised manner. It is a test that is commonly used in clinical practice to confirm the diagnosis of lateral elbow tendinosis (Reid, 1992; Whaley & Baker, 2004).

As previously mentioned, there is a lack of validity and reliability testing for this diagnostic test. Furthermore, there is a lack of evidence comparing the effectiveness of isometric, active, or passive diagnostic tests for lateral elbow tendinosis. It is therefore acknowledged that a potential weakness exists with the use of a passive test for the diagnosis of lateral elbow tendinosis. However, it is proposed that this test, together with the use of a VAS to measure pain at the origin, and grip strength testing, may provide an effective combination in the diagnosis of lateral elbow tendinosis.

2.6.1.3.2 Visual analogue scale (VAS)

The visual analogue scale (VAS) for pain was used in this study to record lateral elbow pain reproduced by the passive test for lateral elbow tendinosis described above, and later to record wrist pain reproduced by Finkelsteins test. The VAS has been shown to be a reliable and valid measurement tool for pain intensity (Jenson, 1986, Brunton, 2004).

The VAS for pain is a unidimensional scale, indicating that it only measures one construct, that of pain intensity. It does this on a non-graduated 10cm line anchored by two extremes of pain, no pain and unbearable pain. Subjects are requested to mark a position on the line that corresponds to their perceived level of pain intensity, and the investigator then scores the scale by the measurement of the distance between “no pain” and the subject’s mark (Jenson, 1986).

The advantages of this type of scale are that it is simple to use, and it is able to measure small changes in pain intensity (Brunton, 2004). Ramer *et al* (1999), studied pain assessment in Hispanic, African American, and Anglo cancer patients to establish whether different pain scales (including the VAS), were appropriate for use in a multicultural population. Results showed that there were no significant differences between groups for measurement of pain perception using different pain scales. It was concluded that the pain scales used in the study by Ramer *et al* (1999), including the VAS for pain, were appropriate for use in a multicultural population.

However, it is acknowledged that there is a lack of evidence regarding the use of the VAS for pain within a South African context. Although the VAS for pain was utilised only to confirm the presence of pain during diagnostic testing, it is suggested that the results of the VAS testing should be interpreted with caution.

2.6.1.3.3 Grip strength testing

Lateral elbow tendinosis is associated with a reduction in grip strength (Peters & Baker, 2001, Vincenzino, 2003; Alizadehkhayat *et al.*, 2007). Grip strength is routinely assessed in clinical practice using the Jamar dynamometer, which registers static grip strength in kilograms of force. Several studies have found that the Jamar dynamometer has high reliability and validity (Smidt *et al.*, 2002; Ashton & Myers, 2004; Tyler *et al.*, 2005).

Grip strength should be tested bilaterally to ascertain whether gripping reproduces pain in the region of the lateral epicondyle, and whether grip strength is decreased compared to the unaffected side (Vincenzino, 2003; Whaley & Baker, 2004). There is a good correlation between grip strength and visual pain scales, and therefore grip strength may be used to objectively assess the severity of symptoms (Reid, 1992).

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Shechtman *et al* (2005) described a standard testing position for the measurement of grip strength. Any deviation from this position has been shown to have a significant influence on the results obtained (Ashton & Myers, 2004).

Maximal grip strength is most commonly recorded at testing position two (3.8cm) of the Jamar dynamometer (Ashton & Meyers, 2004).

Studies have been unable to demonstrate a significant difference between one, three and an average of three maximum grip strength trials for each side tested, and therefore it is accurate and time efficient to use a single measurement for both sides. When studying rest periods between trials on one side, or between trials on either side, a study was unable to find a significant difference between 15, 30 and 60 second rest periods between maximal grip strength measurements. All of the above were found to be adequate for measurement accuracy (Ashton & Myers, 2004).

The 10% rule states that non-injured right-handed subjects should have a grip strength that is 10% stronger on the right hand side than the left hand side. The same rule states that non-injured left-handed subjects should have equal grip strength on both sides (Crosby *et al.*, 1994).

Therefore a right-handed subject with an injured right arm, who has equal grip strengths bilaterally on grip-strength testing, would be diagnosed as having lateral elbow tendinosis if the same test elicits lateral elbow pain during grip-strength testing (Crosby *et al.*, 1994; Schmidt & Toews, 1970).

Further, a left-handed subject with an injured left hand side that presents with lower grip strength on this side compared to the right hand side, would be diagnosed as having lateral elbow tendinosis under the same circumstances described as above (Crosby *et al.*, 1994; Schmidt & Toews, 1970).

The “10% rule” has also been challenged by Armstrong & Oldham (1999), who found that there were significant differences of only 0.1-3% between grip strengths of the dominant and non-dominant hands in right-handed subjects, and as such they advised caution when applying the rule. However, other studies have confirmed that the 10% rule is valid for right-handed subjects and that grip strength should be considered as equal bilaterally for left-handed people (Peterson *et al.*, 1989).

2.6.1.4 Treatment of lateral elbow tendinosis

Lateral elbow tendinosis is an overuse injury that is challenging to treat and is prone to recurrent bouts (Vincenzino, 2003). There is little consensus in the literature to date on the management of lateral elbow tendinosis (Bisset *et al.*, 2005). Generally, although some interventions have been shown to improve musculotendinous function, there is currently little evidence to support the mechanisms underlying these therapeutic effects (Cook *et al.*, 2002).

A comprehensive appraisal of the literature regarding the management of lateral elbow tendinosis is beyond the scope of this study. The reader is referred to Cook *et al.*, 2002; Vincenzino, 2003; Bisset *et al.*, 2005; and Bisset *et al.*, 2006 for comprehensive reviews of the management of lateral elbow tendinosis.

The restoration of normal tendon histology is one of the primary objectives in the treatment of lateral elbow tendinosis (Thomas *et al.*, 1995). Eccentric loading of the Achilles tendon has been associated with improvements in the alignment of collagen fibres, as well as the extent of cross-bridge formation, which may be related to increases in tensile strength (Ashe *et al.*, 2004, Bisset *et al.*, 2005). It is noted that the literature on the effects of eccentric strengthening in tendinosis are primarily based on studies of Achilles tendinosis rehabilitation. There is a lack of evidence regarding the role of eccentric muscle strengthening in the treatment of upper limb overuse injuries.

Furthermore, a recent study has proposed that lateral elbow tendinosis may be a self-limiting conditioning of approximately fifty-two weeks in duration, provided that appropriate advice is given to the subject. This advice includes specific instructions regarding the modification of daily activities to avoid pain aggravation. Subjects were also instructed in the use of analgesics or anti-inflammatory drugs, heat, cold, or braces as required (Bisset *et al.*, 2006).

2.6.2 DeQuervains tenosynovitis

Overuse injuries of the wrist, and in particular DeQuervains tenosynovitis, are upper limb injuries frequently encountered in a sporting population (Reid, 1992; Fulcher *et al.*, 1998; Rettig, 2001). DeQuervains tenosynovitis is a stenosing tenosynovitis of the tendon sheath of the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons at the level of the radial styloid process (Ashe *et al.*, 2004). DeQuervains tenosynovitis commonly occurs due to activities that require a forceful grip combined with ulnar deviation, or due to the repetitive use of the thumb (Fulcher *et al.*, 1998).

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During the paddling stroke a power grip is utilised, involving the extrinsic muscles of the hand. A power grip generally involves ulnar deviation and extension of the wrist (Hamill & Knutzen, 1995). Paddling also requires repetitive supination and pronation of the forearm. These actions may contribute to the development of tenosynovitis of the radial deviators, APL and EPB (Hamill & Knutzen, 1995).

2.6.2.1 Aetiology and pathophysiology of DeQuervains tenosynovitis

Historically, DeQuervains tenosynovitis has been regarded as a disease affecting middle-aged women. However, it is becoming increasingly prevalent among younger populations and competitive athletes (Fulcher *et al.*, 1998).

The proposed mechanism of injury of DeQuervains tenosynovitis is that repetitive wrist movements may lead to shearing forces and subsequent degeneration of the tenosynovium of the APL and the EPB tendons. The degeneration occurs as the tendons pass in a common synovial sheath within the first dorsal wrist extensor compartment at the radial styloid process (Brukner & Khan, 2001, Richie & Briner, 2003; Ashe *et al.*, 2004).

Work requiring repetitive movement of the wrist and thumb, while gripping an object, puts the tendons of APL and EPB on stretch over the radial styloid process. This puts pressure on the tendon sheath, which is unable to avoid this pressure due to its close proximity to the bone. Repeated overstretching of the tendon sheath results in an injury to the gliding mechanism, and may predispose the subject to the development of DeQuervains tenosynovitis (Rettig, 2001).

Historically, histological examination of the affected tendons of APL and EPB, showed rough, thickened tendons without signs of inflammation. In latter years, vastly improved histological techniques have confirmed that inflammatory cells are indeed absent in DeQuervains tenosynovitis, and that there are signs of tendon degeneration (Ashe *et al.*, 2004).

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Clarke *et al* (1998) determined that DeQuervains tenosynovitis was associated with a five-fold increase in tendon thickness, increased vascularity and an accumulation of mucopolysaccharide within the fibrous tendon sheath. These histological changes were collectively referred to as “mucoïd degeneration”. There was also an absence of inflammatory cells.

2.6.2.2 Clinical features of DeQuervains tenosynovitis

Typical symptoms of DeQuervains tenosynovitis include pain over the radial styloid process. The pain may radiate proximally into the wrist or distally into the thumb, and may be reproduced by resisted thumb abduction or extension. Pain may also be reproduced by ulnar deviation of the wrist. Further, supination is often more painful than pronation. In addition, swelling may develop over the first dorsal compartment of the wrist (Finkelstein, 1930; Ashe *et al.*, 2004). Crepitus or triggering of the thumb may also occur infrequently. In chronic DeQuervains tenosynovitis, there may be palpable fibrous thickening of the tendon sheath, and a ganglion cyst may also be present (Fulcher *et al.*, 1998).

Several studies have shown a higher incidence of separation of the APL and EPB tendons into two discrete compartments in patients with DeQuervains tenosynovitis when compared to unaffected wrists (Finkelstein, 1930; Witt *et al.*, 1991).

Finkelstein (1930) proposed that the sheath that separates the first dorsal compartment in some subjects may serve as a further mechanical hindrance to the normal tendon gliding of APL and EPB. Further research is required to determine whether this is a true clinical feature of DeQuervains tenosynovitis.

2.6.2.3 Diagnostic test for DeQuervains tenosynovitis

Finkelsteins test was first documented in 1930 (Finkelstein, 1930), and is used extensively in clinical practice (Brukner & Khan, 2001; Fulcher *et al.*, 1998; Rettig, 2001; Ashe *et al.*, 2004).

In this test, the thumb is flexed into the palm of the hand, and the fingers are flexed over the thumb to form a fist. The examiner maintains this position and then performs passive ulnar deviation. This position places a maximal stretch on the tendons of APL and EPB. A positive result is recorded if the patient indicates that the test reproduces pain over the area of the first dorsal compartment of the wrist (Finkelstein 1930, Fulcher *et al.*, 1998; Rettig 2001; Ashe *et al.*, 2004).

