

2010

An injury survey and biomechanical analysis of strength and conditioning exercises and maximal hiking test (HM180) in junior sailors

Wee Wing Kuen
Edith Cowan University

Follow this and additional works at: https://ro.ecu.edu.au/theses_hons



Part of the [Exercise Science Commons](#)

Recommended Citation

Kuen, W. W. (2010). *An injury survey and biomechanical analysis of strength and conditioning exercises and maximal hiking test (HM180) in junior sailors*. https://ro.ecu.edu.au/theses_hons/1218

This Thesis is posted at Research Online.
https://ro.ecu.edu.au/theses_hons/1218

Edith Cowan University

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study.

The University does not authorize you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following:

- Copyright owners are entitled to take legal action against persons who infringe their copyright.
- A reproduction of material that is protected by copyright may be a copyright infringement. Where the reproduction of such material is done without attribution of authorship, with false attribution of authorship or the authorship is treated in a derogatory manner, this may be a breach of the author's moral rights contained in Part IX of the Copyright Act 1968 (Cth).
- Courts have the power to impose a wide range of civil and criminal sanctions for infringement of copyright, infringement of moral rights and other offences under the Copyright Act 1968 (Cth). Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

An injury survey and biomechanical analysis of strength and conditioning exercises and maximal hiking test (HM₁₈₀) in junior sailors



Wee Wing Kuen

Bachelor of Science (Honours) Sports Science

This thesis is presented in fulfilment of the requirements for the award of
Bachelor of
Science (Sports Science) Honours

Faculty of Computing, Health and Science,
Edith Cowan University

Date of Submission

24th February 2010

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

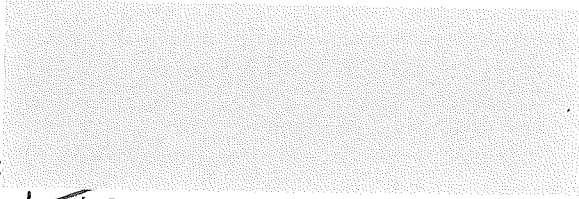
In Olympic sailing, the “hiking” position is adopted by sailors to counteract forces of the wind acting on the sail and improve boat speed. Hiking is widely regarded as the main physical challenge faced by single-handed dinghy sailors and senior dinghy sailors are known to have high rates of low back and knee injury. However, the extent of these injuries in junior sailors is yet to be reported. Although strength and conditioning exercises have been prescribed to enhance performance and prevent injury in sailors, little is known about these exercises in comparison to the demands placed on the sailor’s musculature whilst hiking maximally. Therefore, the first aim of this study was to determine the incidence of back and knee pain in a group of 29 male and female sailors from the Singaporean National Byte Class training squad ($n=12$) and the Singapore High Participation Group ($n=17$). Utilising this group of participants, the second aim of the study was to compare the levels of muscle (EMG) activation in four muscle bilaterally (rectus abdominus, superficial lumbar multifidus, vastus lateralis, and biceps femoris) in selected strength and conditioning exercises (leg extension, back squat, back extension, 30 second isometric hiking hold) and a three-minute maximal hiking test performed on a hiking simulator (called the HM₁₈₀). In the first part of this study, there was a low incidence of low back pain and knee pain (14.8% and 31% respectively). Results from the second part of this study indicated that both the leg extension and back squat are capable of providing an overload stimulus for the HM₁₈₀ test. However, higher than expected activation of the lumbar multifidus during the back squat exercise suggests that the leg extension exercise is an appropriate exercise for development of quadriceps strength whilst squatting technique is refined. When comparing the level of muscle activation in the strength and conditioning exercises to the HM₁₈₀ test, it was evident that the level of muscle activation was greater for; 1) the superficial lumbar multifidus in the back extension exercise, 2) the rectus abdominus in the hiking hold exercise, and 3) the vastus lateralis muscle in the back squat and leg extension exercises. Between-ability group and between-gender comparisons for the HM₁₈₀ test revealed that significant differences existed ($p=0.002$ and $p=0.027$ respectively). Findings from this study which examined a developmental sailing cohort has the potential to inform practical decision making in everyday exercise prescription.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

- (i) Incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education.
- (ii) Contain any material previously published or written by another person except where due reference is made in the text of this thesis; or
- (iii) Contain any defamatory material.
- (iv) Contain any data that has not been collected in a manner consistent with ethics approval.

I also grant permission for the Library at Edith Cowan University to make duplicate copies of my thesis as required.

Signature: 

Date:11/ 3/ 10.....

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Lord for His strength and providence throughout the course of my honours thesis, could not have done anything without Him.

To my dearest family, Wee Boon Keng, Magaret Chan and Wee Wing Kwong. Although they were not with me physically throughout this journey, their encouragement and concern has always been a source of support and motivation.

Mr Franco Siani, my pastor who has given me constant guidance and motivation to finish this thesis well and not cave in nor waiver when times were tough.

Dr Angus Burnett, my principal supervisor, who contributed to a big part of this thesis. He had the brains, while I did the physical work. A gifted individual who has a brilliant mind and the ability to put his thoughts and ideas across to my simple brain. Thank you for the opportunity you have given me and the grace you have shown me with my work. I have gained much more out of this than I thought I would.

To Dr Xie Wei, Mr Paul Oh Wee, Mr Julian Lim, Mr Derrick Sim and staff from the Singapore Sports Council, Mr Kelvin Tan and colleagues from the Singapore Sailing Federation and, Mrs Era Sidhu and her teachers from Mayflower Secondary School for their tremendous support. This thesis would not have been possible without your wonderful assistance.

Mr Jack Burns and Ms Nadija Vrdolijak for your wonderful logistical support both on campus and when I was away, your tireless work has not gone unnoticed by me. To Mr Joe Mate and rest of the ECU Sports Science postgraduates, thanks for the many conversations and guidance in the time spent with all of you. Keep persevering for your respective theses.

Lastly, to my fellow brothers and sisters in Christ who have always shown me their love and support each time I see you all. The journey has been challenging, but I am glad to have gone through it. Thank you again to all those who I have mentioned or have left out. Shalom.

TABLE OF CONTENTS

USE OF THESIS	ii
ABSTRACT	iii
DECLARATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
CHAPTER ONE	1
1.0 INTRODUCTION	1
1.1 Background	1
1.2 Significance of the Study	5
1.3 Purpose of the Study	5
1.4 Research Questions	6
1.5 Hypotheses	6
CHAPTER TWO	7
2.0 REVIEW OF LITERATURE	7
2.1 Introduction	7
2.2 The Sport of Sailing	7
2.3 Sports Science and Sports Medicine in Sailing	9
2.3.1 Injuries in Sailing	9
2.3.2 Physiology	11
2.3.3 Biomechanics of Sailing	12
2.3.4 Strength and Conditioning for Sailors	14
2.4 Summary	15
CHAPTER THREE	16
3.0 MATERIALS AND METHODS	16
3.1 Participants	16
3.2 Experiments Protocol	16
3.3 Data Collection	17

3.3.1	Participant Demographics, Height, Mass, and Injury Status	17
3.3.2	Visual Analog Scale (VAS) (those with back pain only)	17
3.3.3	Six Repetition Maximum (6RM) Testing	18
3.3.4	Strength and Conditioning Exercises and the Maximal Hiking Test (HM ₁₈₀)	19
3.3.4.1	Description of Strength and Conditioning Exercises	19
3.3.4.2	Maximal Hiking Test (HM ₁₈₀)	20
3.3.5	Surface Electromyography	21
3.4	Phase of Exercise Detection and Data Synchronisation	23
3.5	Data Analysis	23
3.5.1	Electromyography	23
3.5.2	Maximal Hiking Test (HM ₁₈₀)	24
3.6	Reliability Analysis	25
3.7	Statistical Analysis	27
CHAPTER FOUR		28
4.0	RESULTS	28
4.1	Low Back Pain and Knee Pain in Sailors	28
4.1.1	Incidence of Low Back Pain and Knee Pain	28
4.2	Electromyography Data	29
4.2.1	Strength and Conditioning Exercises	29
4.2.1.1	Leg Extension	29
4.2.1.2	Back Squat	30
4.2.1.3	Back Extension	31
4.2.1.4	Hiking Hold	32
4.2.2	Maximal Hiking Test (HM ₁₈₀)	33
CHAPTER FIVE		35
5.0	DISCUSSION	35
5.1	Introduction	35
5.2	Low Back Pain and Knee Pain in Junior Sailors	35
5.3	Level of Muscle Activation in Strength and Conditioning Exercises and the Maximal Hiking Test (HM ₁₈₀)	38

5.4	Maximal Hiking Moment	41
5.5	Limitations of the Study	41
5.6	Conclusions	42
5.7	Recommendations for Future Research	43
REFERENCES		44
APPENDICES		50
	APPENDIX A	50
	APPENDIX B	54
	APPENDIX C	56
	APPENDIX D	59

LIST OF TABLES

Table 1	Between-trial intra-class correlation coefficients, relative standard error of measurement (%SEM) for the EMG activity for rectus abdominus, bicep femoris, lumbar multifidus and vastus lateralis during the four exercises.	26
Table 2	Incidence (%) of low back pain and knee pain in Singaporean junior sailors.	28
Table 3	Level of low back pain: Current and past levels of low back pain for Singaporean junior sailors.	28
Table 4	Mean (\pm SD) hiking moment values of male and female participants in the national and high performance group and, pooled group and gender values for the HM ₁₈₀ test.	33

LIST OF FIGURES

Figure 1	Diagram of external forces acting on a) heeling and b) balanced dinghy.	2
Figure 2	Side views of a) short and b) long hiking positions.	2
Figure 3	Side view of the hiking simulator used in this study.	21
Figure 4	Screen shot of the LabVIEW data analysis program showing 1) raw EMG (red trace) and the corresponding linear envelope (white trace) and 2) critical time event data.	24
Figure 5	Force diagram of the hiking simulator in the HM ₁₈₀ test	25
Figure 6	Comparison of the normalized electromyographic data (%MVIC) of the vastus lateralis muscle for the concentric and eccentric phases of the leg extension exercise.	29
Figure 7	Comparison of the normalised electromyographic data (%MVIC) of the biceps femoris, lumbar multifidus and rectus abdominus muscle for the concentric and eccentric phases of the back squat exercise.	30
Figure 8	Comparison of the normalised electromyographic data (%MVIC) of the biceps femoris and lumbar multifidus muscle for the concentric and eccentric phases of the back extension exercise.	31
Figure 9	Comparison of the normalised electromyographic data (%MVIC) of the multifidus, rectus abdominus and vastus lateralis muscle for the isometric (ISO) hiking hold exercise.	32

Figure 10 Comparison of the normalised electromyographic data (%MVIC) of the rectus abdominus, vastus lateralis and lumbar multifidus muscles at three separate 30-sec windows (30-60s, 90-120s and 150s-180s) of the HM₁₈₀ test.

34

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Sailing is a sport undertaken by 16 million recreational and competitive participants worldwide. It boasts the oldest competing trophy in modern sport (the America's Cup), which predates the modern Olympics by 45 years (Allen & De Jong, 2006; Neville & Folland, 2009). Whilst open water yacht races can last up to several months, an Olympic sailing race is typically of an hour's duration and involves sailing 7-11 legs around marker buoys in three different directions in relation to the direction of the wind (Legg, Mackie, & Smith, 1999). Although Olympic sailing is a relatively short duration event, it requires high levels of physical exertion. Therefore, it is not surprising that previous studies have shown that elite sailors are aerobically fit athletes, with VO_{2max} values ranging from 50-60 ml/kg/min (Bojsen-Møller, Larsson, Magnusson, & Aagaard, 2007; Castagna & Brisswalter, 2007; Larsson et al., 1996). In addition, Olympic sailors possess well-developed levels of strength and strength endurance due to the unique demands of the sport (Bojsen-Møller et al., 2007; Legg et al., 1997; Wright, Clarke, Niinimaa, & Shephard, 1976). Specifically, a manoeuvre called "hiking" is considered to be the most demanding aspect of Olympic class sailing (Felici, Rodio, Madaffari, Ercolani, & Marchetti, 1999).

The purpose of the sailor adopting a hiking position on the windward side of the boat is to keep the sailing dinghy upright. This is done by counterbalancing the forces of the wind on the sail (termed the heeling force) through developing a "righting moment" which is generated by a combination of the sailor's bodyweight and the length of their body extended off from the boat (Tan et al., 2006). An increased righting moment enables the dinghy to capitalize upon drag forces acting on the sail, which in turn, creates greater dinghy speed (Aagaard et al., 1998; Legg et al., 1999; Sekulic, Medved, & Rausavljevi, 2006). The abovementioned forces are shown in Figure 1a and 1b.

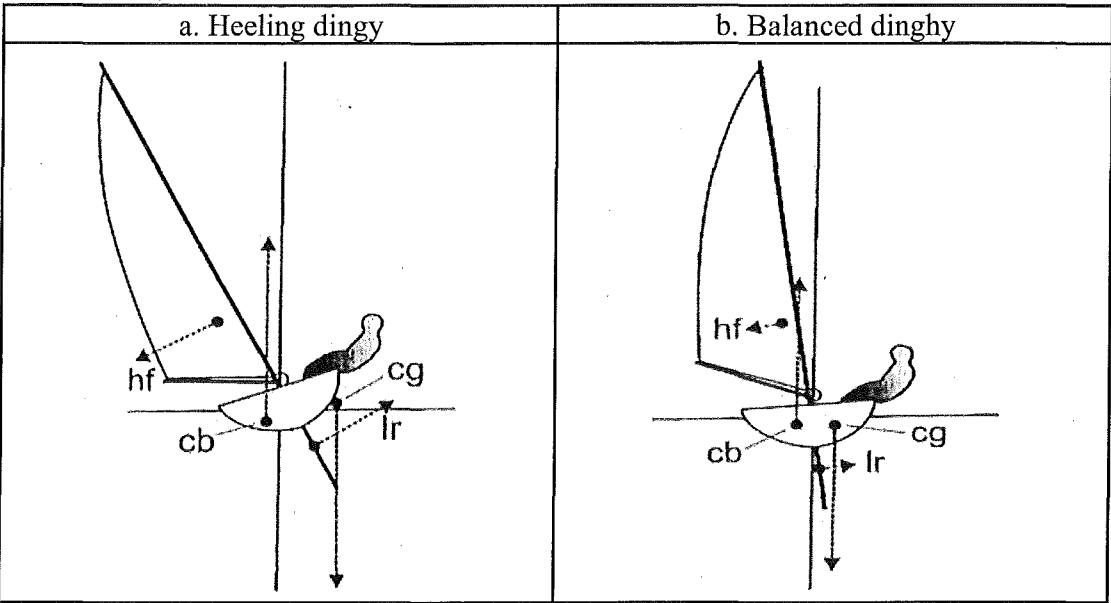


Figure 1. Diagram of external forces acting on a) heeling and b) balanced dinghy (Adapted from (Bojsen-Møller & Bojsen-Møller, 1999)) (hf = hiking force, cg = centre of gravity, cb = centre of buoyancy, lr = lateral resistance) .

Two hiking positions are typically used in Olympic sailing. These include the short hiking position (Figure 2a), where the trunk is kept rigid whilst the knees and hips are flexed and the long hiking position (Figure 2b), where the trunk, hips and knees are relatively extended. These hiking positions are utilized in downwind and upwind conditions respectively (De Vito, Di Filippo, Felici, & Marchetti, 1993; Sekulic et al., 2006). Whilst in the hiking position, the sailor has three points of contact with the side-deck; the harness of the ankles by a foot strap, the posterior side of the legs on the internal boat side-deck and the external side-deck of the boat (Castagna & Brisswalter, 2007; Vogiatzis, Spurway, Jennett, Wilson, & Sinclair, 1996). Depending on technical or environmental factors, the hiking position can be either static or dynamic in nature (Felici et al., 1999; Spurway, 2007).

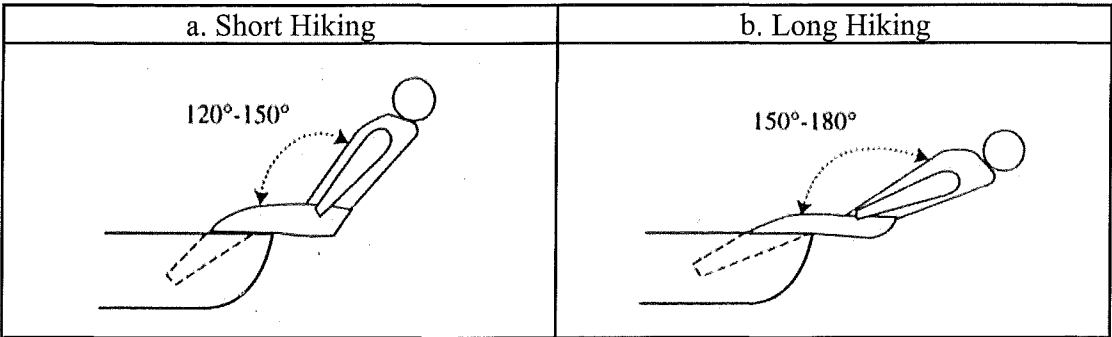


Figure 2. Side views of a) short and b) long hiking positions (Adapted from (Sekulic et al., 2006)).

Due to an increased level of interest from those involved in the Olympic sailing classes, the amount of research conducted in this area has increased over the last 15 years (Allen & De Jong, 2006). However, conducting investigations into sailing provides some unique challenges to the researcher. For example, there are a number of vessels of different weight and length specifications namely; the double-handed classes (Mistral, Tornado, 470, 49er) and the lighter solo classes (Laser, Europe, Finn). Furthermore, in the 2010 Youth Olympic Games, the Byte class has been selected as the girls and boys single-handed class. Another obstacle in sailing research is the difficulty in obtaining the external forces acting on the sailor and boat whilst actually sailing, (e.g. hiking moment, wind shearing force on the sails and drag force on the boat) (Mackie, Sanders, & Legg, 1999; Mackie & Legg, 1999). This is further compounded by the different hiking positions used, and various roles adopted by the sailor, which are dependent upon sailing class (Allen & De Jong, 2006). Another difficulty faced in sailing research is the constant change in environmental factors (e.g. fluctuations in the strength and direction of the wind and wave motion) (Bojsen-Møller & Bojsen-Møller, 1999). In view of the aforementioned challenges, it has been difficult to examine factors that may be predictive of injury and related to higher levels of performance (Neville & Folland, 2009).

In an attempt to address some of these problems, sailing simulators have been used in recent years in the laboratory environment to better control confounding factors during data collection (Gale & Walls, 2000). This development has allowed researchers to replicate factors such as boat position (Boyas, Maïsetti, & Guével, 2009; Gale & Walls, 2000) and orientation (Blackburn, 1994; Putnam, 1979), as well as better controlling the measurement of kinetic variables such as torque generated whilst hiking and forces exerted on the sailor's foot strap (Mackie & Legg, 1999). One such study (Tan et al., 2006), found that maximal hiking performance measured on a hiking dynamometer over three minutes (the so-called HM₁₈₀ test), was associated with better results in a race. Data resulting from a controlled laboratory environment may lead to a better understanding of the physiological and biomechanical demands of the sport (Castagna & Brisswalter, 2007; Spurway & Burns, 1993) as well as allowing the evaluation of sport-specific factors that lead to better performance in the junior or elite sailor (Bojsen-Møller et al., 2007).

Due to the physical demands of Olympic sailing, injuries are common. However, in the current literature there has been minimal reporting of injury statistics. One such report was a questionnaire-based study, which examined 22 elite New Zealand Olympic Class sailors, ranging from 17 to 36 years (Legg et al., 1997). The study reported an injury rate of 0.2 per year. In another study examining elite Brazilian sailors (Moraes et al., 2003), the lumbar spine was reported as the most frequently injured area (45%) with knee injuries also being considered as common (22%). Examination of the incidence of low back pain (LBP) in junior sailors is of importance as the biggest risk factor of LBP is reported to be a previous episode of LBP (Burton, 2005; Hestbaek, Leboeuf-Yde, Kyvik, & Manniche, 2006). Furthermore, the incidence of knee injuries in junior sailors has yet to be reported.

One of the possible avenues for preventing injury in sport is through the appropriate design and implementation of strength and conditioning programs (Cockerill, 1999; Cockerill & Taylor, 1998). With reference to sailing, previous authors have reported the main sites of muscle activation and the prime synergists involved in hiking (Allen & De Jong, 2006; Neville & Folland, 2009) and this has been determined using surface electromyography (EMG) (Boyas et al., 2009; Sekulic et al., 2006; Vangelakoudi, Vogiatzis, & Geladas, 2007). Findings from these studies have revealed that the main muscles / muscle groups of interest in sailing are: the quadriceps, hamstrings, paraspinal muscles and the abdominals. These muscles and muscle groups are believed to work synergistically when the sailor is in the hiking positions to stabilise the body whilst producing the righting moment (Sekulic et al., 2006). To hold such a position requires high levels of muscle activation. For instance, previous research has found that highly skilled sailors, who produce high levels of hiking performance, have stronger quadriceps (isometric-eccentric knee extensor strength) and trunk musculature (maximal concentric trunk flexor-extensor strength) when compared to highly strength-trained national team volleyball players (Bojsen-Møller et al., 2007). Further, sailors have been shown to have high levels of leg strength even though they do not systematically train their leg musculature (Aagaard et al., 1998; Blackburn, 1994; Bojsen-Møller et al., 2007). This adaptation may be due to the many hours of sailing training and competition (Legg & Mackie, 2000).

Further, the investigation of Vangelakoudi and associates (2007) found that the best-trained sailors exhibited a superior capacity to resist the development of quadriceps

muscle fatigue. This may be important as in a study where the temporal patterns of Olympic dinghy racing were investigated (Legg et al., 1999), sustained hiking was found to last no more than 21 seconds, before the sailors changed to an extended or upright position. Although research has been conducted and recommendations have been made on the strength and conditioning of sailors to improve their hiking performance, there is still a lack of knowledge pertaining to sailing-specific exercises and how they relate to superior hiking performance.

1.2 Significance of the Study

With the increased interest in the Olympic Sailing, the sport has garnered greater financial support. Consequently, the standard of competition has also risen steadily, with higher performance attributes expected from sailors. It is of importance for sailors to keep themselves injury free whilst maximizing performance and this is especially important for junior sailors who form the competitive base of the sport and who have the potential to be the next generation of elite athletes. In the current literature, there is still a lack of clear understanding of low back and knee injury patterns in junior sailors and a paucity of literature pertaining to the examination of strength and conditioning exercises prescribed to sailors. By examining key strength and conditioning exercises prescribed to junior sailors and comparing the level of muscle activation evident in these exercises to those generated in a simulated maximal hiking test (HM₁₈₀), this may improve knowledge to enhance performance and possibly inform strategies to prevent injury in the sport. Such a study is of significance to coaches, sports scientists and rehabilitation professionals.