In this study, a standard VAS for pain, as described and evaluated in the section on lateral elbow tendinosis, was used to record pain elicited over the first dorsal compartment of the wrist during Finkelsteins test in order to grade the severity of symptoms (Jenson, 1986; Ramer *et al* 1999; Vincenzino, 2003; Brunton, 2004; Rompe *et al.*, 2007).

2.6.2.4 Treatment of DeQuervains Tenosynovitis

A comprehensive appraisal of the literature regarding the management of DeQuervains tenosynovitis is beyond the scope of this study. The reader is referred to Witt *et al.*, 1991; Speed, 2001; Ashe *et al.*, 2003; and Richie & Briner, 2003 for comprehensive reviews of the management of DeQuervains tenosynovitis.

It is notable that corticosteroid injections are commonly used in the management of DeQuervains tenosynovitis, despite evidence indicating that it is a non-inflammatory condition. Animal studies have shown that intratendinous corticosteroid injections adversely affect the biomechanical properties of the injected tendon. Corticosteroids may inhibit the formation of granulation, adhesions, and connective tissue. Further, tendon mass and biomechanical integrity is reduced, decreasing the load to failure of the tendon (Speed, 2001).

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Furthermore, a pooled quantitative literature evaluation of seven studies that used corticosteroid injections in the management of DeQuervains tenosynovitis determined an 83% cure rate with the use of corticosteroid injections. Although there were minor differences in the type of corticosteroid injected, and the injection techniques between studies, these findings strongly support the use of corticosteroid injections in the management of DeQuervains tenosynovitis. However, the underlying mechanisms of action require further investigation (Richie & Briner, 2003).

University of Cape Town

3 AIM AND OBJECTIVES

3.1 Aim

To determine which intrinsic and extrinsic factors differed between paddlers who developed lateral elbow tendinosis and DeQuervains tenosynovitis reported during a K1 marathon race, the 2006 Berg River Canoe Marathon, and those who did not.

3.2 Objectives

- 1) To establish whether there were differences in demographics and structural characteristics (age, mass, height, BMI) between K1 marathon paddlers showing symptoms of lateral elbow tendinosis and DeQuervains tenosynovitis and those without symptoms.
- 2) To establish whether there were differences in paddle grip to handgrip ratios, or training preparation between K1 marathon paddlers showing symptoms of lateral elbow tendinosis and DeQuervains tenosynovitis and those without symptoms.
- 3) To determine if there were differences in extrinsic variables (race time, atmospheric temperature, flow rate, water level, rainfall, distance) potentially contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis between days of the 2006 Berg River Canoe Marathon, and if so, was there a correlation between these variables and the incidence of new occurrences of lateral elbow tendinosis and DeQuervains tenosynovitis.

4 METHODS

4.1 Study design

A descriptive correlational cross-sectional study of K1 marathon paddlers participating in the 2006 Berg River Canoe Marathon was conducted. The study was granted ethical clearance by the Ethics and Research Committee of the Faculty of Health Sciences, University of Cape Town (*Appendix I*).

4.2 Subjects

4.2.1 Subject recruitment

This study used a sample of convenience, and healthy K1 marathon paddlers were requested to volunteer for the study. The study was advertised before the event, through posters and pamphlets at local canoe clubs, and electronic advertisements on the official race website. In addition, the study was advertised in electronic newsletters, which were sent to all participants who registered for the event, during the two months prior to the event (*Appendix II*). Recruitment of subjects was also conducted at the event registration, where information regarding the study was distributed through regular verbal announcements. The questionnaire and testing stations were adjacent to the registration table at the event in direct sight of all race participants.

Race participants that consented to testing at race registration were asked to present for testing during the race should they develop elbow or wrist pain.

During the race, ten 4th year physiotherapy students stood at the exit point from the river for each stage of the race and encouraged all race participants to present for testing if they complained of elbow or wrist pain. The physiotherapy students each had a list of the boat numbers of subjects that presented for testing at race registration, and they were especially vigilant for these paddlers.

The testing station for this study was placed in direct line of sight of the exit point from the river so that race participants would not have to go far to be tested. The physiotherapy students carried the race participants' paddle and canoe to their respective berthing stations and walked them to the testing station.

Subjects were included in this study if they were participants in the 2006 Berg River Canoe Marathon and completed the race. Subjects were excluded from this study if they had elbow or wrist pain at the start of the canoe marathon.

Subjects were included in the asymptomatic group if they presented for testing at race registration, had no elbow or wrist pain at race registration, and did not develop elbow or wrist pain during the 2006 Berg River Canoe Marathon.

Subjects were included in the symptomatic group if they had no elbow or wrist pain at the start of the 2006 Berg River Canoe Marathon but developed elbow or wrist pain during the race, and were positive on the diagnostic tests for either lateral elbow tendinosis and/or DeQuervains tenosynovitis.

4.3 Informed consent

Subjects were informed about the purpose of the study, the testing to be undertaken, the possible risks related to the study, and their right to withdraw from the study at any stage. All subjects were required to complete an informed consent form (*Appendix III*) prior to the start of the study.

4.4 Questionnaire

The subjects completed a questionnaire (*Appendix IV*) that was adapted from a previously validated questionnaire (Micklesfield, 2005), and was used by several researchers conducting studies at the 2006 Berg River Canoe Marathon. Each researcher therefore used the parts of the questionnaire that contained data that was pertinent to their study and the volunteers only had to fill out a single questionnaire.

Micklesfield (2005) developed this questionnaire for the South African population, and specifically for data collection in athletes. The questionnaire was simply adapted by removing the section with questions pertaining to osteoporosis, as this was not applicable to the population. Further, the training section (section three) remained unchanged, except for the type of training being stipulated as paddling. In the section on specific sport history, section four, parts (a) and (b), were made paddling specific by including a list of local paddling events. Section 5, the sports equipment section, was adapted to the paddler and paddling equipment. The above adaptations of the questionnaire to paddling were minor, and were therefore not thought to influence the validity of the questionnaire itself.

Data from the questionnaire relevant to this study included:

- a) Previous medical history – including previous upper limb surgery, previous elbow injuries, previous wrist injuries, and previous bouts of lateral elbow tendinosis and DeQuervains tenosynovitis.
- b) Use of medication - including the use of non-steroidal anti-inflammatories and analgesics in the three months prior to the 2006 Berg River Canoe Marathon.
- c) Paddling history - including total number of months paddling, number of Berg River Marathons completed, and number of other canoeing marathons completed.
- d) Stretching history - including data pertaining to the stretching of the elbow/wrist only.
- e) Training history - including average number of training days in 12 off-season weeks, average number of training days in the 12 weeks prior to the 2006 Berg River Canoe Marathon, average duration of each training session in 12 off-season weeks, average duration of each training session in the 12 weeks prior to the 2006 Berg River Canoe Marathon, and the average speed over a 10km time-trial completed no longer than 6 months prior to the 2006 Berg River Canoe Marathon.
- f) Paddling equipment - including paddle-shaft shape (oval or round), paddle-shaft modification at the position of the handgrip, whether or not the paddler used a 'slimline boat' in the 2006 Berg River Canoe Marathon, and the paddle length.

Two qualified physiotherapists assisted the race participants in completing the questionnaire at race registration. The researcher assisted race participants in completing the questionnaire during the race if they had not completed it at race registration.

4.5 Height and body mass measurements

Body mass (kg) was recorded using a calibrated scale (Seca model, 708 Germany). Height (m) was determined with a measuring rule. These measurements were performed by two qualified physiotherapists at race registration. The researcher performed any further body mass or height measurements required after race registration.

4.6 Diagnostic tests

Lateral elbow tendinosis was diagnosed using a passive test, which consisted of passive wrist flexion with the elbow in full extension and pronation (Reid, 1992; Whaley & Baker, 2004), and grip strength testing (Shechtman *et al.*, 2005). DeQuervains tenosynovitis was diagnosed using Finkelsteins test (Finkelstein, 1930). A VAS for pain (Jenson, 1986, Brunton, 2004) was completed to determine the pain response during the passive test for lateral elbow tendinosis and Finkelsteins test respectively.

Inclusion in the symptomatic group required either a positive response for both of the tests for lateral elbow tendinosis, or a positive on Finkelsteins test. Subjects were also included in the symptomatic group if positive responses were elicited on testing for both lateral elbow tendinosis and Finkelsteins test.

The researcher performed all diagnostic tests at both race registration and after each race stage. A 4th year physiotherapy student assisted the researcher for the duration of the event by acting as scribe.

4.6.1 Diagnostic tests for lateral elbow tendinosis

Two tests were used to diagnose lateral elbow tendinosis, the first test was passive wrist flexion with the elbow in full extension and pronation (Reis, 1992; Whaley & Baker, 2004), and the second test was bilateral grip strength testing (Shechtman *et al.*, 2005).

4.6.1.1 Passive wrist flexion with full elbow extension and pronation

A passive test was performed to diagnose lateral elbow tendinosis in the subjects (figure 4.1). If the subject complained of elbow pain prior to testing, the unaffected arm was always tested first. If no elbow pain was present prior to testing, then the dominant arm was tested first. The test was performed with the subject in supine. The researcher passively pronated the forearm and extended the elbow. This position was maintained and passive wrist flexion was then added off the edge of the bed, and sustained for 10 seconds.

The subject was asked to distinguish between a stretching sensation of the forearm musculature and lateral elbow pain. A positive test was only recorded if the subject reported lateral elbow pain localised to the common extensor origin on the lateral epicondyle of the humerus during the test (Whaley & Baker, 2004), with a pain score of greater than zero on a standard VAS (Brunton, 2004). Each side was tested once with a 30 second rest period between each test.



Figure 4.1 *Passive wrist flexion with full elbow extension and pronation (Reid, 1992; Whaley & Baker, 2004).*

4.6.1.2 Grip strength measurement

Grip strength was assessed using the Jamar dynamometer, which registers static grip strength in kilograms of force.

❖ Standard testing position for grip strength measurement

The subject was positioned in sitting on a straight-backed chair, with the feet resting flat on the floor, and with the hips as far back in the chair as possible, with hips and knees at approximately 90°. The arms were unsupported and the shoulder of the arm to be tested was adducted and neutrally rotated, the elbow joint flexed to 90° with the forearm in neutral. The wrist was positioned between 0° and 30° of dorsiflexion and 0° and 15° of ulnar deviation. A small block was placed between the upper arm of the arm to be tested and the thorax in an attempt to avoid muscle substitution patterns. The subject was instructed to maintain this position during the grip strength test (Shechtman *et al.*, 2005).

❖ Handgrip position, number of trials and duration of rest periods

The researcher used position two of the Jamar dynamometer, and performed one maximal 30-second grip strength trial for one hand followed by a rest period of 30 seconds before testing on the opposite side. All subjects received a consistent level of verbal encouragement on all grip strength testing.

❖ Testing procedure for measuring handgrip strength

The subject was verbally instructed to grip the dynamometer and apply the maximal amount of pressure possible in a smooth manner. They were instructed to maintain this contraction for 30 seconds. The subjects were allowed to perform one practice test followed by a rest period of 30 seconds. This was followed by one maximal grip strength trial. The procedure was then repeated for the other hand (Shechtman *et al.*, 2005).

A coin was flipped to determine which hand was tested first in subject number one. Subject number two then had the opposite hand tested first and so on, alternating for each subsequent subject.

The subject was asked whether gripping reproduced the same pain as elicited during the passive elbow test described above. A positive result for this test was recorded if the subject indicated that the pain was in the same area, and the grip strength on the affected arm was weaker than would be expected according to the 10% rule.

A right-handed subject with an injured dominant arm and equal grip strengths bilaterally on testing, would score a positive result in this study as his dominant arm should be 10% stronger than his non-dominant arm according to the "10% rule" (Crosby et al., 1994; Schmidt & Toews, 1970).

Further, as grip strength is expected to be the same bilaterally in non-injured left-handed subjects, a left-handed subject with an affected left side that presents with lower grip strength on this side compared to the other side would score a positive result, as the grip strengths should be the same bilaterally (Crosby et al., 1994; Schmidt & Toews, 1970). The above rules were applied to the grip strength data in this study and a positive or negative result was assigned accordingly.

4.6.2 Diagnostic test for DeQuervains tenosynovitis

Finkelsteins test was performed as a diagnostic test to establish the presence of DeQuervains tenosynovitis in subjects. If the subject complained of wrist pain prior to testing, the unaffected arm was always tested first. If the subject had no wrist pain, then the dominant arm was tested first. The test was performed with the subject in supine with the forearm in neutral, the elbow in extension, and the wrist maintained in neutral over the edge of the bed. The subject's thumb was passively flexed into the palm of the hand, and the subject was instructed to form a fist by closing the fingers around the thumb. This position was maintained passively while the investigator ulnarly deviated the wrist to induce a maximal stretch on the abductor pollicis longus (APL) and extensor pollicis brevis tendons (EPB) (Rettig, 2001). The position was held for 10 seconds.

A positive test was recorded when the subject reported pain along the tendons of APL and EPB and a pain intensity of greater than zero on a standard VAS (Brunton, 2004). Each side was tested once, with a 30 second rest period between each test.



Figure 4.2 *Finkelsteins test (Finkelstein, 1930).*

4.6.3 Pain assessment using the Visual Analogue Scale (VAS).

The researcher assisted all subjects when completing the VAS at both race registration and at the end of each race stage. Subjects were requested to mark a position on a line that corresponded to their perceived level of pain intensity during the passive test for lateral elbow tendinosis and the Finkelstein test. The researcher then scored the scale by the measurement of the distance (mm) between “no pain” and the subject's mark (Jenson, 1986).

4.6.4 Analysis of extrinsic factors involved in upper-limb overuse injuries

4.6.4.1 The Nirschl technique

The Nirschl technique was used to assess the handgrip size for each subject. The patient was instructed to lie comfortably in a supine position on a plinth with the arm extended at the elbow, the forearm supinated and the hand resting on the plinth. The researcher then measured the distance (millimetres) from the distal palmer crease to the fingertip along the radial border of the ring finger using an inflexible transparent ruler (in millimetres) (Nirschl, 1992). The measurement was taken once for each hand. Only the researcher performed the Nirschl technique at both race registration and during the race.

There is a paucity of literature on the reliability or validity of the Nirschl technique. Therefore, the researcher performed a pilot study to determine the standard error of the mean for the Nirschl technique. Ten subjects were measured on two different occasions, with any difference found between the first and second measurements being used to determine the standard error of the mean (Standard deviation/mean difference x 100). The standard error of the mean was calculated at 1.41mm, a value that is acceptably low (*Appendix V*).



Figure 4.3 *The Nirschl technique (Nirschl, 1992).*

4.6.4.2 Measurement of paddle grip size

The paddle grip size was measured by two qualified physiotherapists at race registration. The researcher did any further measurements required during the race.

During testing, the subject was asked to hold their paddle in the exact orientation of use while standing. The paddle diameter (millimetres) was measured using a soft tape measure at the position of both hands. Any grip modifications were noted. The shape of the paddle shaft (oval or round) was also recorded.

4.6.4.3 Paddle grip: handgrip size ratio

A ratio was calculated for each subject using the values obtained from the Nirschl technique and measurement of the paddle grip size. Ratios were determined for both hands.

The paddle grip: handgrip size ratio was calculated to determine whether there is a relationship between the paddle grip: handgrip size ratio and the development of lateral elbow tendinosis and DeQuervains tenosynovitis at the 2006 Berg River Canoe Marathon.

4.7 Testing procedure

A schematic representation of the testing procedure is shown in Figure 4.4. Permission to conduct the study was obtained from the Berg River Canoe Marathon race organizers.

The study was advertised 2 months prior to the race, and subjects were recruited for this study during race registration before the start of the race, and at the end of each day of the 4-day Berg River Canoe Marathon. The testing procedure that is described was conducted at the race registration, and at the end of each stage of the race.

Subjects were required to complete the informed consent form (*Appendix III*) prior to the commencement of testing. The subjects were then requested to complete the questionnaire to determine previous medical history, medication use, paddling history, stretching history, training history, and paddling equipment (*Appendix IV*).

Body mass (kg) was measured on a calibrated scale, and height (m) was measured with a measuring rule. The measurement of paddle shaft diameter for both hand positions was performed using a flexible tape measure.

The patient was then positioned in supine on a plinth and the passive diagnostic test for lateral elbow tendinosis was performed. The diagnostic test required the subject to indicate the area of pain, and the intensity of pain elicited by the test on a separate standard VAS (Brunton, 2004).

To keep position change to a minimum, this was followed by the diagnostic test for DeQuervains tenosynovitis, the Finkelstein test (Rettig, 2001). The diagnostic test required the subject to indicate the area of pain, and the intensity of pain elicited by the test on a separate standard VAS (Brunton, 2004).

Again to minimise position change, the handgrip size (Nirschl, 1992), was then measured bilaterally using the Nirschl technique with a measuring rule.

The subject was then positioned in a chair and bilateral grip strength measurements were taken. The measurement of grip strength was done using a handgrip dynamometer to compare grip strength between the arms as a second test for lateral elbow tendinosis (Ashton & Myers, 2004).

On completion of the testing, all subjects received a pamphlet containing information and advice regarding the prevention of lateral elbow tendinosis and DeQuervains tenosynovitis, as well as relevant stretching and strengthening exercises.

At the completion of the race daily weather and river conditions, and total race time and daily finishing time for each participant, was obtained. Daily race speed and time-trial speed for each participant was determined, and the paddle grip: handgrip size ratio for each participant was calculated.

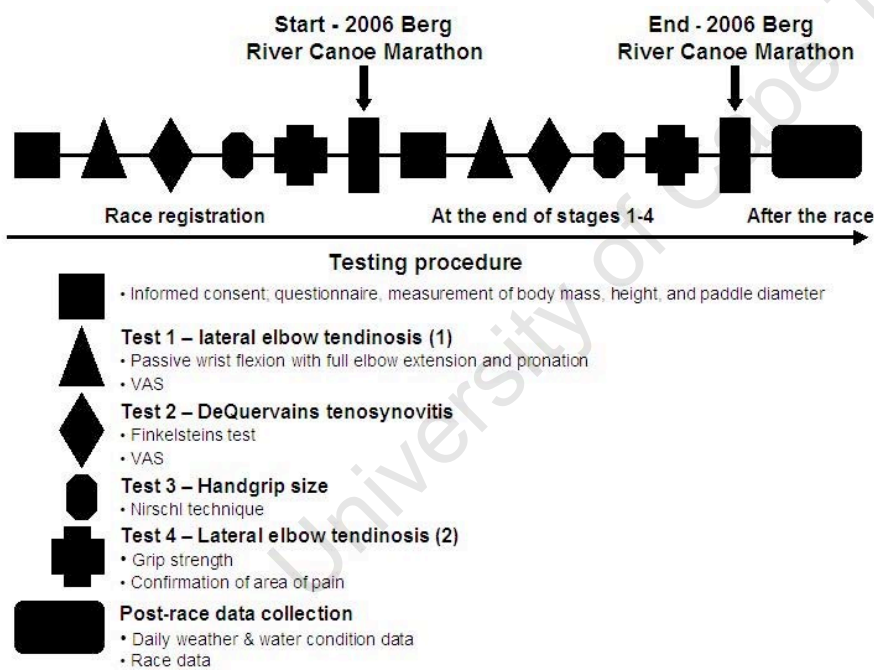


Figure 4.4 Testing procedure

4.8 Post-race data collection and analysis

Daily weather and river condition data were obtained from the Department of Forestry and Water Affairs of South Africa, and from www.dwaf.gov.za/hydrology. Data included minimum and maximum atmospheric temperatures, water levels, flow rate, and rain fall for each of the four stages of the 2006 Berg River Canoe Marathon.

The time taken to complete each race stage, as well as total race time was obtained for each subject. Race data were obtained from the race web site (www.canoesa.co.za) once the official results had been posted. In addition, the average daily race speed and the average time-trial speed was calculated for each subject.

4.9 Statistical analysis

All data are presented as the mean \pm standard deviation. Statistical analyses were performed using STATISTICA software (Statsoft, Inc. 2004, version 7), a data analysis software system (www.statsoft.com).

Variables that may influence the development of lateral elbow tendinosis and DeQuervains tenosynovitis were tested for normality using the Shapiro-Wilk's W test (the variable is not normally distributed if $p < 0.05$). A summary of the results of the Shapiro-Wilkes test for normality may be found in *Appendix VI*

The variables that were normally distributed (age, body mass, height, body mass index, total race time, race speed for day 2, race speed for day 3, race speed for day 4, average race speed, right paddle diameter, left hand grip size, right handgrip size, left paddle grip: handgrip size ratio, right paddle grip: handgrip size ratio, dominant grip strength, and non-dominant grip strength) were then analysed using an Independent T-test. Statistical significance was accepted as $p < 0.05$.

The variables that were not normally distributed (total number of months paddling, number of Berg River Canoe Marathons completed, number of other canoe marathons completed, average number of training days in 12 off-season weeks, average number of training days in the 12 weeks before the 2006 Berg River Canoe Marathon, average duration of training sessions in 12 off-season weeks, average duration of training sessions in the 12 weeks before the 2006 Berg River Canoe Marathon, time-trial speed, paddle length, race speed for day 1, and left paddle diameter) were analysed using a Mann-Whitney U test. Statistical significance was accepted as $p < 0.05$.

The relationship between categorical variables (previous upper limb surgery, previous elbow injury, previous wrist injury, previous bouts of lateral elbow tendinosis, previous bouts of DeQuervains tenosynovitis, use of non-steroidal anti-inflammatory drugs in the 3 months before the race, use of analgesic drugs in the 3 months before the race, stretching history, paddle-shaft shape, paddle-shaft modification, and slimline boat) was analysed using a Pearson Chi-square test. Statistical significance was accepted as $p < 0.05$.

A Pearson's product-moment correlation coefficient determined relationships between variables (incidence of injury and race distance, minimum and maximum temperature, water level, flow rate, and rainfall). Statistical significance was accepted as $p < 0.05$.