1.3 Purpose of the Study

The purpose of this study is twofold. Firstly, to determine the incidence of low back and knee pain in a group of high-level junior Singaporean Byte class sailors and secondly, to compare the level of muscle activation in selected lower limb and trunk muscles during four selected strength and conditioning exercises, and a maximal hiking test.

1.4 Research Questions

The research questions of this study were: -

- i. What is the incidence of low back and knee pain in a group of high-level junior Singaporean sailors?
- ii. Is there a difference in the level of muscle activation between selected lower limb and trunk muscles (rectus abdominus, superficial lumbar multifidus, vastus lateralis and biceps femoris muscle) during the performance of strength and conditioning exercises (leg extension, back squat, back extension and hiking hold) in junior sailors?
- iii. Is there a difference in the levels of muscle activation in selected lower limb and trunk muscles in a maximal hiking test (HM₁₈₀) and selected strength and conditioning exercises prescribed for junior sailors?

1.5 Hypotheses

- i. There will be a low incidence of low back and knee pain in a group of high-level junior Singaporean sailors.
- ii. The rectus abdominus will produce the highest level of muscle activation in both the 30-second isometric hiking hold and the maximal hiking test (HM₁₈₀).
- iii. Strength and conditioning exercises utilized by sailors will elicit higher levels of muscle activation when compared with the HM₁₈₀ test.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Introduction

The paucity of literature available concerning sports science in sailing is surprising due to the extent of participation in the sport (Neville & Folland, 2009). This lack of information may be due to the (false) impression that the sport is not particularly physical demanding. With the studies that have been conducted in this area the majority seem to have been carried out by health care professionals who happen to sail, or have sailed before, and have a keen interest to address any issues related to sailing (Allen & De Jong, 2006; Shephard, 1990). Nevertheless, in the last 15 years, the number of studies covering the various aspects of sailing has increased. The following literature review will provide background to the sport of sailing and will also present and discuss the findings relevant to; commons of injuries sustained in sailing, physiology of sailors, biomechanics of sailing and strength and conditioning exercises for sailors.

2.2 The Sport of Sailing

The sport of sailing appeals to a wide audience and this may be at the recreational and competitive levels (Neville & Folland, 2009). Due to reputable events like Olympic Sailing, the Volvo Ocean Race and America's Cup, the last two decades have witnessed a growth in the sponsorship, commercialisation and media interest (Allen & De Jong, 2006). Although basic technical knowledge is required to attain a certain level of competence in the sport, sailing has no restriction on age, sex or disability alike. Hence, the standard of competition has also risen steadily, with higher physical, technical and mental demands being placed on the sailors.

It has been stated by coaches and sailors alike, that racing feels like competing in a marathon on the physical level and strategising like a chess player on the mental level (Spurwary, 1999). During a typical Olympic sailing race an individual needs to; adapt to the ever-changing environmental conditions, closely observe the racing rules and tactics, and draw upon their physical strength, endurance and agility. The specific

biomechanical and physiological demands of Olympic sailing (in dinghies) differ when compared with sailboards, keelboats and large offshore boats (Bojsen-Møller & Bojsen-Møller, 1999). The latest vessel to join the solo category of Olympic sailing is the Byte class, which has been selected as the girls and boys single-handed. Currently, no studies have been conducted to investigate the physical and biomechanical demands for a byte class sailor.

All classes of Olympic boat racing are unrestricted in their movement, with the boats experiencing six degrees of freedom they being: three angular movements (yawing, rolling and pitching) and three translation movements (heaving, swaying and surging) (Bojsen-Møller & Bojsen-Møller, 1999). Further, the speed and movement of the boat are largely dependent upon the wind that is acting upon the main sail area and the ability of the sailor to balance and keep the boat upright (Cunningham & Hale, 2007). This requires the sailor to possess well developed aerobic capacity, strength and agility to be able to produce the righting moment to counter the heeling forces of the sail and anticipate the subtle shifts in the wind while racing. In addition to providing the righting moment (Tan et al., 2006), the sailor needs to pull on the controls of the main sail. This is known as “trimming” and in certain conditions this will be done vigorously in an action called “pumping”. The sailors hike to produce the righting moment by hooking their feet under a strap inside the boat, and by extending their bodies over the side deck on the windward side of the boat (Felici et al., 1999). Depending on the wind conditions experienced, the righting moment is provided by either the short or long hiking positions (Sekulic et al., 2006).

The short hiking position is utilized in off-wind (or down-wind) conditions where the contribution of the upper-body predominates. Due to the absence of favourable wind conditions, the main sails are pulled at regular intervals to reduce boat resistance and increase boat speed (Cunningham & Hale, 2007). Conversely, the long hiking position is employed at critical periods to; 1) gain an advantage at the starting line, 2) attempt to overtake another dinghy and 3) avoid being overtaken (Tan et al., 2006). The long hiking position is also executed during strong wind (up-wind) conditions, to counteract the heeling forces of the main sail (Sekulic et al., 2006).

Finally, the last element that may affect the outcome of any sailor's race are environmental factors such as the wind and wave conditions. Primarily, these are the

energy sources that propel the boat. Even in strong winds, well-conditioned sailors might be in danger of capsizing. As for wave conditions, factors such as viscous resistance from the water, induced drag (pressure acting on one side of the hull), form drag (due to the shape of vessel), wave resistance, tides and currents decrease the boat velocity (Shephard, 1990).

2.3 Sports Science and Sports Medicine in Sailing

2.3.1 Injuries in Sailing

Due to the aforementioned demands of the sport, injuries are common in Olympic sailing sport. Several studies have been conducted to determine the incidence of sailing injuries in various populations. The discipline of boardsailing has recently had reports of extensive injuries in the lower extremity and lower back regions (Dyson, Buchanan, & Hale, 2006). In a sample of 107 boardsailors, Dyson and co-workers (2006) reported that injuries occurred to the thigh and calf (22%), ankle and foot (31%), lumbar spine (23%) and shoulders (18%). The injury incidence observed was 1.5/person/year, with these injuries considered to be mainly due to adverse interactions with the equipment (Dyson et al., 2006). In some instances, severe injuries sustained in sailing have resulted in hospitalisation (Kalogeromitros, Tsangaris, Bilalis, & Karabinis, 2002).

In Olympic sailing, three studies have investigated the incidence of injury in sailors (Legg, Smith et al., 1997; Moraes et al., 2003; Ruschel et al., 2009). Legg and associates (1997) carried out a study which involved surveying 28 elite New Zealand Olympic sailors (from the Finn, Tornado, Laser, Europe, 470 and Mistral classes), ranging from 17 to 36 years, while they were preparing for the 1996 Olympic Games. An injury rate of 0.2 injuries/athlete/year was reported, with the lumbar spine being reported as the most frequently injured area (45%), followed by the knee (22%), shoulder (18%) and arm (15%) (Legg et al., 1997). Similarly, Moraes et al. (2003) conducted a study which examined 21 elite athletes from the Brazilian 2004 Olympic sailing team and it was reported that the lumbar spine as the area most commonly affected region (53% of participants), with the thoracic spine (41%) and the knee (34%) also being reported as commonly injured. Finally, Ruschel et al. (2009) investigated a total of 172 Brazilian Olympic sailors and other sailors of varying age and ability, and

reported the back and knee as the most commonly injured areas. Finally, Ruschel and colleagues (2009) reported that sailors who had a higher age mean and more practice time, were at an increased risk of injury, while the lowest incidence of injury was amongst children and adolescents.

Low back injuries in sport are believed to be due to a combination of factors such as; 1) overuse, 2) spinal postures that result in high mechanical loads (e.g. non-neutral postures), 3) poor physical preparation and 4) genetic predisposition (Nadler et al., 2001; Tse, McManus, & Masters, 2005; Vera-Garcia, Elvira, Brown, & McGill, 2007). In Olympic sailing, it has been postulated that the predisposing factor to low back injury is due to a weakness and lack of endurance in the abdominal musculature of sailors while hiking, resulting in a greater hip flexor muscle (iliopsoas) activity and loading (Blackburn, 1994). Hence, high tension of the iliopsoas muscle increases the compressive force on the intervertebral discs of the lumbar and sacral vertebrae, promoting lumbar lordosis (Spurway, 1999). In addition, a posterior shear force also occurs during hiking, thereby increasing the potential risk of chronic injury (Aagaard et al., 1998).

Apart from low back problems being the most commonly reported injury by sailors (Neville & Folland, 2009), knee injuries have been considered the second most prevalent musculoskeletal problem in sailors. During short hiking, where the knee is in relatively flexed posture (30-50° flexion), the anterior shear component of the quadriceps muscle adds additional strain to the anterior cruciate ligament (Bojsen-Møller & Bojsen-Møller, 1999). This is largely stabilised by the co-contraction of the hamstrings muscle, as seen in the study by Aagaard et al. (1998) where sailors exhibited a significant ability to stabilise their knee joint, despite extremely high quadriceps strength. As muscles become fatigued during a race, the ability for knee stabilization becomes susceptible and the knee becomes vulnerable to injuries (Aagaard et al., 1998). In long hiking, whilst shear forces exerted on the knee are reduced due to the relatively straight-leg position (Zheng, Fleisig, Escamilla, & Barrentine, 1998), the moment load about the knee joint is increased when compared to short hiking (Bojsen-Møller et al., 2007; Mackie et al., 1999). Incorrect foot positioning whilst hiking is also believed to be a predisposing factor to knee injury as accumulating fatigue causes the external rotation of both legs. This is believed to promote the overdevelopment of the vastus lateralis, possibly increasing lateral tracking of the patella. This may then increase the risk of chronic knee pain (Cockerill & Taylor, 1998). Conversely, with external rotation of the

legs, an increased activation of the vastus medialis, may lead to patellofemoral pain (Cockerill, 1999). The chance of knee injuries in sailors is further exacerbated by having to sustain a high moment load for long periods while hiking and exposure to cold weather conditions (Shephard, 1990).

2.3.2 Physiology

An Olympic sailing regatta consists of two to three races per day for 5-7 days. Although each race is of relatively short duration, high levels of physical exertion are required. Therefore, it is not surprising that previous studies have shown that elite sailors are aerobically fit athletes (Bojsen-Møller et al., 2007; Castagna & Brisswalter, 2007; Larsson et al., 1996). Based on Spurway's (2007) work, it has been suggested that hiking is characterised by sustained and restricted blood flow to muscles, which bear the main anti-gravity load. Previous studies (Castagna & Brisswalter, 2007; Vangelakoudi et al., 2007) supported this belief but concluded that extra oxygen demand is incurred due to the frequent changing of sides by the sailor to steer the dinghy round the racecourse. Cunningham & Hale (2003) reported that hiking was in fact a dynamic activity. The opposing findings of these studies may be due to the fact there were significant changes in the thigh position, and if the muscles were loaded and unloaded frequently or substantially (Spurway, Legg, & Hale, 2007). Interestingly, Castagna & Brisswalter (2007) found in their study that due to increased aerobic activity during sailing, oxygen consumption rate rose, without affecting blood lactate levels. Although the heart rate observed coincided with the range seen in aerobic based sports, a contrast in 50% of oxygen consumption rates were measured. Further, a common finding in the literature is that blood lactate concentrations for sustained maximal hiking is normally recorded at around 4-5 mmol.l⁻¹ (Castagna & Brisswalter, 2007; Cunningham & Hale, 2007). Hence, Spurway (1999) and Felici et al. (1999) described the hiking action as "quasi-isometric", due to the continuous adjustment of the muscle length to compensate for the heeling moment of the boat caused by wind changes and waves. Even though the solution to this debate would be determined through detailed physiological monitoring of elite performers during competition, nonetheless, this has never been feasible. Importantly, two studies that have been conducted on water; 1) where Legg and colleagues (1999) analysed the movement of elite sailors and 2) where Castagna & Brisswalter (2007) investigated the aerobic demand and blood lactate concentration in a

30 minute period of simulated upward sailing with a tacking performed every 2 minutes. A further analysis of these two studies would be encouraged to further explain the relationship between hiking, tacking strategies and energy expenditure during prolonged races.

2.3.3 Biomechanics of Sailing

Due to the unique demands of Olympic sailing, elite sailors are required to possess well-developed levels of strength and strength endurance (Bojsen-Møller et al., 2007; Legg, Miller et al., 1997; Wright et al., 1976). This is evident in previous research (Mackie et al., 1999) that quantified forces produced by the feet on the hiking strap and forces on the mainsheet of four Olympic class dinghies. In their study, Mackie and co-workers found that the peak level of muscle activation from the hiking strap exceeded 100% of maximum voluntary isometric contraction (MVIC), while mainsheet forces reached 40-50% of MVIC (Mackie et al., 1999). Further, knee extensors had the highest activation when the wind rose above 10 knots. Larsson et al.'s (1996) study examined elite male and female sailors over a 9-month period and revealed that greater levels of isometric trunk strength, hiking endurance, and arm endurance was evident in sailors when compared to non-sailors. Aagaard et al. (1998) proposed that hiking performance depended on maximal isometric-eccentric knee extensor strength. Furthermore, it seemed that maximal strength of trunk extensors, which possibly stabilize the lower back and spine, is considered as one of the factors to superior hiking performance. As mentioned briefly in section 2.3.1, Bojsen-Møller et al. (2007) found that high-level Olympic sailors exhibited quadriceps strength that was comparable to elite volleyball and table tennis players. However, the sailors in this study displayed hamstring strength that was less during isometric and eccentric contractions. The resulting decrease in the hamstring/quadriceps strength ratio could possibly predispose sailors to the risk of knee joint overload or injury (Bojsen-Møller et al., 2007).

As mentioned in section 2.2, the purpose of hiking is to keep the dinghy in a relatively upright position to either maintain or increase boat speed (De Vito et al., 1993). Whilst hiking, there are three points of contact with the side-deck; the harness of the ankles by a foot strap, the posterior side of the legs on the internal boat side-deck and the external side-deck of the boat (Maisetti, Guevel, Iachkine, Legros, & Briswalter, 2002). The

activity of hiking requires generally static activity of the knee extensors, and both static and dynamic action in the hip flexors and abdominals (Sekulic et al., 2006).

A challenge faced by sports scientists is to better analyse the hiking posture in Olympic sailing. This challenge is due to the constant change in environmental factors such as fluctuations in the strength and direction of the wind and wave motion (Allen & De Jong, 2006). In an attempt to address these problems, laboratory-based sailing simulators have been used to better control confounding factors during data collection. Using such a lab-based approach, Putnam (1979) examined resultant muscle torques required for hiking whilst Marchetti et al. (1980) investigated the EMG activation pattern of a number of muscles involved in hiking. From the simple set up utilized in the two previous mentioned studies, basic hiking simulators have evolved into a more complex dinghy simulator that can replicate the load of the mainsheet and rudder, into the hiking bench (De Vito et al., 1993). Next, a virtual reality dinghy simulator was created (Walls, Bertrand, Gale, & Saunders, 1998), then a dynamic dinghy ergometer that could simulate actual boat movement of a pre-recorded race was designed (Cunningham & Hale, 2007).

In recent times, the hiking moment produced via force plates has been investigated (Tan et al., 2006). These recent developments have given researchers several clear advantages. Firstly, hiking simulators can provide real-time feedback to sailors to assist in hiking maximally. Furthermore, the dynamometer gives a quantitative output for all out maximal hiking that can be used to track performance, to set benchmarks, and to serve as a laboratory-based testing for sailing. Next, the hiking dynamometer can help differentiate between an optimal posture versus a 'lazy posture', to prevent a misleading performance from occurring. Lastly, the hiking dynamometer has the ability to assess the effectiveness of dynamic hiking movements. One such study (Tan et al., 2006), found that maximal hiking performance measured on a hiking dynamometer over three minutes (the HM₁₈₀ test), was associated with better results in a race. Although, data resulting from a controlled laboratory environment has lead to a better understanding of the physiological and biomechanical demands of the sport, it would be of interest to reproduce a similar set-up in an on-water environment.

2.3.4 Strength and Conditioning for Sailors

Based on several studies undertaken using hiking dynamometers, previous authors have reported the main sites of muscle activation and the prime synergists involved in hiking (Allen & De Jong, 2006; Neville & Folland, 2009) and this has been determined using surface electromyography (EMG) (Boyas et al., 2009; Sekulic et al., 2006; Vangelakoudi et al., 2007). Findings from these studies have revealed that the main muscles / muscle groups of interest in sailing are: the quadriceps, hamstrings, paraspinal muscles and the abdominals. In addition, individuals who were found to have exhibited superior capacity to resist the development of quadriceps fatigue fared well in hiking endurance tests (Boyas et al., 2009; Sekulic et al., 2006; Vangelakoudi et al., 2007). The muscles and muscle groups (i.e. trunk, hips and thighs) of sailors are believed to work synergistically when in the hiking positions, in order to stabilise the body whilst producing the righting moment (Vangelakoudi et al., 2007). Additionally, Vangelakoudi and associates (2007) explained that better trained sailors would be expected to alternate recruitment between muscle groups and hence the ability to sustain the hiking hold longer, thus enhancing endurance time.

Previous literature has suggested, and agreed that due to the physical demands of sailing; one of the possible avenues for preventing injury in sport is through the appropriate design and implementation of strength and conditioning programs (Allen & De Jong, 2006; Neville & Folland, 2009; Shephard, 1990). However, there is a lack of literature examining strength and conditioning exercises prescribed to sailors. As mentioned previously, hiking is considered as the most demanding aspect of Olympic class sailing, therefore it requires training of the muscles specific to these activities (Felici et al., 1999). Through the outcomes of the force demands revealed through previous studies (Aagaard et al., 1998; Bojsen-Møller, Larsson, Magnusson, & Aagaard, 2003; Sekulic et al., 2006) physical conditioning programs may be designed more specifically to the demands of the boats being sailed. Some recommendations for strength and conditioning programs for sailors should include: maximal strength training, hiking endurance, whole-body aerobic training, weight gain (hypertrophy), agility, and coordination sessions (Bojsen-Møller & Bojsen-Møller, 1999). In order to ensure a superior performance in the long hiking position, greater emphasis should be placed on abdominal muscles as well as the hamstring strength to better stabilize the knee joint (Aagaard et al., 1998; Bojsen-Møller et al., 2007).

2.4 Summary

Due to the repetitive nature of activities involved in sailing (hiking, pumping, trimming), the possibility of chronic injuries especially is relatively high in Olympic sailing. This has been already been demonstrated in high-level sailors (Legg et al., 1997; Moraes et al., 2003; Ruschel et al., 2009). However, there is still a lack of clear understanding of low back and knee injury patterns in junior sailors.

As the ability to exhibit superior hiking performance is seen as a predictor of achieving excellent race results (Tan et al., 2006), the physiological, physical and biomechanical demands of hiking revealed through previous studies are of interest. Although research has been conducted and recommendations have been made on the strength and conditioning of sailors to improve their hiking performance, there is still a lack of knowledge pertaining to sailing-specific exercises and how they relate to superior hiking performance. With such knowledge, coaches and practitioners alike will therefore be able to propose strength and conditioning training programs with a better rationale to meet the needs of sailors.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Participants

In this study, 29 high-level junior Singaporean sailors aged between 14 and 16 years were recruited from the Singaporean National Byte Class training squad ($n=12$, 8 males, 4 females) and the High Participation Group ($n=17$, 9 males, 8 females). Mean (\pm SD) characteristics of male participants in this study were age 14.1 ± 0.7 years, height 167.8 ± 4.5 cms, mass 55.5 ± 7.7 kg and BMI 20.3 ± 3.6 . Females in this study were of age 14.3 ± 1.0 years, height 158.6 ± 6.8 cms, mass 51.1 ± 10.0 kg and BMI 19.7 ± 2.3 . The majority of the National Byte Class sailors had more than one year of extra sailing experience when compared to the high performance group. The national level sailors were participating in, on average, eight training sessions per week, when compared to their high performance counterparts who were participating in three training sessions a week.

Ethical approval was obtained from the Faculty of Human Research Ethics Committee of Edith Cowan University and the Singapore Sports Council prior to the commencement of this study. Due to the age of the participants, they and one of their parents or guardians were required to read the information letter, and sign the informed consent form (Appendices A and B respectively) before being permitted to participate in this study.

3.2 Experimental Protocol

In this study, there were two separate test sessions. In the first session, the maximum weight participants were able to lift for six repetitions (i.e. their 6RM) for two lower limb exercises (back squats and leg extension) was determined. This weight was used to set the load for these exercises in the second session. This session took approximately 60 minutes to complete for each participant. The second session lasted approximately 90 minutes and consisted of two distinct parts. In the first part of this session, questionnaires pertaining to participant's demographics and injury status (low back pain

and knee pain) were completed. Prior to the second (physical) part of this session testing, participants warmed up by cycling for approximately 5 minutes on an exercise bike and performed their usual stretching routine. Participants were then requested to undertake a short familiarization on the hiking simulator described in Section 3.3.4.2. EMG signals were then collected from selected lower limb and trunk muscles whilst participants performed four selected strength and conditioning exercises (leg extension, back squat, back extension and hiking hold). Each of these exercises was repeated three times and the order of testing was randomised to prevent any ordering effects. A two minute break was taken between sets to prevent fatigue. Finally, participants performed a single, three-minute maximal hiking test (HM₁₈₀) (Tan et al., 2006). Each of the test sessions was separated by at least 24 hours.

3.3 Data Collection

3.3.1 Participant Demographics, Height, Mass, and Injury Status

Firstly, participants were required to answer a series of questions on demographics, and whether they have experienced low back and/or knee pain (Appendix C). All participants also had their height and mass measured.

3.3.2 Visual Analog Scale (VAS) (those with back pain only)

Participants who reported having LBP, completed a visual analog scale (VAS) to assess their level of pain. The VAS consists of a 100mm horizontal line, anchored by word descriptors at each end, namely; “no pain” and “very severe pain” (See Appendix D). Participants indicated the level of low back pain they felt at the time of testing, the same time in the previous week, in the last episode when it occurred, the worst episode felt due to sailing or sailing related activities and the worst episode outside of anything related to training. This method of measuring pain has been widely used and has been previously found to be reliable and valid (Ogon, Krismer, Sollner, Kantner-Rumplmair, & Lampe, 1996).

3.3.3 Six Repetition Maximum (6RM) Testing

The leg extension and back squat exercises were commonly used exercises for National junior sailors during their strength and conditioning sessions at the Singapore Sports Council. To assess the participant's strength levels and to determine the intensity of exercise for EMG testing (see Section 3.3.5), a 6RM strength test based on NSCA guidelines (Beachle & Earle, 2000) was undertaken by participants in this study. Whilst there is some debate on the use/non-use of 1RM testing in adolescent athletes (eg. Christou et al., 2006; Faigenbaum et al., 2009; Mayhew, Hill, Thompson, Johnson, & Wheeler, 2007; Reynolds, Gordon, & Robergs, 2006) a 6RM testing protocol was used for two reasons they being 1) this number of repetitions was more in line with what was being performed in day-to-day training and 2) a squat rack/power cage (to maximise safety in the case of 1RM strength testing) was not available at the testing venue.