5 RESULTS

5.1 Subject selection

Forty-one paddlers completed the questionnaire and volunteered for testing at race registration. Five of these paddlers were excluded immediately due to the presence of elbow or wrist pain at the time of testing. Therefore, the researcher had data from thirty-six paddlers at the start of the 2006 Berg River Canoe Marathon.

At the end of the 2006 Berg River Canoe Marathon, twenty-five of the original thirty-six paddlers had not developed elbow or wrist pain during the race and were therefore eligible for inclusion in the asymptomatic group. However, two subjects were excluded from this group as one subject did not complete the canoe marathon, and the other was an extreme outlier in the majority of factors studied. Therefore, twenty-three subjects made up the asymptomatic group at the end of data collection.

During the race, eleven subjects who had volunteered for testing at race registration and had no elbow or wrist pain at the start of the race, developed elbow or wrist pain during the race and returned for testing. All measurements and testing were repeated for these eleven paddlers. No measurements or testing data taken at race registration was used for these paddlers. The questionnaire that they had filled out at race registration was used.

A further eight paddlers who had no elbow or wrist pain at the start of the race and did not volunteer for testing at race registration, developed elbow or wrist pain during the race and presented for testing. These eight paddlers completed the questionnaire at the time of testing. Pre-race data on grip-strength could obviously not be obtained for these paddlers.

At the end of the 2006 Berg River Canoe Marathon, nineteen paddlers were eligible for inclusion in the symptomatic group. However, two subjects were then excluded from the symptomatic group, as one subject did not complete the canoe marathon, and the other subject was the only female in the group. Therefore, seventeen subjects made up the asymptomatic group at the end of data collection.

In conclusion, a total of forty subjects ($N = 40$) were accepted for study. Seventeen subjects formed the symptomatic group ($n = 17$) and twenty-three subjects formed the asymptomatic group ($n = 23$).

5.2 Data analysis

When the data were analysed, 11 subjects from the symptomatic group ($n = 17$) tested positive for both lateral elbow tendinosis and DeQuervains tenosynovitis. Of the remaining 6 subjects, 3 subjects tested positive for lateral elbow tendinosis only, and 3 subjects tested positive for DeQuervains tenosynovitis only. This study primarily aimed to assess the paddle grip: handgrip size ratio, together with other associated factors influencing the development of lateral elbow tendinosis and DeQuervains tenosynovitis, and not factors influencing the development of the individual conditions. Therefore all subjects who met the inclusion criteria for the symptomatic group were placed into a single group for analysis.

In addition, the unexpected small sample sizes for subjects who developed lateral elbow tendinosis only, or DeQuervains tenosynovitis only, unfortunately did not allow for meaningful comparative analyses to be performed. It may further be proposed that, due to the inherent difficulties related to quantifying the relative biomechanical contributions of the elbow and the wrist during the paddling stroke, it may therefore also be feasible to study the anatomical regions together as a functional unit.

5.3 Daily subject totals for the symptomatic group

The incidence of wrist and elbow pain on days one to four of the 2006 Isuzu Berg River Marathon is shown in Table 5.1. A total of 144 paddlers completed the Canoe Marathon, 11.81% ($n = 17$) of which formed the symptomatic group.

Table 5.1. Incidence of wrist and elbow pain on days one to four of the 2006 Berg River Canoe Marathon.

	Day 1	Day 2	Day 3	Day 4	Total
Number of Subjects	1	11	3	2	17
Daily Incidence (%)	5.88	64.71	17.65	11.76	100.00

5.4 General characteristics of subjects

Table 5.2 presents the general characteristics of the subjects. The symptomatic and asymptomatic groups were well matched, with no significant differences between groups in age ($p = 0.632$; $t = -0.483$), body mass ($p = 0.931$; $t = -0.087$), height ($p = 0.348$; $t = 0.951$) or body mass index ($p = 0.408$; $t = -0.837$).

Table 5.2. General characteristics of subjects in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).

Variable	Symptomatic group (n = 17)	Asymptomatic group (n = 23)
Age (years)	32.76 \pm 10.05	34.61 \pm 13.14
Body mass (kg)	81.62 \pm 11.85	81.93 \pm 10.69
Height (m)	1.80 \pm 0.07	1.78 \pm 0.07
Body mass index (BMI)	25.11 \pm 2.66	25.85 \pm 2.85

5.5 Previous medical history

Table 5.3 presents the previous medical history of the symptomatic and asymptomatic groups. There were no significant differences between groups for previous upper limb surgery ($p = 0.229$), previous elbow injuries ($p = 0.687$), or previous wrist injuries ($p = 0.896$). There were also no significance differences between the symptomatic and asymptomatic groups for previous bouts of lateral elbow tendinosis ($p = 0.379$), or for previous bouts of wrist tenosynovitis ($p = 0.368$).

Table 5.3. *Previous medical history in the symptomatic and asymptomatic groups.*

Variable	Symptomatic group (n = 17)	Asymptomatic group (n = 23)
Previous upper limb surgery	4	4
Previous elbow injury	3	2
Previous wrist injury	7	9
Previous bout/s of lateral elbow tendinosis	2	1
Previous bout/s of DeQuervains tenosynovitis	5	4

5.6 Use of medication

29.41% of the symptomatic group and 17.39% of the asymptomatic group used non-steroidal anti-inflammatory drugs (NSAID's) for paddling-related elbow or wrist pain in the 3 months preceding the 2006 Berg River Canoe Marathon. In addition, 35.29% of the symptomatic group and 21.74% of the asymptomatic group used analgesics for paddling-related elbow or wrist pain within the same time period. There were no significant differences between groups for either NSAID ($p = 0.368$) or analgesic ($p = 0.342$) use.

5.7 Paddling history

The characteristics of the subject's paddling history are shown in Table 5.4. There were no significant differences between groups in the total number of months paddled since starting paddling ($p = 0.766$; $U = 184.5$), the number of Berg River Canoe Marathons completed ($p = 0.808$; $U = 186.5$), and number of other paddling endurance events completed ($p = 0.626$; $U = 177.5$).

Table 5.4. Paddling history of subjects in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).

Variable	Symptomatic group (n = 17)	Asymptomatic group (n = 23)
Total number of months paddling	117.17 \pm 109.02	100.26 \pm 92.01
Number of Berg River Canoe Marathons	4.94 \pm 6.87	4.74 \pm 7.24
Number of other canoe marathons completed	9.12 \pm 7.50	11.83 \pm 11.40

5.8 Stretching history

When comparing the stretching activity between groups, it was found that 76.47% of the symptomatic group and 65.22% of the asymptomatic group stretched the upper-limb regularly, with no significant difference between the groups ($p = 0.443$).

5.9 Training history

Figure 5.1 shows the number of training days in twelve off-season weeks for the symptomatic (43.06 \pm 16.46 days) and asymptomatic (58.43 \pm 21.19 days) groups. There was a significant difference between groups ($p = 0.007$; $U = 99.0$), with the asymptomatic group training for a significantly greater number of days during 12 off-season weeks prior to the canoe marathon compared to the symptomatic group.

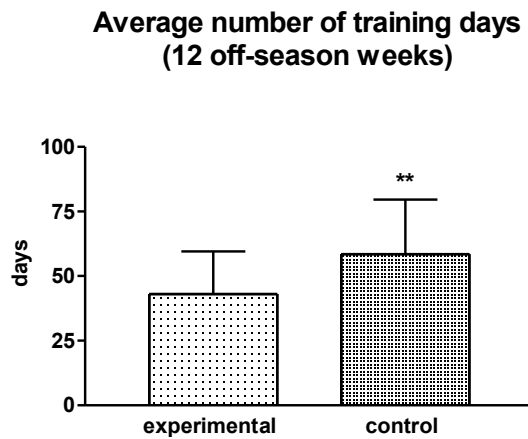


Figure 5.1. Average number of training days in 12 off-season weeks in the symptomatic ($n = 17$) and asymptomatic ($n = 23$) groups. (** $p = 0.007$)

Figure 5.2 represents the number of training days in the twelve weeks preceding the 2006 Berg River Marathon for the symptomatic (52.94 ± 17.52 days) and asymptomatic (62.61 ± 19.47 days) groups. There was a significant difference between groups ($p = 0.025$; $U = 117.0$), with the asymptomatic group training for a significantly greater number of days during the 12 weeks preceding the canoe marathon compared to the symptomatic group.

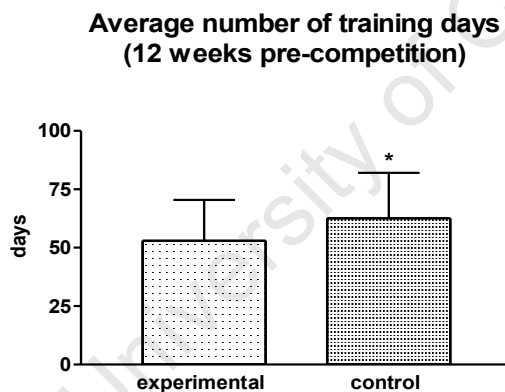


Figure 5.2. The average number of training days in 12 weeks preceding the 2006 Berg River Canoe Marathon in the symptomatic ($n = 17$) and asymptomatic ($n = 23$) groups. (* $p = 0.025$)

Figure 5.3 shows the average duration of each training session in the 12 off-season weeks for the symptomatic (91.71 ± 25.51 minutes) and asymptomatic (84.37 ± 32.19 minutes) groups. There was no significant difference between groups for off-season training session duration ($p = 0.498$; $U = 170.0$).

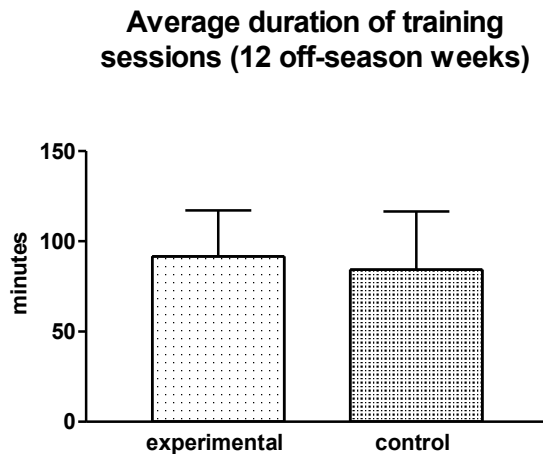


Figure 5.3. The average duration of training sessions in 12 off-season weeks in the symptomatic ($n = 17$) and asymptomatic ($n = 23$) groups.

Figure 5.4 shows the average duration of each training session in the 12 weeks preceding the 2006 Berg River Canoe Marathon for the symptomatic (109.35 ± 31.32 minutes) and asymptomatic (93.98 ± 28.12 minutes) groups, with no significant difference between groups ($p = 0.098$; $U = 134.0$).