Participants from the national Byte class training squad had a minimum of six months resistance training experience, whilst the high participation group had no structured resistance training experience prior to participation in this study. However, prior to strength testing, the high participation group were provided with sufficient familiarisation to both these exercises.

Prior to the strength tests being undertaken, participants cycled for approximately 5 minutes on an exercise bike and stretched as required. The 6RM was recorded as the weight that could be lifted throughout the full range of motion using good form. End range for the back squat exercises was defined as when the top of their thighs was lower than the top of their knee joint. Due to the absence of a power cage and a need for a spotter, control of each repetition was ensured through video playback and observation from a mirror placed in front of the squat rack by the tester. While for leg extensions, end range was defined at the point where the participant's legs were horizontally straight. Before attempting the 6RM load, participants performed 10 repetitions with a relatively light load, then 8 repetitions with a heavier load, and finally a series of 6 repetitions was undertaken with increasing loads. A rest period of 3 minutes was taken between sets while a rest period of 10 minutes was set for between exercises. If the weight was lifted with the proper form, it was then increased by approximately 2.5–5 kg, and participants attempted another set. Typically, 5–7 sets were required to achieve the 6RM for both the leg extension and back squat exercises. Failure was defined as a

lift falling short of the full range of motion or participants being unable to continue due to fatigue. Communication between the participants and the investigator was always positive, and questions such as “How do you feel?”, “Is the weight light, medium or heavy?” and “Can you lift more?” were asked to aid in the progression of the 6RM trials. Participants were verbally encouraged to reach their maximum weight and were regularly reminded to maintain proper exercise technique.

Participants mean (\pm SD) 6RM testing results were 59.1 ± 17.3 kg and 40.8 ± 13.1 kg for leg extension, and 47.5 ± 15.7 kg and 32.3 ± 12.6 kg for the back squat for males and females participants respectively. When normalised to body mass index, relative strength values were 3.00 ± 0.80 and 2.05 ± 0.68 for leg extension, and 2.40 ± 0.64 and 1.61 ± 0.60 for the back squat for males and females participants respectively.

3.3.4 Strength and Conditioning Exercises and the Maximal Hiking Test (HM₁₈₀)

3.3.4.1 Description of Strength and Conditioning Exercises

Participants performed four exercises that are typically used in strength and conditioning sessions by junior sailors in Singapore. Each exercise was performed in three sets of three repetitions. These exercises were as follows:-

- i. Leg extension – This exercise was performed with participants in a leg extension machine with their feet firmly hooked under the padded bar. From a starting position of 90° of knee flexion, participants were required to fully extend their knees and then return to the starting position. Participants performed three repetitions of this exercise at the weight achieved for their 6RM strength test. The tempo for this exercise was two seconds for the concentric phase, one second hold, then two seconds for the eccentric phase (i.e. 2-1-2). The weight lifted during EMG testing was determined by the method outlined in Section 3.3.3. This exercise is used in strength and conditioning sessions to strengthen the quadriceps.
- ii. Back squat – This exercise was executed in the confines of a power cage, with participants performing back squats using an Olympic bar and weights. Participants were required to bend their knees and lower their body until the top

of their thighs was lower than the top of their knee joint. The end phase of this exercise was when the body was in an upright position with knees locked. Participants performed three repetitions of this exercise at the weight achieved for their 6RM strength test. The tempo for this exercise was 2-1-2. The weight lifted during EMG testing was determined by the method outlined in Section 3.3.3. This exercise is used to condition the quadriceps and hamstring muscles.

- iii. Back extension – In this exercise, participants adopted a supine position, with feet firmly secured by the padded rollers. The starting position was with the trunk flexed and relaxed over the end of the bench, subsequently their upper torso was raised until their hips and waists were fully extended. Participants then returned to the starting posture. Participants performed three repetitions of this exercise. The tempo for this exercise was 2-1-2. This exercise is used to condition the paraspinal muscles and the hamstring group.
- iv. Hiking hold – In this test, participants adopted a supine position on a hyperextension machine with feet firmly secured by the padded rollers with hamstrings resting on a thick pad. This posture was held for 30 seconds with an erect body position (long hiking position). Data were collected 10-15 seconds after the beginning of this exercise. This isometric exercise is used to condition the abdominal and quadriceps muscles.

3.3.4.2. Maximal Hiking Test (HM₁₈₀)

Participants performed a maximal hiking test (HM₁₈₀) using hiking postures similar to those adopted during Byte sailing. This test was performed on a hiking bench similar to that reported previously (Tan et al., 2006) however, the bench was reconfigured for the Byte class rather than the Laser class. The modifications to the hiking bench included having two force plates instead of one and these two components were separately mounted onto two force plates (Advanced Medical Technology Inc., model OR6-6-2000, MA, USA). These plates were in turn, secured to a metal plate (1m x 1m x 0.1m) (see figure 3). The average hiking moment produced by participants was determined from the hiking forces produced by the two components (each mounted separately on the two force plates) of the hiking bench. Participants were requested to hike maximally

for a period of three minutes and were allowed to adopt long or short hiking postures, jerk, crouch or alternate their body weight on either leg. However, when collecting data, long hiking postures were always used by participants.



Figure 3. Side view of the hiking simulator used in this study.

3.3.5 Surface Electromyography

Whilst participants performed selected strength and conditioning exercises and the HM₁₈₀ test, surface electromyography (EMG) signals were collected bilaterally from four muscles. These data were collected via a portable ME 3000 P8 data logger (Mega Electronics®, Kuopio, Finland). The muscles investigated and their specific electrode placements are outlined below:-

- i. Rectus abdominis (RA) - 1cm above the umbilicus and 2 cm lateral to the midline (Ng, Kippers, & Richardson, 1998).
- ii. Superficial fibers of lumbar multifidus (sLM) - At L5 and aligned parallel to the line between the posterior superior iliac spine (PSIS) and the L1-L2 interspinous space (Hermens et al., 1999).
- iii. Bicep femoris (BF) - Postero-lateral portion of the thigh, midpoint of ischial tuberosity and the lateral epicondyle of the tibia ((Hermens et al., 1999).
- iv. Vastus lateralis (VL) - 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella (Hermens et al., 1999).

Participant's skin was shaved, abraded and cleaned with alcohol to reduce skin impedance to below $5K\Omega$. Pre-gelled red-dot 20 mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN) were placed in a bipolar configuration parallel to muscle fibres. Raw EMG signals were acquired using the data logger at a sampling rate of 1000 Hz.

After the warm-up, participants performed a series of maximum voluntary isometric contractions (MVICs), for the purpose of EMG data normalisation. Participants were required to perform three repetitions of a five-second MVIC trial as follows:-

- i. Rectus Abdominus (RA) - To generate MVIC for the RA, participants were positioned supine with the legs bent at 45° and strapped with a belt. A resisted curl up with maximal manual isometric resistance applied in a symmetrical manner through the shoulders of the participant by the investigator (standing at the head end of the couch) was used for left and right rectus abdominis (Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004).
- ii. Superficial Lumbar Multifidus (sLM) - Participants adopted a prone position, hands on their neck and were asked to lift their head, shoulders and elbows off the examination table. Symmetrical manual resistance was provided to the scapular region by the investigator standing at the head of the participant (Dankaerts et al., 2004).
- iii. Vastus Lateralis (VL) – To generate MVIC for the VL, participants were strapped onto a leg extension machine with arms across their shoulders. A resisted knee extension with knees bent at 45° measured with a goniometer, applied in a symmetrical manner by the investigator (Lin, Hsu, Chang, Chien, & Chang, 2008).
- iv. Biceps Femoris (BF) – Participants adopted in a prone position with their knees flexed at 90° and hands on their neck. A resisted knee flexion with maximal manual isometric resistance was applied in a symmetrical manner from the participant's legs by the investigator (kneeling at distal end of the participant) was be used (Mohr, Pink, Elsner, & Kvitne, 1998).

All EMG data were collected and saved to file for later analysis.

3.4 Phase of Exercise Detection and Data Synchronisation

For the purpose of identifying the phases of participant's movement during the leg extension, back squat and back extension exercises (i.e. the eccentric and concentric phases), participants were filmed by a digital camera (25Hz) whilst performing these exercises (Canon Inc., Ota, Tokyo, Japan). To enhance the ability to determine these phases both quickly and reliably, a retro-reflective marker was placed on the padded bar for leg extension, at the end of the barbell for back squat and on the participant's ear for back extension. Each participant's video footage during these exercises was converted to digital file using Dartfish ProSuite 4.5.1.0 software (Dartfish Company, Fribourg, Switzerland) for further analysis. An auto tracking function of the software package was used to track the retro-reflective markers so that the start of the exercise, turn around point/transition and the end of the exercise were identified for each repetition for each of the above exercises. The time that these critical events occurred was recorded for use in the EMG analysis phase. EMG data was synchronised to the video records by triggering the illumination of an LED visible to the field of view of the video when EMG data collection began.

3.5 Data Analysis

3.5.1 Electromyography

For each of the strength and conditioning exercises and the HM₁₈₀ test, the main muscles of interest for EMG analysis were as follows; back extension (biceps femoris and lumbar multifidus), back squat (bicep femoris, lumbar multifidus and vastus lateralis), leg extension (vastus lateralis), isometric hiking hold (lumbar multifidus, rectus abdominus and vastus lateralis) (data collected 10-15 seconds after the beginning of exercise) and the HM₁₈₀ test (lumbar multifidus, rectus abdominus and vastus lateralis).

Raw EMG data were demeaned, full-wave rectified and low pass filtered at 4 Hz using a second order Butterworth filter to produce a linear envelope (Winter, 2005). EMG signals for each muscle were normalized to the MVIC obtained for that particular muscle in order to allow for comparison between the prescribed exercises. The MVIC value for each muscle was considered as the greatest mean value recorded for a 200 msec window of the linear envelope measured in any of the three MVIC trials for each muscle. Critical event data obtained (as described in Section 3.4) were used to identify the concentric and eccentric phases for each exercise in the EMG data (Figure 4). EMG data for the concentric and eccentric phases were then time normalized (0-100%) using cubic spline interpolation and the ensemble average was calculated. All analyses were conducted using a customized software program written in LabVIEW V8.5 (National Instruments, Texas, USA).

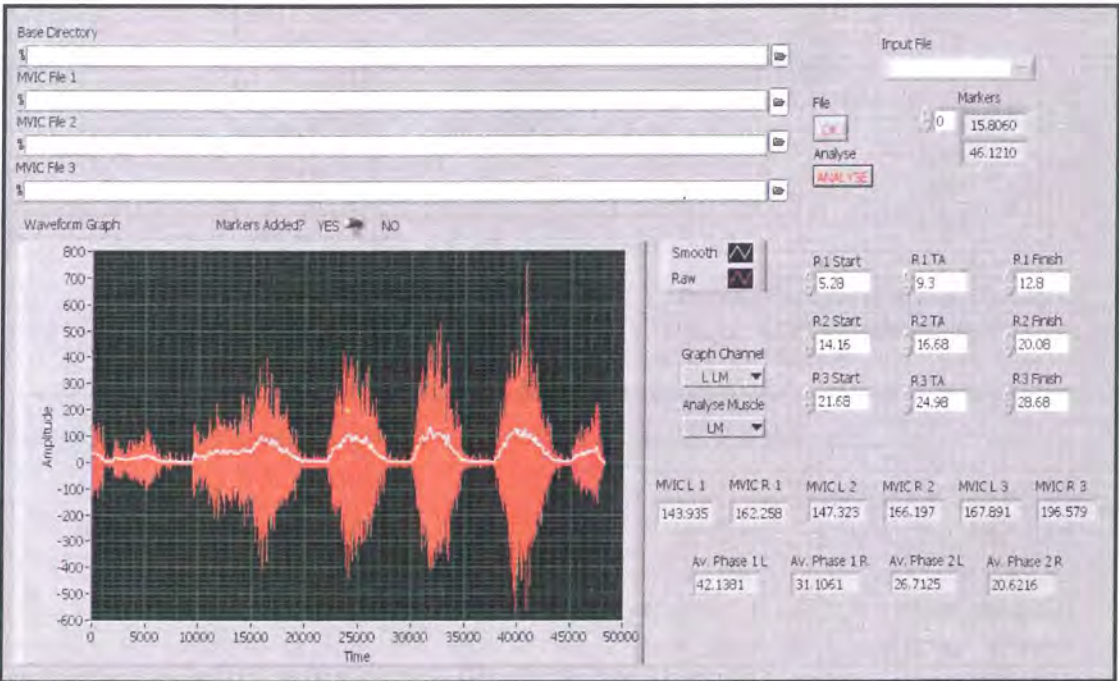


Figure 4. Screen shot of the LabVIEW data analysis program showing 1) raw EMG (red trace) and the corresponding linear envelope (white trace) and 2) critical time event data.

3.5.2 Maximal Hiking Test (HM₁₈₀)

The maximum hiking moment of the sailor during the HM₁₈₀ test, was produced by the following equation, $HM = HM1 + HM2$. HM was defined as total hiking moment

produced, HM1 as moment produced via the outside deck and HM2 as moment produced via the inside deck (Tan et al., 2006). HM1 was produced through the horizontal distance between the point at which the participant's knee came in contact with the edge of the outside deck and the foot strap, multiplied by the participant's mass. While HM2 was produced by the product of subject's mass and the horizontal distance between the participant's centre of mass to the edge of the outside deck (see figure 5).

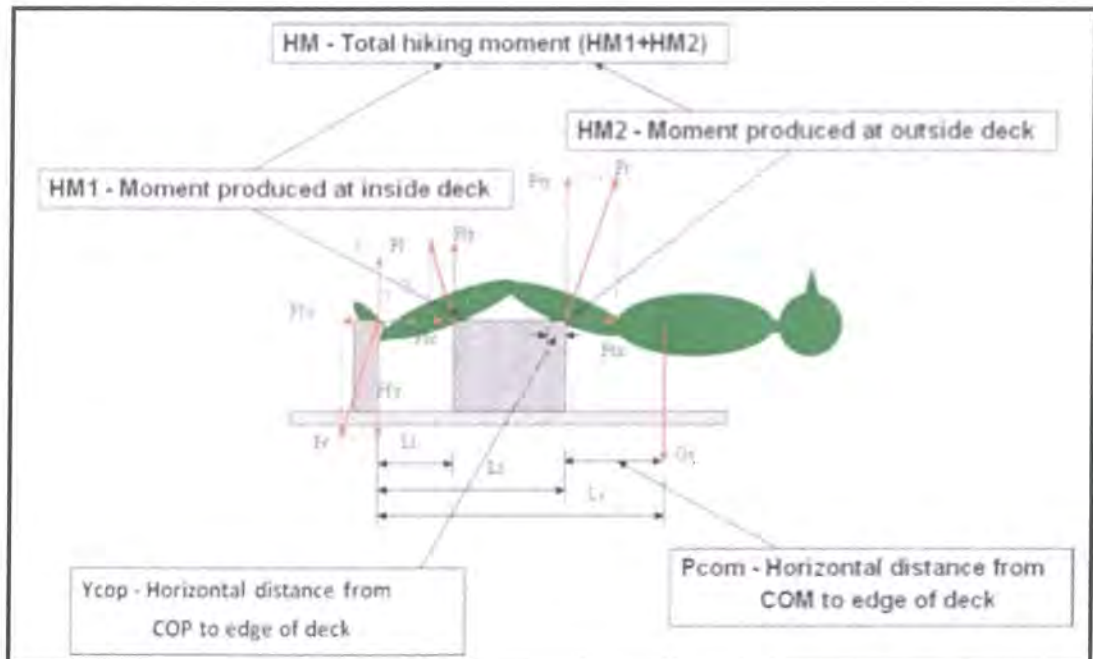


Figure 5. Force diagram of the hiking simulator in the HM₁₈₀ test

3.6 Reliability Analysis

Intra-class correlation coefficients calculated as a two-way mixed model and relative standard error of measurement (%SEM) values were calculated to determine the between-set reliability for the level of muscle activation. These data are detailed in Table 1. ICC values were considered as 0.75 = excellent reliability, 0.40–0.75 = fair/good reliability, and 0.40 = poor reliability. As data were shown excellent reliability as all ICC values were >0.75 (Shrout & Fleiss, 1979), data for the three sets of each exercise were averaged for the purpose of subsequent analysis.

Table 1. Between-trial intra-class correlation coefficients (ICC), relative standard error of measurement (%SEM) for the EMG activity for rectus abdominus, bicep femoris, lumbar multifidus and vastus lateralis during the four exercises (n=29) (L = left, R = right, HH = hiking hold, BS = back squat, BE = back extension, LE = leg extension, ISO = isometric, CON = Concentric, ECC = Eccentric).

Muscles	Side	Exercise	Activation	ICC	%SEM
Rectus Abdominus	L	HH	ISO	0.897	19.1
	R	HH	ISO	0.822	23.2
Bicep Femoris	L	BS	CON	0.954	11.9
		BE	CON	0.894	14.1
		BS	ECC	0.957	10.5
		BE	ECC	0.882	15.8
	R	BS	CON	0.903	11.4
		BE	CON	0.848	14.5
		BS	ECC	0.930	10.1
		BE	ECC	0.909	13.8
Lumbar Multifidus	L	BS	CON	0.933	8.6
		BE	CON	0.948	8.9
		BS	ECC	0.908	9.3
		BE	ECC	0.936	8.8
	R	BS	CON	0.911	8.6
		BE	CON	0.934	9.4
		BS	ECC	0.946	7.1
		BE	ECC	0.944	8.5
Vastus Lateralis	L	BS	CON	0.879	12.7
		LE	CON	0.947	8.2
		BS	ECC	0.846	13.8
		LE	ECC	0.882	13.3
		HH	ISO	0.764	23.8
	R	BS	CON	0.922	11.4
		LE	CON	0.960	7.5
		BS	ECC	0.918	11.2
		LE	ECC	0.873	12.1
		HH	ISO	0.786	23.4

3.7 Statistical Analysis

Firstly, descriptive statistics were compiled for the incidence of LBP and knee pain in the cohort in addition to the level of LBP. Independent t-tests were used to determine whether differences were evident for the level of muscle activation between the left and right sides of each muscle during each exercise. Where no significant differences were evident, left and right side data were averaged to provide a single representative value for each muscle.

Two sets of between-group comparisons were then conducted. Firstly, independent t-tests were carried out to determine whether any differences for the level of muscle activation between-gender were evident. Secondly, due to small sample sizes being evident in one group, Mann-Whitney tests were conducted to examine whether subjects with low back pain or knee pain displayed any differences for the level of muscle activation. The latter comparisons were only conducted for selected exercises (back squat, back extension and hiking hold). If no gender-effect or pain-effect was evident, data were again pooled.

A one-way ANOVA with repeated measures was used to determine whether significant differences existed in the level of muscle activation between the three time periods examined for the HM₁₈₀ test. If a significant difference was detected post-hoc tests (LSD test) were undertaken. Finally, descriptive statistics were used to compare the mean level of muscle activation for the HM₁₈₀ test with the data obtained from the specific strength and conditioning exercises examined. Data analysis was performed using SPSS 17.0 for Windows (SPSS Inc, Seattle, WA, USA). As this was an exploratory study adjustments of the alpha level were not carried out. Therefore, the level of significance was set at $p < 0.05$.

CHAPTER FOUR

4.0 RESULTS

4.1 Low Back Pain and Knee Pain in Sailors

4.1.1 Incidence of Low Back Pain and Knee Pain

Table 2 presents the incidence of low back pain and knee pain in Singaporean junior sailors. Data are reported for the current incidence, the monthly incidence, and whether pain was caused by sailing related training.

Table 2. Incidence (%) of low back pain and knee pain in Singaporean junior sailors.

Variable	% Incidence
Low Back Pain (Current)	13.8
Low Back Pain (Last Month)	27.6
Low Back Pain (Training)	24.1
Knee Pain (Last Month)	31.0
Knee Pain (Training)	20.7

Table 3 outlines the current level of low back pain (a score out of 10) and at other periods of time. These data show that if pain was experienced the pain level was relatively low and that the highest level of pain was experienced during training related activities.

Table 3. Level of low back pain: Current and past levels of low back pain for Singaporean junior sailors.

Pain Status	Level of Pain Reported
Current	1.5
Last Week	1.2
Last Episode	2.1
Worst Episode (Training)	4.6
Worst Episode (Non-Training)	3.2

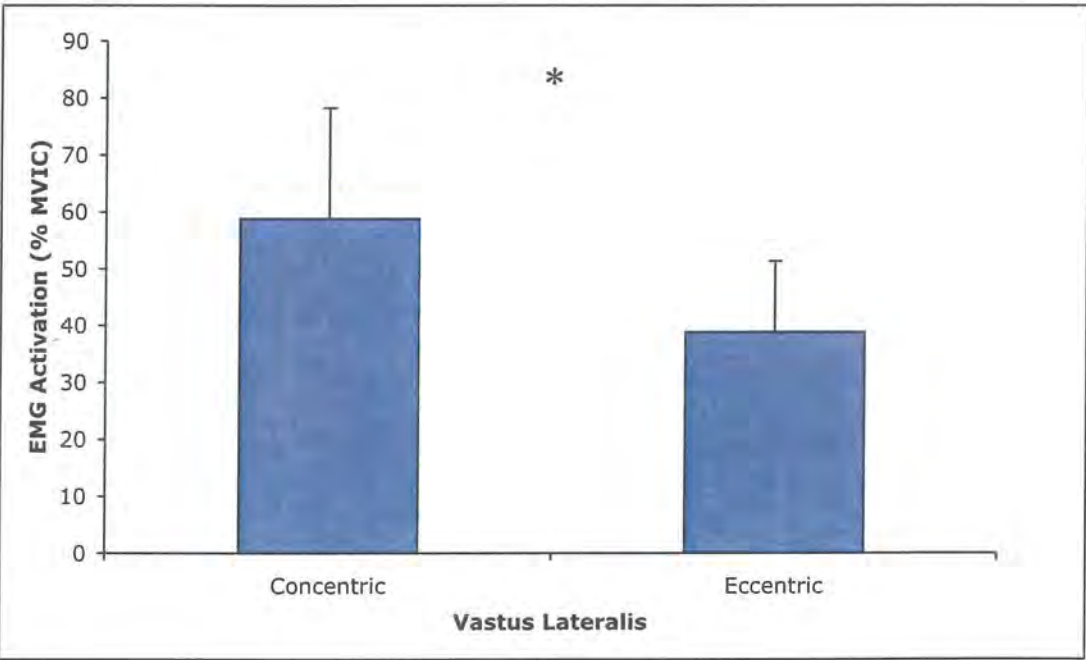
A score of greater than 3 out of 10 on the VAS has previously been considered to represent a moderate pain level (Collins, Moore, & McQuay, 1997). Moderate levels of pain were evident in the worst episode in training and non-training activities only. Otherwise, the level of pain reported in this group of junior sailors was low.