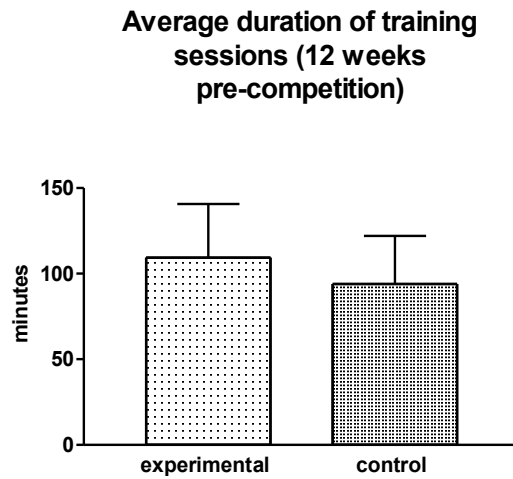


Figure 5.4. *The average duration of training sessions in 12 weeks preceding the 2006 Berg River Canoe Marathon in the symptomatic ($n = 17$) and asymptomatic ($n = 23$) groups.*

5.10 Time-trial speed

The average time-trial speeds ($\text{m}\cdot\text{s}^{-1}$) for the symptomatic ($3.14 \pm 0.35 \text{ m}\cdot\text{s}^{-1}$) and asymptomatic ($3.43 \pm 0.42 \text{ m}\cdot\text{s}^{-1}$) groups are presented in Figure 5.5. The time-trial speeds were recorded within a 6-month period prior to the 2006 Berg River Canoe Marathon. One subject from each group was excluded from this analysis, as neither subject had a time-trial result within the 6-month period. There was a significance difference between groups ($p=0.034$; $U = 126.5$), with the asymptomatic group having significantly faster average time-trial speeds compared to the symptomatic group.

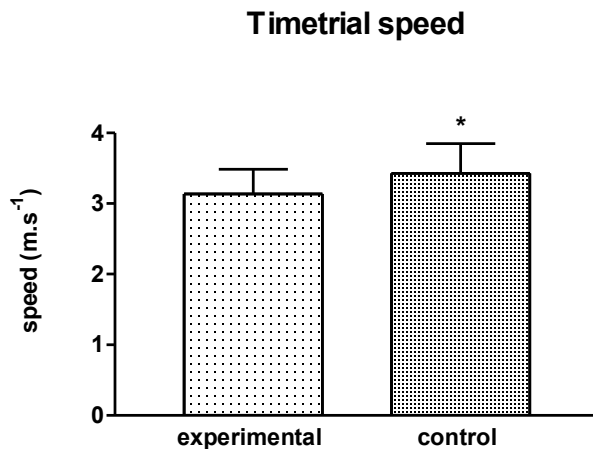


Figure 5.5. The average time-trial speeds recorded within a 6-month period prior to the 2006 Berg River Canoe Marathon in the symptomatic ($n = 17$) and asymptomatic ($n = 23$) groups. (* $p = 0.034$)

5.11 Paddling equipment

When comparing the paddle-shaft shape (oval or round) for the symptomatic and asymptomatic groups, 47.06% of the symptomatic group and 34.78% of the asymptomatic group had oval shafts. There was no significant difference between groups in paddle-shaft shape ($p = 0.433$). With respect to paddle-shaft modification, 41.18% of the symptomatic group and 34.78% of the asymptomatic group had modified their shafts in some way. There was no significant difference between the groups for paddle-shaft modification ($p = 0.680$). In addition, 64.71% of the symptomatic group and 60.87% of the asymptomatic group paddled a 'slimline' boat in the 2006 Berg River Canoe Marathon, with no significant difference between the groups ($p = 0.804$).

Fifteen subjects in the symptomatic group and twenty-two subjects in the asymptomatic group reported their paddle length. There was no significant difference in paddle length between the symptomatic group ($216.20 \pm 2.65\text{cm}$) and the asymptomatic group ($215.41 \pm 2.34\text{cm}$), with $p = 0.290$ and $U = 130.0$.

5.12 Race results for the 2006 Berg River Canoe Marathon

Table 5.5 represents the race results of subjects. There were no significant differences between groups in total race time ($p = 0.273$; $t = 1.113$). In addition, there were no significant differences between groups in race speed for day 1 ($p = 0.277$; $U = 155.0$), day 2 ($p = 0.175$; $t = -1.383$), day 3 ($p = 0.291$; $t = -1.070$), and day 4 ($p = 0.284$; $t = -1.086$), or in average race speed ($p = 0.224$; $t = -1.235$).

Table 5.5. Race results in the symptomatic and asymptomatic groups. (Mean \pm standard deviation).

Variable	Symptomatic group (n = 17)	Asymptomatic group (n = 23)
Total race time (hrs)	22.09 \pm 1.79	21.34 \pm 2.33
Speed day 1 (m.s ⁻¹)	2.96 \pm 0.28	3.10 \pm 0.37
Speed day 2 (m.s ⁻¹)	2.99 \pm 0.29	3.13 \pm 0.34
Speed day 3 (m.s ⁻¹)	3.26 \pm 0.27	3.37 \pm 0.34
Speed day 4 (m.s ⁻¹)	2.92 \pm 0.23	3.02 \pm 0.33
Average race speed (m.s ⁻¹)	3.02 \pm 0.26	3.15 \pm 0.34

5.13 Paddle grip: handgrip size ratio

The paddle grip and handgrip characteristics of subjects are shown in Table 5.6. There were no significant differences between groups in the left paddle diameter ($p = 0.787$; $U = 185.5$) and right paddle diameter ($p = 0.423$; $t = 0.810$). There were also no significant differences between groups in the left handgrip size ($p = 0.467$; $t = 0.735$) and the right handgrip size ($p = 0.852$; $t = 0.188$). The paddle grip: handgrip size ratio was compared between the symptomatic and asymptomatic groups, and there were no significant differences between groups in the left paddle grip: handgrip size ratio ($p = 0.337$; $t = 0.973$) and the right paddle grip: handgrip size ratio ($p = 0.574$; $t = -0.568$).

Table 5.6. Paddle grip size, handgrip size and the paddle grip: handgrip size ratio for the symptomatic and asymptomatic groups. (Mean \pm standard deviation).

Variables	Symptomatic group (n = 17)	Asymptomatic group (n = 23)
Left paddle diameter (mm)	96.41 \pm 4.44	95.91 \pm 3.45
Right paddle diameter (mm)	100.35 \pm 4.96	99.13 \pm 4.53
Left handgrip size (mm)	115.80 \pm 8.39	113.87 \pm 7.60
Right handgrip size (mm)	114.73 \pm 6.51	114.30 \pm 7.11
Left paddle grip: handgrip	1.22 \pm 0.10	1.19 \pm 0.08
Right paddle grip: handgrip	1.14 \pm 0.08	1.15 \pm 0.08

5.14 Grip strength

Table 5.7 represents the dominant and non-dominant grips strengths for each group. Uninjured grip strengths (in kilograms of force) were recorded for the subjects who presented for the testing at race registration. These grip strengths were all pre-exertion grip strengths. Nine subjects from the symptomatic group and twenty-three subjects from the asymptomatic group were present for the testing at race registration. There were no significant differences between groups in the dominant grip strength ($p = 0.166$) and the non-dominant grip strength ($p = 0.900$).

Table 5.7. Dominant and non-dominant grip strengths for the symptomatic and asymptomatic groups. (Mean \pm standard deviation).

Variables	Symptomatic group (n = 9)	Asymptomatic group (n = 23)
Dominant grip strength	60.11 \pm 5.64	55.83 \pm 8.29
Non-dominant grip Strength	53.89 \pm 7.99	53.48 \pm 8.31

5.15 Weather conditions

Figure 5.6 presents the daily race distances for the 2006 Berg River Canoe Marathon. There was no significant correlation between the incidence of injury and daily race distance ($r = 0.388$; $p = 0.611$).

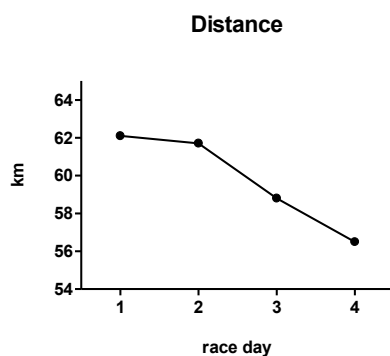


Figure 5.6. Daily race distances for the 2006 Berg River Canoe Marathon.

Figure 5.7 presents the minimum and maximum temperatures, the water levels, the flow rates, and the rainfall for days one to four of the 2006 Berg River Canoe Marathon. There were no significant correlations between the incidence of injury and minimum temperature ($r = -0.555$; $p = 0.445$), maximum temperature ($r = 0.875$; $p = 0.125$), water level ($r = -0.310$; $p = 0.690$), flow rate ($r = 0.055$; $p = 0.945$), or rainfall ($r = 0.906$; $p = 0.094$).

Environmental conditions

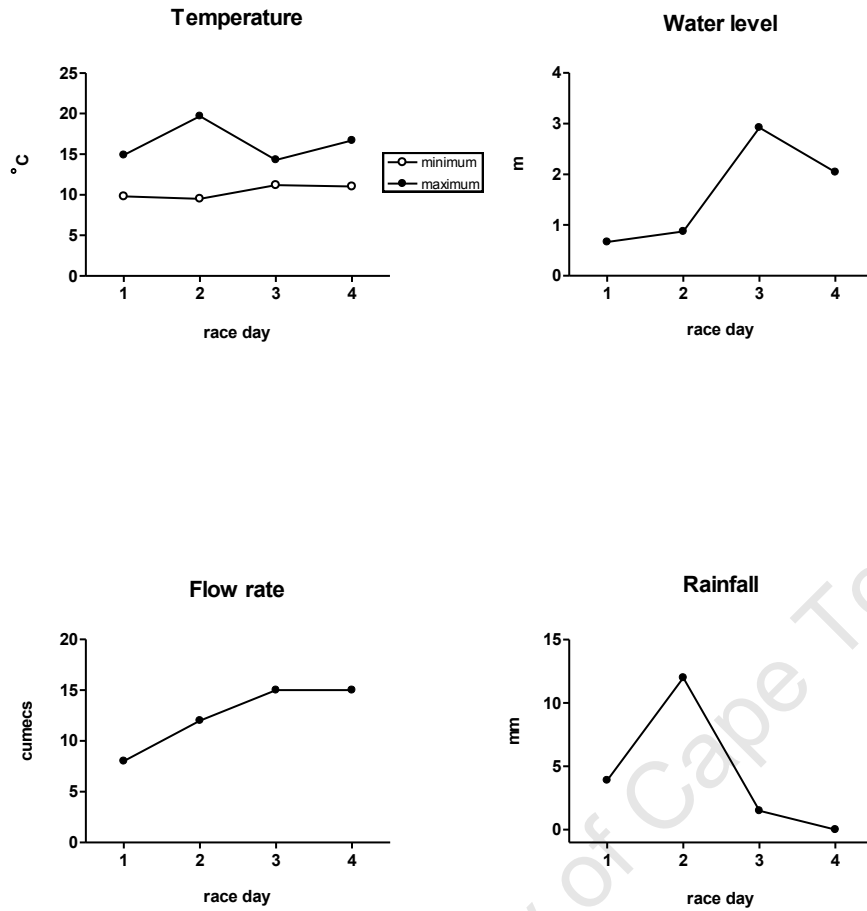


Figure 5.7. Environmental conditions for days one to four of the 2006 Berg River Canoe Marathon. Daily incidence of injury; day 1 ($n = 1$), day 2 ($n = 11$), day 3 ($n = 3$), and day 4 ($n = 2$).

6 DISCUSSION

The incidence of overuse tendinopathy of the elbow and wrist in K1 marathon paddlers during the 2006 Berg River Canoe Marathon was 11.81%. The results of this study demonstrated that age, the number of months paddling, and the number of endurance paddling events completed were not predictors of the incidence of elbow and wrist injury. Further, the paddlers in the asymptomatic group trained significantly more days both during twelve off-season weeks and the twelve weeks preceding the 2006 Berg River Canoe Marathon than the symptomatic group; while the asymptomatic group was significantly faster over a 10km time-trial compared to the symptomatic group in the six-month period before the race. No direct relationships between the incidence of injury and environmental conditions were established in this study and no significant differences between groups in paddle parameters such as the shape of the paddle shaft, paddle-shaft modifications or paddle length were observed. In addition, there was no significant difference between groups in the type of boat used for the event. There were also no significant differences between groups in paddle diameter and handgrip size in this study; nor were there any significant differences between groups in the paddle grip: handgrip size ratio.

The above findings will be discussed in the order in which the variables studied are presented in the results section of this thesis.

6.1 Incidence of injury

Kameyama *et al* (1999) reported an incidence of 3.8% for elbow pain and 10.8% for wrist pain ($\Sigma = 14.6\%$) in an injury survey of 417 competitive Japanese paddlers. These results were obtained through a questionnaire that was administered to determine present pain status in paddlers. Of the 144 paddlers who completed the 2006 Berg River Canoe Marathon, seventeen (11.81%) presented with elbow or wrist pain. Hence there is a similar incidence of injury between the two studies.

Du Toit *et al* (1999) established that 23% of the 510 marathon paddlers interviewed in their study suffered from acute tenosynovitis of the forearm. This is higher than the incidence of injury from the 2006 Berg River Canoe Marathon. A possible explanation for this difference may be that du Toit *et al* (1999) gave pooled results from four different paddling marathons, including the 1999 Berg River Canoe Marathon. The paddling marathons were chosen for their diversity in weather, water conditions, water temperature, and total race distance.

Moreover, du Toit *et al* (1999) interviewed every tenth race finisher at the end of each race stage, with a subsequent sample size of thirty paddlers per day in the 1999 Berg River Canoe Marathon. The total sample size was therefore 120 compared to the 40 paddlers tested in the 2006 Berg River Canoe Marathon. It is noted that the study by du Toit *et al* (1999) used a true sampling method typical of an incidence study, whereas in this study, an attempt was made to identify all paddlers who presented with elbow or wrist pain during the 2006 Berg River Canoe Marathon.

It is also difficult to compare the results from du Toit *et al* (1999) and the 1999 Berg River Canoe Marathon, to the results from this study of the 2006 Berg River Canoe Marathon, as the race conditions between the two studies were completely different. In addition, du Toit *et al* (1999) only provided basic anecdotal descriptions of the river height, such as “water was high”, and no objective measurements of the environmental conditions were recorded. It is therefore unfortunate that further detailed comparisons between the environmental conditions of two studies were not feasible. Anecdotally, the 1999 Berg River Canoe Marathon was contested in conditions that included low water levels and low flow rates. This compared to the 2006 Berg River Canoe Marathon, where uncharacteristically high water levels and high flow rates were recorded.

While it is acknowledged that there were differences in both the race conditions between the 1999 and the 2006 Berg River Canoe Marathons, and the sampling methods used between this study and that of du Toit *et al* (1999), the daily incidences of injury (%) reported by du Toit *et al* (1999) were 13%, 40%, 22% and 19% for days one to four respectively. This compared to figures from this study of 2.5%, 27.5%, 7.5% and 5% for days one to four respectively.

Both du Toit *et al* (1999) and this study demonstrate that the incidence of injury is the lowest on day one and highest on day two of the event. It may be suggested that the probability of injury increased due to accumulative strain on the forearm musculature during the first two days of the canoe marathon. Du Toit *et al* (1999) proposed that this may be associated with the fast flowing river sections, together with numerous whirlpools and small rapids, that are typically encountered on the first two days of the race. It is theorised that these river conditions may require a tighter grip on the paddle, and may therefore possibly contribute to the development of forearm pain.

In addition, it may be hypothesized that the reduction in the incidence of injury over the latter stages of the race observed in both this study and by du Toit *et al* (1999), may possibly be related to easier and less technical paddling conditions. In the last two stages of the race the river becomes wider, slower, and less technical.

A further explanation for the increased injury incidence on the first two days of the race may be related to the onset of exercise-induced muscle damage, which is a common phenomenon resulting from the performance of exercise with an increased intensity or duration. Indicators of exercise-induced muscle damage include the disruption of intracellular muscle structure, prolonged impairment of muscle function, and delayed onset muscle soreness (DOMS), with associated stiffness and swelling. The DOMS that follows a bout of exercise that induces muscle damage has a characteristic time course. Exercised muscles remain pain-free for approximately 8 hours. The pain then gradually increases, and usually peaks within 24 to 48 hours. This timeframe would therefore coincide with the second day of the Berg River Canoe Marathon. It may therefore also be theorised that a paddler with exercise-induced muscle damage of the upper limbs may experience reductions in isometric and dynamic strength, a loss of muscle power, and impaired neuromuscular control on the second day of the canoe marathon (Schutte & Lambert, 2001).

However, there is currently a lack of evidence regarding the impairments in muscle function or the presentation of DOMS during multi-day endurance events, and further investigation is required. It is further recognised that it is difficult to distinguish between DOMS or tendinosis during a sporting event such as the Berg River Canoe Marathon. The only definitive means to distinguish between the two conditions would be to perform a tendon biopsy or a magnetic resonance imaging (MRI) scan. Assessing plasma creatine kinase activity, and obtaining daily ratings of muscle pain may quantify DOMS further.

Moreover, variable levels of type II fibre damage and reflex inhibition associated with exercise-induced muscle damage have the potential to adversely affect dynamic, multi-joint movements required during paddling. Performance may be further impaired by an elevated physiological response, including increased pain, swelling, white-blood cell count, prostaglandins, and plasma creatine kinase activity, that occurs following exercise-induced muscle damage, as well as an associated decrement in motor control (Schutte & Lambert, 2001). These alterations may manifest as an increase in subjective effort (Byrne *et al.*, 2004). It is hypothesised that all of the above responses may potentially affect performance on the second day of the Berg River Canoe Marathon, leading to subsequent alterations in the paddling stroke, with an associated increased risk of injury.

The performance of a single bout of eccentric exercise that results in muscle damage, leads to adaptation of the muscle in that there is less evidence of damage when the same exercise bout is repeated (Clarkson & Hubal, 2002). This is known as the "repeated bout" effect and may provide a potential mechanism to support the hypothesis that the onset of elbow and wrist pain measured in this study may not have been related to exercise-induced muscle damage and DOMS. Cleary *et al* (2002) established that performing a similar exercise bout up to 2 months pre-competition could reduce the pain and muscular tenderness associated with an eccentric exercise bout. It may therefore be proposed that the training required to complete a multi-day canoe marathon may provide sufficient exposure to eccentric exercise bouts of the upper limb. It may further be theorised that the adaptations resulting from these exercise bouts may provide the necessary protective effect for the elbow, forearm, and wrist during the 2006 Berg River Canoe Marathon.

Tee

Comment [12]: Do you mean associated with exercise-induced muscle damage?

A final consideration when analysing the increased incidence of injury on day 2 of the 2006 Berg River Marathon, is to acknowledge that none of the extrinsic factors studied in this thesis were correlated with the injury incidence on day 2. Further study is required in this regard.

6.2 Training history

It has previously been proposed that older paddlers may have an increased risk of injury, due to the repetitive nature of the sport, and the accumulation of months of training and competition in endurance paddling events (Hagemann *et al.*, 2004). The results of this study demonstrated that age, the number of months paddling, and the number of endurance paddling events completed were not predictors of the incidence of elbow and wrist injury.

At the whole muscle level, a reduction in intrinsic muscle force has been shown to occur with increasing age. It has also been demonstrated that alterations in muscle architecture and the mechanical properties of the tendons contribute to the reduction in intrinsic muscle force (Narici *et al.*, 2008). Age-related changes in the mechanical properties of the tendons include increased tendon stiffness and a 10-14% increase in the modulus of elasticity of the tendon, both of which may adversely affect the force to failure threshold of the tendon, and may thus predispose to tendon strain injury (Reeves, 2006).

It is therefore of interest to note that there were no significant differences in age between the symptomatic and asymptomatic groups in this study. It is acknowledged that age is one of numerous intrinsic and extrinsic factors that may contribute to the development of elbow or wrist pain. However, it is recommended that future studies should investigate the relationship between age-related alterations in the mechanical properties of tendons and the incidence of elbow and wrist injuries in K1 marathon paddlers.

Du Toit *et al* (1999) postulated that the repetitive load involved in paddling may lead to the adaptation of the forearm muscles and tendons, thereby providing a protective mechanism against injury. Adaptations associated with a repetitive training stimulus include increased fibroblastic activity, increased collagen production, thickening of collagen fibres and fibrils, and increased tropocollagen cross-links, with subsequent tendon hypertrophy. There is also improved alignment and orientation of tendon fibres, in order to optimally manage the high stress levels transmitted from the muscle to the tendon (LaStayo *et al.*, 2003).

These adaptations may be related to a reduction in the risk of injury to the musculotendinous unit due to an improvement in the ability of the musculotendinous unit to absorb increased amounts of energy during repetitive eccentric loading. In addition, there may also be an associated increase in the failure force threshold. These adaptations are collectively referred to as the conditioning effect of training, and may provide an explanation for the finding that paddlers with an increased exposure to the repetitive loading associated with endurance training and competition may be less prone to injury of the muscles and tendons of the forearm (LaStayo *et al.*, 2003).

6.3 Training factors

It is generally accepted that, for endurance athletes to remain competitive, regular training is essential in order to develop cardiovascular and muscle respiratory capacity (Brooks *et al.*, 2005). It is also proposed that a training-related increase in fitness level may protect the paddler from early fatigue during a canoe marathon. The paddler may therefore be able to maintain an optimal paddling stroke for a longer period during the race (Macleod, 2003).

Du Toit *et al* (1999) established that training distances of more than 100 km per week in the eight weeks preceding a canoe marathon was associated with a significantly lower incidence of injury. Similarly, in this study, the paddlers in the asymptomatic group trained significantly more days both during twelve off-season weeks and the twelve weeks preceding the Berg River Canoe Marathon than the symptomatic group.