4.2 Electromyography Data

4.2.1 **Strength and Conditioning Exercises**

4.2.1.1 Leg Extension

Between-side comparisons for the level of muscle activation for the vastus lateralis muscle in the leg extension exercise for concentric and eccentric phases revealed that no significant differences existed ($t=-0.285$, $p=0.778$ and $t=0.482$, $p=0.633$ respectively). Furthermore, between-gender comparisons for the vastus lateralis muscle in the leg extension exercise revealed that no significant differences existed ($t=-0.312$, $p=0.757$ and $t=0.599$, $p=0.554$ for concentric and eccentric phases respectively). Therefore, these data were pooled for side and gender. The means (SD's) for concentric and eccentric phases in the leg extension exercise are presented in Figure 6. There was a significant difference ($p<0.001$) evident between the concentric and eccentric phases of this exercise.

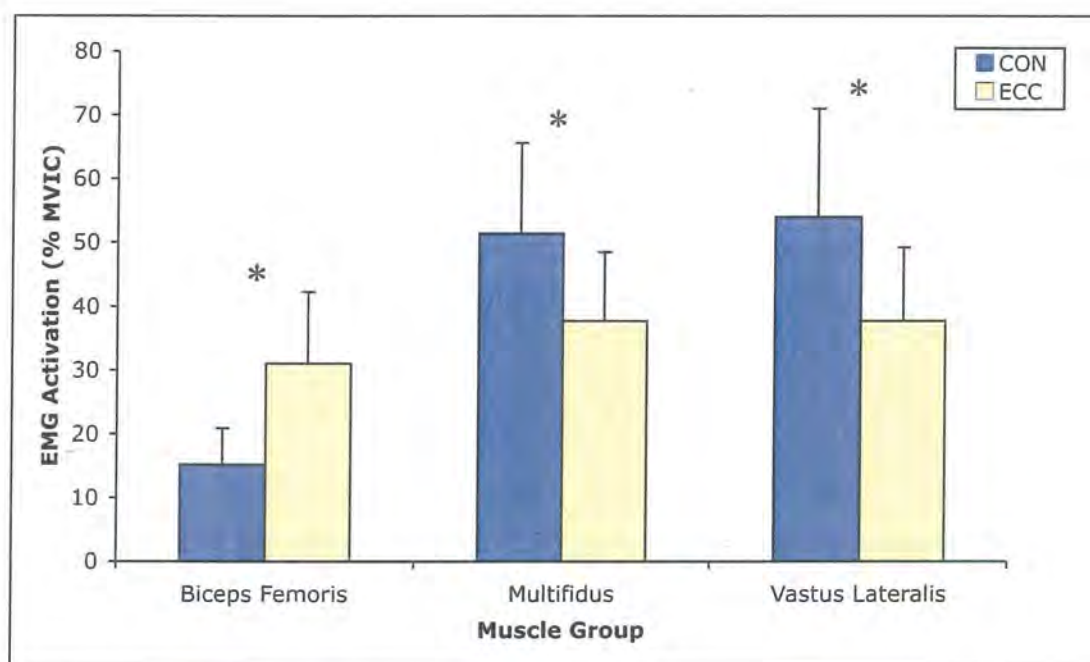


Note: * indicates a significant difference ($p < 0.001$) between the concentric and eccentric phases of the leg extension exercise

Figure 6. Comparison of the normalized electromyographic (EMG) data (% maximum voluntary isometric contraction [MVIC]) of the vastus lateralis muscle for the concentric and eccentric phases of the leg extension exercise.

4.2.1.2 Back Squat

Between-side comparisons for the level of muscle activation for the biceps femoris, lumbar multifidus and vastus lateralis muscles in the back squat exercise, revealed that no significant differences were evident for the concentric phase ($t=1.159$, $p=0.256$, $t=-0.149$, $p=0.882$ and $t=1.063$, $p=0.297$ respectively) or the eccentric phase ($t=0.473$, $p=0.64$, $t=-0.724$, $p=0.475$ and $t=0.736$, $p=0.468$). Between-gender comparisons for the biceps femoris, lumbar multifidus and vastus lateralis muscles exhibited no significant differences (p -value range =0.271-0.964). Also, no significant differences ($p<0.05$) were found for any pain comparison. As a result, these data were pooled for side, gender and pain. The means (SD's) for the muscles in the concentric and eccentric phases for the back squat exercise are shown in Figure 7. There were significant differences ($p<0.001$) evident for the biceps femoris, lumbar multifidus and vastus lateralis muscles between the concentric and eccentric phases of this exercise.

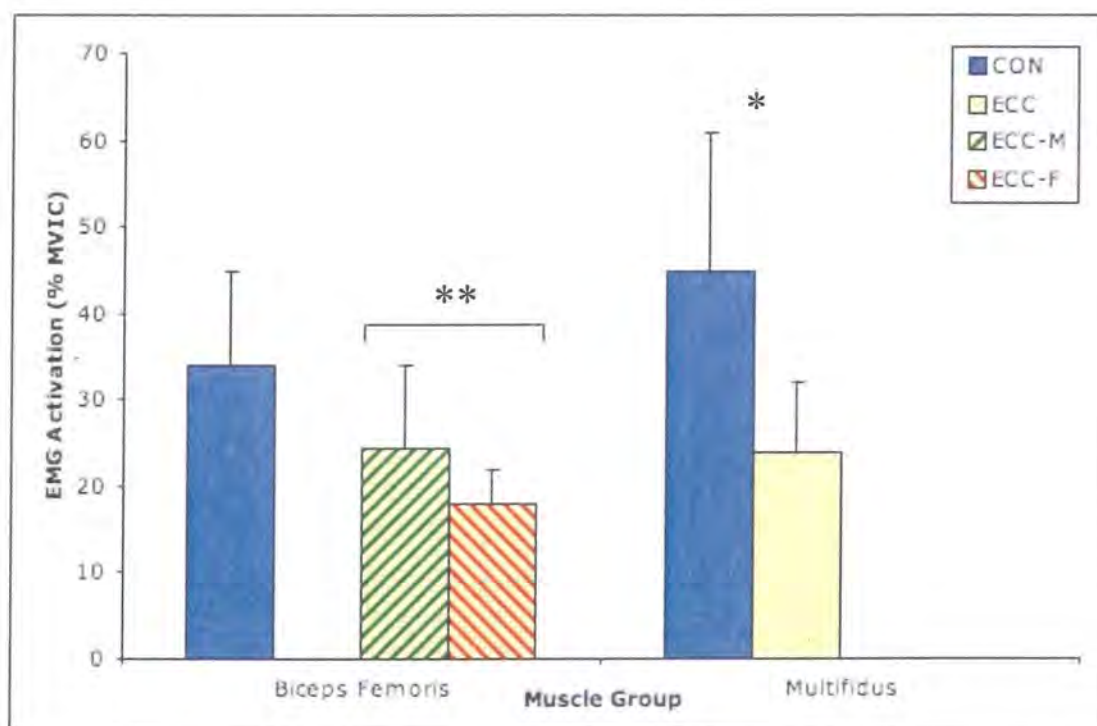


Note: * indicates a significant difference ($p < 0.001$) between the concentric and eccentric phases of the back squat exercise.

Figure 7. Comparison of the normalised electromyographic (EMG) data (% maximum voluntary isometric contraction [MVIC]) of the biceps femoris, lumbar multifidus and rectus abdominus muscle for the concentric and eccentric phases of the back squat exercise.

4.2.1.3 Back Extension

Between-side comparisons for the level of muscle activation for the biceps femoris and lumbar multifidus muscle in the back extension exercise indicated that no significant differences (p-value range = 0.144-0.794) for concentric and eccentric phases existed. However, between-gender comparison for the biceps femoris and lumbar multifidus muscles revealed that a significant difference was evident for biceps femoris in the eccentric phase of the exercise ($t=-2.364$, $p=0.027$). With the remaining comparison for the concentric and eccentric phases of the bicep femoris and lumbar multifidus muscles, no significant differences ($t=-1.817$, $p=0.08$, $t=-0.335$, $p=0.74$ and $t=0.044$, $p=0.965$ respectively) were shown. No significant differences ($p<0.05$) were evident for any pain comparison. Hence, all these data, except the eccentric phase of the bicep femoris, were pooled for side, gender and pain. The means (SD's) for the concentric and eccentric phases of the back extension exercise are shown in Figure 8. Significant differences were evident for the lumbar multifidus between the concentric and eccentric phase of the exercise.



Note: * indicates a significant difference ($p<0.001$) between the concentric and eccentric phases of the back extension exercise

Note: ** indicates a significant difference ($p=0.027$) between gender in the eccentric phase of the back extension exercise

Figure 8. Comparison of the normalised electromyographic (EMG) data (% maximum voluntary isometric contraction [MVIC]) of the biceps femoris and lumbar multifidus muscle for the concentric and eccentric phases of the back extension exercise.

4.2.1.4 Hiking Hold

Between-side comparisons for the multifidus, rectus abdominus and vastus lateralis muscle in the hiking hold exercise revealed that no significant differences ($t=-0.825$, $p=0.416$ $t=-0.54$, $p=0.594$ and $t=-0.657$, $p=0.517$ respectively) for this isometric exercise existed. Likewise, between-gender comparison for the rectus abdominus and vastus lateralis revealed that no significant differences ($t=1.855$, $p=0.075$, $t=1.667$, $p=0.107$ and $t=0.501$, $p=0.621$ respectively) occurred. No significant differences ($p<0.05$) were evident for any pain comparison. Therefore, these data were pooled for side, gender and pain. The means (SD's) for the isometric phase in the hiking hold exercise are presented in Figure 9.

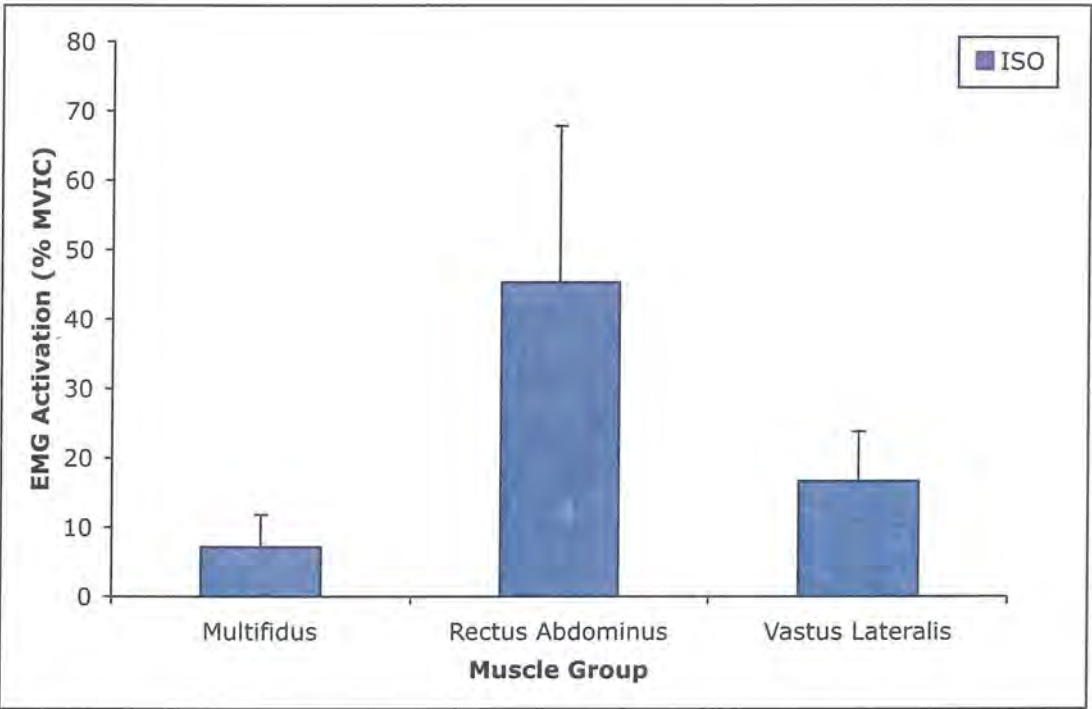


Figure 9. Comparison of the normalised electromyographic (EMG) data (% maximum voluntary isometric contraction [MVIC]) of the multifidus, rectus abdominus and vastus lateralis muscle for the isometric (ISO) hiking hold exercise.