The proposed long-term consequences of more training days may be explained by the cumulative effect of training, in which positive training adaptations may occur as a result of repetitive bouts of intense exercise. It is theorised that degenerative fibres, or fibres susceptible to stress may be destroyed by repeated bouts of exercise, whereas strong, healthy fibres that are able to withstand repetitive loading will survive the exercise stimulus. Repeating similar bouts of intense exercise also acts as a stimulus for new collagen synthesis. Collagen structure is therefore strengthened and protected from further damage (Schutte & Lambert, 2001). Further, after a repeated bout of intense exercise, the inflammatory response to exercise induced muscle damage is blunted. This results in lower levels of circulating inflammatory mediators, which ultimately results in less muscle damage (Clarkson & Hubal, 2002). Therefore, it may be hypothesised that the greater the number of separate training bouts, the greater the degree of protective adaptation of the musculotendinous units involved in paddling.

It should be noted that there were no significant differences between the asymptomatic group and the symptomatic group in this study with respect to the average weekly training hours or the number of minutes trained per session. All paddlers in this study paddled only one session per day. It is also acknowledged that no data on training intensity or training distance was obtained in this study, and therefore further comparison of the training characteristics between groups is limited.

6.4 Time-trial

In this study, the asymptomatic group was significantly faster over a 10km time-trial compared to the symptomatic group in the six-month period before the 2006 Berg River Canoe Marathon.

Endurance is defined as the length of time that a subject can perform work of a given intensity. Endurance depends on many factors, which include athletic willpower, aerobic capacity, anaerobic capacity, speed, muscle force, technical skill, psychological status, and the ability to use physiological potential economically (Bompa, 1999).

There are two types of endurance, general endurance and specific endurance. General endurance is defined as the subject's ability to perform work for a prolonged period of time and involves several systems, such as the central nervous system (CNS), cardiorespiratory system, and the neuromuscular system, as well as several muscle groups. Specific endurance depends on the technical and tactical characteristics of a particular sport (Bompa, 1999).

The development of endurance depends on a further factor called speed reserve. Speed reserve is the difference between the fastest time achieved over a distance much shorter than the competition distance (i.e. a 10km time-trial) and the same short distance during a longer race (i.e. the Berg River Canoe Marathon). A subject that is able to cover a short distance in a fast time will be able to cover longer distances at a lower speed with greater ease. Therefore, a subject with a higher speed reserve would expend less energy to maintain a given speed compared to a subject with a lower speed reserve (Bompa, 1999).

It is proposed that the significant difference between the time-trial results of the asymptomatic and symptomatic groups may be explained by this concept of speed reserve. The asymptomatic group, with faster time-trial times, may have been able to paddle the 2006 Berg River Canoe Marathon with relatively less energy expenditure. This may have resulted in lower stress and strain levels on the paddling musculature and therefore a lower incidence of injury.

It is further proposed that faster time trials may reflect the possibility that paddlers who did not sustain injuries were biomechanically more efficient and therefore did not place as much load on the elbows and wrists.

6.5 Paddling equipment

No significant differences between groups in paddle parameters such as the shape of the paddle shaft, paddle-shaft modifications or paddle length were observed in this study. In addition, there was no significant difference between groups in the type of boat used for the event. These results are supported by du Toit *et al* (1999) who reported no significant relationships between the incidence of injury and paddle or boat parameters, including the angle of the paddle-blade, the feather of the blade, paddle material, and the inherent stability of the boat.

6.6 Handgrip size and the paddle grip: handgrip size ratio

In tennis players who present with forearm pain, altering the grip size on the tennis racquet has been shown to reduce forearm stress. The Nirschl technique has been proposed as a method to aid in appropriate grip size selection (Nirschl, 1992; Reid, 1992; Peters & Baker, 2001; Whaley & Baker, 2004).

There were no significant differences between groups in paddle diameter and handgrip size in this study. Hatch *et al* (2006) studied the effect of tennis racquet grip size on forearm muscle firing patterns. The Nirschl technique was used to determine the recommended grip size of 16 asymptomatic college tennis players. Subjects were then required to perform a single-handed backhand groundstroke with racquets of three different grip sizes; the recommended grip size, an undersized by $\frac{1}{4}$ inch grip size, and an oversized by $\frac{1}{4}$ inch grip size. Muscle activity of the forearm musculature was recorded for the backhand stroke using each grip size. There were no significant differences in muscle activity between oversized, recommended, and undersized grips in the forearm musculature.

Hatch *et al* (2006) concluded that the clinical relevance of the above results is that ¼ inch of Nirschl's recommended sizing may not represent a significant risk factor for upper limb overuse injuries, such as lateral elbow tendinosis. The results of this study are in accordance with that of Hatch *et al* (2006), in that there were no significant differences between groups in left or right handgrip size. Clinically this is significant, as there is therefore no evidence to support the alteration of grip size in either the injured subject or for injury prevention, although further studies are needed.

Further, there were no significant differences between groups in the paddle grip: handgrip size ratio in this study. No other studies to date have looked at this ratio, and as such it is proposed that a larger sample size may be required to increase the statistical power of this ratio. Further, it is suggested that future study include measurement of the paddle that the paddler uses in training, as anecdotal evidence suggests that several paddlers may use different paddles for different training and racing conditions.

6.7 Weather and water surface conditions

Although no direct relationships between the incidence of injury and environmental conditions were established in this study, it may be postulated that the highest air temperature and therefore the increased air resistance on day two of the canoe marathon may have contributed to the increased incidence of injury on day two, compared to days one, three and four of the race when the air temperature and resistance were lower. Air becomes more viscous and provides more resistance to flow as air temperature increases (Hamill & Knutzen, 1995).

Anecdotally, paddlers in the 2006 Berg River Canoe Marathon also reported a strong head wind at the end of day two that may have provided further resistance to the forward movement of the paddler and canoe. This may provide a further explanation for the high incidence of injury on day two of the race.

The Berg River Canoe Marathon follows the Berg River towards the sea, and as a result the direction of river flow occurs in the same direction as the forward motion of the paddler and canoe. Therefore, increases in flow rate and water level may be associated with faster race finishing times.

The water level of the Berg River increased from days one to three of the 2006 Berg River Canoe Marathon, and there was a slight decrease in the water level on day four of the race. The flow rates of the water increased from days one to four of the race.

It may be proposed that the increased water levels and flow rates during the 2006 Berg River Canoe Marathon may have resulted in reductions in inherent velocity and drag, and paddling duration and intensity, with a subsequent decrease in repetitive use of the forearm musculature. These factors may be related to a lower predisposition to injury. This may provide an explanation for the higher incidence of injury of the forearm musculature reported by du Toit *et al* (1999), compared to the findings of this study.

7 CONCLUSION

The incidence of overuse tendinopathy of the elbow and wrist in K1 marathon paddlers during the 2006 Berg River Canoe Marathon was 11.81%. The results of this study suggest that the incidence of overuse tendinopathy is not related to the type or the dimensions of the equipment used, the previous injury history, the number of years paddling, the total number of endurance events completed, nor to performance on the 2006 Berg River Canoe Marathon. In addition, there was no significant difference in the paddle grip: handgrip size ratio between the symptomatic and asymptomatic groups. However, there were significant differences in training frequency and time-trial performances. Possible explanations for these differences include the "repeated bout" effect and speed reserve respectively

7.1 Limitations of this study and recommendations for future research

It is recognised that it is difficult to distinguish between DOMS, tendonitis or tendinosis during a sporting event such as the Berg River Canoe Marathon. The only definitive means to distinguish between the three conditions would be to perform a tendon biopsy or a magnetic resonance imaging (MRI) scan. DOMS may be investigated further by assessing plasma creatine kinase activity, and daily ratings of muscle pain.

It is acknowledged that a methodological concern in this study is the false positive diagnosis of lateral elbow tendinosis, due to the use of the passive test, passive wrist flexion with full elbow extension and pronation, as one of the tests for the diagnosis of lateral elbow tendinosis. Future studies should include an active test for diagnosis of lateral elbow tendinosis, such as resisted wrist or finger extension with the elbow in extension and pronation. This may help to strengthen the diagnosis of the lateral elbow tendinosis, and decrease the likelihood of a false positive during testing.

It is further acknowledged, that due to the paucity of literature on the reliability and validity of the tests clinically used to diagnose lateral elbow tendinosis, that all tests used to diagnose lateral elbow tendinosis in future studies should be used in a pilot study first to assess reliability and validity. This is particularly relevant in relation to the determination of intra-tester reliability.

Generally, a larger sample size would be recommended for future study, so that the variables such as paddler proficiency and grade of injury may be added to further quantify the results. It is also proposed that a larger sample size may help to identify an optimal paddle grip: handgrip size ratio for use in marathon paddling.

It is acknowledged that further information regarding training history is required. This is with specific reference to the speed reserve of each subject, therefore detail regarding training intensity and conditions should be explored in future studies.

There is a paucity of literature on the biomechanics of the paddling stroke, and literature presented in this study describing the paddling stroke itself, was obtained in part from a coaching manual (Almasi, 2004), from specific internet paddling sites and via anecdotal evidence. It is acknowledged that although these references are of low scientific quality, they were used in an attempt to provide a basic anatomical and biomechanical description of the paddling stroke, which is not available in the literature to date. It is apparent that due to the fact that there is presently little evidence regarding normal and abnormal paddling biomechanics, it is possible that some contributing factors to injury were not identified in this study. Further investigation of the biomechanics of the paddling stroke is indicated.

7.2 Clinical relevance of this study

This study demonstrated that there is approximately a 10% incidence of forearm pathologies associated with K1 marathon paddling. This provides important information to physiotherapists involved with the sport.

In addition, this study was not able to establish a relationship between the paddle grip: handgrip size ratio and the incidence of lateral elbow tendinosis and DeQuervains tenosynovitis. This has potential relevance in the physiotherapy management of these conditions.

Furthermore, increased training frequency and time trial performance were negatively associated with the incidence of injury. This may provide training guidelines for K1 marathon paddlers and coaches, and may facilitate a reduction in the incidence of injury.

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9 APPENDIX I - Ethical clearance certificate



UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • Facsimile [021] 406 6411
e-mail: prc@uct.ac.za

01 June 2006

REC REF: 174/2006

Ms W Viviers
Physiotherapy
Health & Rehabilitation Sciences

Dear Ms Viviers

PROJECT TITLE: THE RELATIONSHIP BETWEEN PADDLE GRIP: HANDGRIP SIZE RATIO AND THE INCIDENCE OF LATERAL EPICONDYLITIS AND WRIST TENOSYNOVITIS IN CANOEISTS DURING THE 2006 ISUZU BERG RIVER CANOE MARATHON

Thank you for submitting your study to the Research Ethics Committee for review.

DATE OF MEETING: 26 May 2006

DECISION: It is a pleasure to inform you that the Ethics Committee has **formally approved** the above-mentioned study.

Suggestion: Recommend that subjects be recruited prior to the start of the marathon at registration for all 3 studies. This should prevent confusion.
See attachment for methodological comments for the above study.

This serves to confirm that the University of Cape Town Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.

The Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

Please quote the REC. REF in all your correspondence.

lemjedi

Yours sincerely

DR. M. BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS



lemjedi

University of Cape Town

10 APPENDIX II - Recruitment notices

Physiotherapy Services at the 2006 Berg River Canoe marathon

Physiotherapists looking after you at the Berg!

Physiotherapy cover will be provided at the 2006 Isuzu Berg River Marathon by students and staff of the UCT Division of Physiotherapy. Some 40 plus physiotherapy students have committed themselves to attending the race this year and will be on hand to give treatment at the end of each day including day 4 to allow you to really relax at the end of the race! The students will work in teams with 10 treatment plinths available at a time. The students will be supervised by qualified physiotherapists. A R50 donation will be requested for half an hour of treatment.

Accompanying the undergraduate students will be three postgraduate Masters in Sports Physiotherapy students from the UCT/MRC Research Unit for Exercise Science and Sports Medicine and the UCT Division of Physiotherapy. They will be asking paddlers to participate in their research as they collect data on the incidence of injuries during the race and take measurements relating to any injuries, which may arise. In particular one of the students will be exploring factors relating to wrist extensor tendinosis (tennis elbow and tenosynovitis) and another will be exploring low back pain. You may be approached to participate in their research studies and we hope that you will take part as we try to increase the knowledge base around paddling injuries.

Physiotherapy will be available at registration where you can get pre-race massage and even book yourself in for daily attention over the course of the race. The researching students will also be on hand to give advice and begin data collection from those interested in participating.

ATTENTION: ALL BERG RIVER PADDLERS (e-mail)

The UCT Division of Physiotherapy and the MRC/UCT Research Unit for Exercise Science and Sports Medicine will be conducting a study at the 2006 Isuzu Berg River Marathon. We will be collecting information regarding the incidence of injuries and contributing factors to injuries as well as training and performance data among marathon paddlers. It is hoped that this information will provide a basis for future studies that aim to decrease the risk of injuries and improve performance in marathon paddlers.

We will have testing stations set up at registration and at the physiotherapy services at the end of each stage of the race. At registration we would appreciate 25 minutes of your time to complete a questionnaire, have your body composition measured and your lower back and wrist function assessed. Please bring your paddle with you to registration!

Thank you!

University of Cape Town

11 APPENDIX III - Informed consent form

INFORMED CONSENT FORM

Title of study: Paddle grip: handgrip size ratio and associated factors contributing to the development of lateral elbow tendinosis and DeQuervains tenosynovitis in K1 marathon paddlers during the 2006 Berg River Canoe Marathon.		
Name of investigator:		
Name of participant:		
Do you understand the implications of your involvement?	YES	NO
Have you read the subject information sheet?	YES	NO
Have you had the opportunity to ask questions?	YES	NO
Have you received satisfactory answers to your questions?	YES	NO
Have you received enough information about the study?	YES	NO
Who have you spoken to?		
Do you understand that you may withdraw from the study:		
- At any time	YES	NO
- Without giving any reasons for withdrawing	YES	NO
Do you agree to participate in this study?	YES	NO

Participant Signature

Date

Witness Signature

Date

Investigators Signature

Date

University of Cape Town

**UNIVERSITY OF CAPE TOWN
BERG RIVER CANOE MARATHON STUDY**

INSTRUCTIONS:

*This questionnaire is 6 pages long and consists of 7 sections

*Please read each question carefully, as it is important that we obtain accurate information.

*Please place information in the appropriate text box

e.g. Date of Birth: Day/Month/Year

*If a question is asked, please place an 'x' in the appropriate text box

e.g. To which ethnic group do you belong?

Black White Coloured Asian Indian Other

*Please answer all questions as truthfully as possible. All personal information will be kept strictly confidential

*If you have any questions, do not hesitate to contact us on:

Richard Feher 082 781 4403

Theresa Burgess 083 300 7763

Romy Parker 072 658 6836

SECTION ONE: PERSONAL DETAILS

- a. Name:
- b. Boat number:
- c. Contact number:
- d. Email address:
- e. Gender: Male Female

f. To which ethnic group do you belong?

Black White Coloured Asian Indian Other

g. Date of Birth: Day/Month/Year

h. Height: (cm)

i. Weight: (kg)

j. Dominant hand: Left Right

SECTION TWO: MEDICAL HISTORY

a. Have you ever been diagnosed with any of the following diseases?

Asthma Renal disease Liver/gall bladder disease
 Diabetes High blood pressure High cholesterol
 Inflammatory Arthritis Tuberculosis Coronary artery disease
 Thyroid disease Osteoporosis Bilharzia/Schistosomiasis
 Osteoarthritis Cancer Other

If other, please specify: _____

b. What medications did you, or do you take to treat these conditions?

Date	Disease	Medication

c. In the last 3 months have you taken any medication, such as:

Non-Steroidal Anti-Inflammatory Drugs (NSAID's)

Pain-killers / analgesics

Please specify: _____

d. Have you ever had surgery to any of the following:

- | | | |
|---------------------------------------|-----------------------------------|---------------------------------------|
| <input type="checkbox"/> Lumbar spine | <input type="checkbox"/> Shoulder | <input type="checkbox"/> Wrist / hand |
| <input type="checkbox"/> Neck | <input type="checkbox"/> Elbow | <input type="checkbox"/> Lower limbs |

Please specify: _____

SECTION THREE: TRAINING HISTORY

PLEASE ONLY INCLUDE YOUR HOURS OF PADDLING TRAINING

a. Routine practise schedule

- Average weekly training hours (hours/wk)
- Maximum weekly training hours (hours/wk)
- Minimum weekly training hours (hours/wk)
- Number of training days per week (days/wk)

b. In preparation for competition (e.g. Berg, Fish), if different to those above

- Average weekly training hours (hours/wk)
- Maximum weekly training hours (hours/wk)
- Number of training days per week (days/wk)

c. Do you warm up prior to training/competition?

- Yes No

d. If yes, how do you warm up?

- Light aerobic exercise
- Walking
- Jogging
- Stretches

e. If you use stretching, please specify which muscle groups:

- Lumbar spine Neck Elbow/wrist
 Thoracic spine/trunk Shoulder Lower limbs

f. How long, on average, do you hold each stretch?

- 5-10 seconds
 11-20 seconds
 21-30 seconds
 31-45 seconds
 46 seconds -1 minute

g. How many times, on average, do you stretch per week?

- Once a week Once a day
 Twice a week Twice a day
 3 times a week 3 times a day
 4 times a week >3 times a day

SECTION FOUR: PADDLING HISTORY

a. Number of year paddling:

b. PADDLING HISTORY

Please complete the following table:

Event	Number Completed	PB			Most recent performance		
		Year	Position	Time	Year	Position	Time
Berg							
Breede							

Dusi							
Fish							
Umko							
Drak challenge							
Vaal							
Lowveld croc							
8 km K1 timetrial							
10 km K1 Timetrial							

c. OTHER EVENTS

Please complete the following table:

Event	Number Completed	PB		Most recent performance	
		Year	Time	Year	Time
Two Oceans					
Cape Argus Cycle Tour					
Freedom Challenge					

SECTION FIVE: BOAT INFORMATION

a. Type of personal floatation device:

Polystyrene sheets Polystyrene balls Polystyrene strips

b. What boat are you using in the 2006 Isuzu Berg River Canoe Marathon?

c. Is this boat a slimline? Yes No

d. What boats do you train in (including surfski's)?

e. Paddle type:

f. Paddle length: cm

g. Hand protection used:

Gloves

Vaseline

Dubbin

Methyalate

h. Head protection used:

None

Cap

Helmet

SECTION SIX: PHYSICAL ACTIVITY PARTICIPATION

a. We would like to find out about any **other** physical activities that you participate in. Below the table are examples of different activities. Please list (by number), any other sports that you regularly participate in.

Type of Sport	Months per year	No. of sessions per week	Duration of each session (hr:min)	Total hours per week

Examples of sporting activities:

- | | | |
|--------------|------------------------|-------------|
| 1. Jogging | 10. Aerobic dance/step | 19. Yoga |
| 2. Swimming | 11. Martial arts | 20. Pilates |
| 3. Cycling | 12. Volleyball | 21. Dancing |
| 4. Walking | 13. Strength training | |
| 5. Squash | 14. Hiking | |
| 6. Badminton | 15. Rock climbing | |
| 7. Netball | 16. Tennis | |
| 8. Soccer | 17. Golf | |
| 9. Rugby | 18. Skating | |

b. Please indicate whether you have performed any of these specific strengthening exercises since January 2006:

Latissimus pull-downs

Upright rows

Behind-the-head military press

One-arm rows

Inclined flyes

Triceps dips with weight belt

Supine flyes

Triceps dips without weight belt

Wide-grip bench press

Chin-ups with weight belt

French curls

Chin-ups without weight belt

Kayak (abdominal) twists with weight belt

On behalf of the UCT Division of Physiotherapy and the MRC/UCT Research Unit for Exercise Science and Sports Medicine, thank you for taking the time to complete the questionnaire. The information will provide further insight into training, performance and injuries among marathon paddlers. In addition, it will provide a basis for future studies that aim to decrease the risk of injuries and improve performance in marathon paddlers.

13 APPENDIX V- Pilot study

Pilot study

Subject	Nirschl measurement 1 (mm)	Nirschl measurement 2 (mm)	Difference (mm)
1.	118	118	0
2.	100	101	1
3.	106	107	1
4.	106	106	0
5.	107	108	1
6.	104	104	0
7.	102	102	0
8.	98	98	0
9.	98	100	2
10.	113	113	0

Basic statistics - Pilot study

	Valid N	Mean	Standard Deviation
Measurement 1	10	105.2000	6.425643
Measurement 2	10	105.7000	6.165315
Difference	10	0.5000	0.707107

Measurement error = $\frac{\text{Standard deviation}}{\text{Mean difference}} \times 100$

$$\begin{aligned} &= \frac{0.707}{0.500} \times 100 \\ &= \mathbf{1.41\text{mm}} \end{aligned}$$

14 APPENDIX VI - Summary of results of the Shapiro-Wilkes test for normality.

VARIABLE	W - value	P - value
Age (years)	0.960	0.166
Body mass (kg)	0.962	0.203
Height (m)	0.990	0.973
Body mass index (BMI)	0.970	0.356
Total number of months paddling	0.796	0.00001
Number of Berg River marathons completed	0.693	0.00000
Number of other endurance events completed	0.871	0.0003
Average number of training days per week (12 off-season weeks)	0.930	0.017
Average number of training days per week (12 pre-season weeks)	0.862	0.0002
Average duration of each training session (12 off-season weeks)	0.940	0.035
Average duration of each training session (12 pre-season weeks)	0.944	0.047
Speed for time trial	0.932	0.018
Paddle length	0.905	0.004
Race results / position	0.931	0.178
Total race time	0.967	0.298
Speed / stage 1	0.921	0.008
Speed / stage 2	0.948	0.067
Speed / stage 3	0.964	0.238
Speed / stage 4	0.966	0.260
Average race speed	0.955	0.110
Left paddle diameter	0.902	0.002
Right paddle diameter	0.958	0.147
Left handgrip size	0.965	0.275
Right handgrip size	0.985	0.877
Left paddle grip: handgrip size ratio	0.981	0.764

Right paddle grip: handgrip size ratio	0.965	0.282
Dominant grip strength	0.983	0.877
Non-dominant grip Strength	0.974	0.612

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