4.2.2 Maximal Hiking Test (HM₁₈₀)

Between-ability group and between-gender comparisons for the maximal hiking (HM₁₈₀) test revealed that significant differences existed ($t=3.453$, $p=0.002$ and $t=-2.333$, $p=0.027$ respectively). Mean data for the maximal hiking moment produced are presented in Table 4.

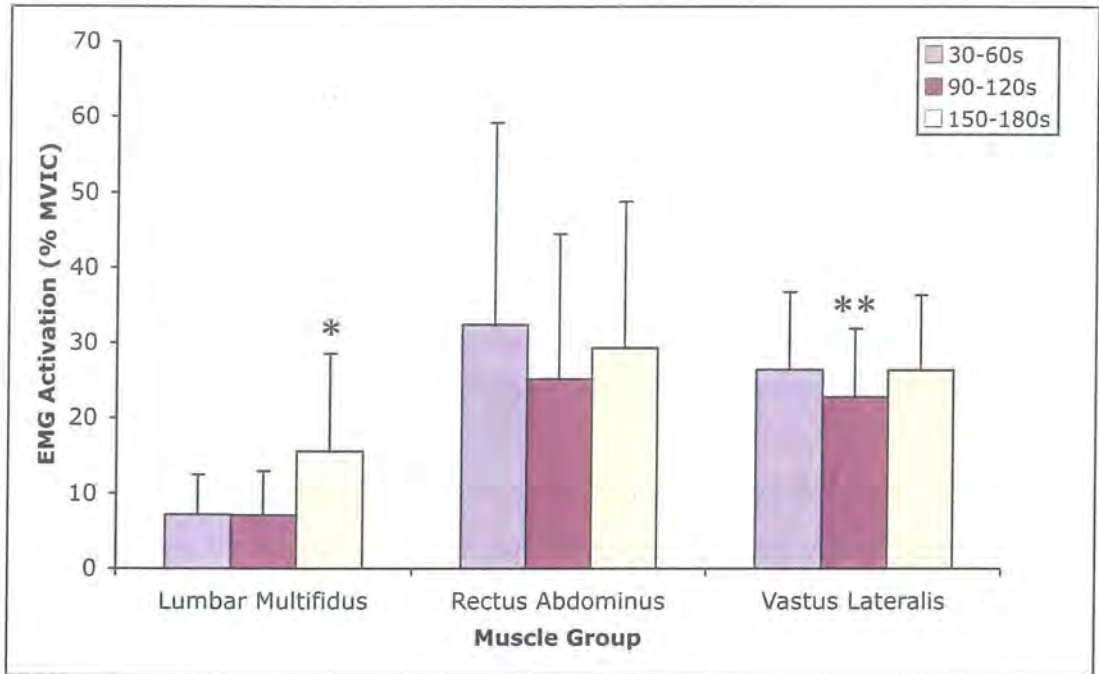
Table 4. Mean (\pm SD) hiking moment values of male and female participants in the national and high performance group and, pooled group and gender values for the HM₁₈₀ test. Units of measure were N.m.s.

	Male (n = 17)	Female (n = 12)	Pooled (Group)
National (n = 12)	86753.3 \pm 7605.9	69579.0 \pm 8667.7	81028.5 \pm 11349.3*
High Performance (n = 17)	67926.0 \pm 8641.8	63564.8 \pm 14948.1	65873.6 \pm 11837.8
Pooled (Gender)	76785.9 \pm 12509.2**	65569.5 \pm 13093.9	

Note: * indicates a significant difference ($p = 0.002$) when compared to the high performance group

Note: ** indicates a significant difference ($p = 0.027$) when compared to the female sailors

Between-side comparisons for the level of muscle activation in the rectus abdominus, vastus lateralis and lumbar multifidus muscle in the HM₁₈₀ test revealed that no significant differences (range of values =0.255-0.938) existed for the three time points examined. Similarly, between-gender comparisons for the rectus abdominus, vastus lateralis and lumbar multifidus muscle revealed that no significant differences (range of values =0.096-0.826) for the three time points occurred. No significant differences ($p<0.05$) were evident for any pain comparison. Consequently, these data were pooled for side, gender and pain. The means for the level of muscle activation during the three time points of the HM₁₈₀ test are presented in Figure 10. There was a significant difference ($F=27.214$, $p<0.001$) evident across time for the lumbar multifidus muscle. Post-hoc tests revealed that the 150-180s sampling period was significantly different to both the 30-60s and 90-120s sampling periods. Further, there was a significance difference ($F=9.815$, $p=0.001$) evident across time for the vastus lateralis muscle. Post-hoc analysis found that the 90-120s period was significantly different to the 30-60s and 150-180s time periods.



Note: * indicates a significant difference ($p<0.001$) for the 150-180s as compared to the 30-60s and 90-120s time periods of the HM_{180} test

Note: ** indicates a significant difference ($p=0.001$) for the 90-120s as compared to the 30-60s and 150-180s time periods of the HM_{180} test

Figure 10. Comparison of the normalised electromyographic (EMG) data (% maximum voluntary isometric contraction [MVIC]) of the rectus abdominus, vastus lateralis and lumbar multifidus muscles at three separate 30-sec windows (30-60s, 90-120s and 150s-180s) of the HM_{180} test.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

This study was designed in two parts. The first part determined the incidence of low back pain and knee pain in a group of high-level junior Singaporean Byte class sailors and the second part involved comparing muscle activation patterns in selected lower limb and trunk muscles during four selected strength and conditioning exercises, and a simulated maximal hiking test (the HM₁₈₀ test). In the second part of the study, only muscles that were expected to display high levels of activation during the strength and conditioning exercises and the HM₁₈₀ test were examined. With an increasing focus being placed on evidence-based practice in exercise and sport science, the quantification of muscle activation in training activities (such as strength and conditioning exercises) and target skills (such as the HM₁₈₀ test) is warranted.

As seen in Section 1.5 there were two hypotheses generated in this thesis. For the first part of the study it was hypothesised that, there would be a low incidence of low back and knee pain in a group of high-level junior Singaporean sailors. From data collected in this study, this hypothesis was accepted. In the second part of the study, the hypothesis was, that strength and conditioning exercises utilized by junior sailors would elicit higher levels of muscle activation when compared to the HM₁₈₀ test. As overload doesn't necessarily require statistical significant to be of importance (i.e. it is practically or clinically meaningful) a comparison-of-means statistical evaluation of this hypothesis was not conducted. Examination of the relevant descriptive data revealed that this hypothesis was also accepted. Other data aside from those relevant to the hypothesis were also described and compared in the results section and findings of interest are discussed below.

5.2 Low Back Pain and Knee Pain in Junior Sailors

In the sailing literature, the low back and knee have been considered as the two most frequently injured areas of the body (Neville & Folland, 2009; Shephard, 1990). In

previous studies examining senior sailors, the incidence of low back pain has been reported as 53% (Moraes et al., 2003) whilst the incidence of knee injury was reported to be 34% (Moraes et al., 2003). These injuries have been attributed to factors such as high mechanical loading on the body caused by environmental conditions relevant to sailing (i.e. strong winds and rough waters), poor hiking technique and inadequate leg strength (Neville & Folland, 2009). Due to the lack of literature examining low back and knee injuries in adolescent sailors, it was considered important to determine the incidence of these injuries.

In this group of athletes, the incidence of low back pain was relatively low which is an important finding as low back pain in adolescence is considered the biggest risk factor for low back pain in late adolescence and adulthood (Burton et al., 2005). The point prevalence of low back pain for this group of Singaporean junior sailors of 14.8% was far lower than the 47.5% point prevalence reported in a large group of Caucasian schoolgirl rowers aged between 14-17 years (Perich, Burnett, & O'Sullivan, 2009). However, this figure was similar to the 15.5% point prevalence reported for the 14-17 year old active non-rowing control group reported by Perich and co-workers (2009) and the approximate 15% point prevalence of low back pain reported for active 3rd year junior high school students in a Japanese city (Sato et al., 2008). The levels of low back pain reported were also low, with moderate levels of pain only being reported during their worst episodes.

Several possible explanations may account for why the incidence of LBP was low in this study. Low back pain in sporting pursuits is typically due to factors such as high mechanical loads produced by the activity, poor physical preparation and/or overuse (Ranson et al., 2008). Further, a person's genetics has also been considered as being of importance (Loud, Micheli, Bristol, Austin, & Gordon, 2007). It could be speculated that low back pain is not prevalent in this group due to the relatively low levels of muscle activation present in the lumbar multifidus and rectus abdominus during the isometric hiking hold exercise and the dynamic HM₁₈₀ test. This EMG result is similar to Sekulic et al. (2006), where the lumbar multifidus and rectus abdominus muscle activation were low for three different hiking positions that were executed in a 90 seconds time period. For this study, it is assumed that only relatively low levels of muscle activation were required to stabilise the trunk in these static and dynamic hiking postures due to the relatively low mass of the subjects. It is of interest that current

epidemiological evidence examining the relation of adolescent carrying heavy schoolbags shows little association with an increase in the risk of future low back pain (Grimmer & Williams, 2000; Watson et al., 2003). The concept of low-medium loads applied over relatively long durations (as would be the case in sailing and adolescents carrying schoolbags) and causing mechanical loads on the spine of adolescents is an interesting point to consider in the etiology of low back injury.

Second, poor technique in the execution of the hiking position could be a potential factor for low back injury. Whilst kinematics of short and long hiking postures were not examined in this study, it is possible that the preferred posture for long hiking would be with the spine flexed rather than hyperextended (Spurway, 1999). However, a detailed kinematic analysis of each participant's hiking posture was not undertaken as the focus of the study was on muscle activations patterns. Another possible reason for the low incidence of low back pain in this study was the amount of training these junior sailors have undergone when compared to senior sailors (Legg et al., 1997; Moraes et al., 2003). A study by Legg & Mackie (2000) showed that sailors had participated in a higher number of training sessions, which may be associated to the sailors overtraining, having insufficient recovery between activities, causing greater exposure to injury, which leads to an increased occurrence of low back pain (Jones, Silman, & Macfarlane, 2003).

In contrast to previous literature where low back pain was reported as the chief injury complaint reported by senior sailors (Legg et al., 1997; Moraes et al., 2003), the incidence of knee pain revealed in this group of adolescent sailors was slightly higher than the incidence of low back pain. Nevertheless, this was comparable to the incidence of knee pain reported in the previously mentioned studies (S. J. Legg, Smith et al., 1997; Moraes et al., 2003), which ranged from 22-32%. It is possible that the onset of knee pain in sailors occurred early on in their sailing careers, as knee pain has been found to still persist even after a lengthy follow-up (Luhmann, Schoenecker, Dobbs, & Eric Gordon, 2008). However, this cannot be proven without use of a longitudinal study design. The byte class boat has a smaller main sail, which in turn produces less heeling force; similarly, the boat hull is also much smaller (and therefore less stable) when compared to other Olympic boat classes. Hence, with a smaller hull the junior sailors are in a more unstable environment, where the boat is more vulnerable to the external

forces (e.g. hiking moment, wind shearing force on the sails and drag force on the boat). This might increase the likelihood of knee pain / knee injuries in junior sailors.

In addition to describing the prevalence of low back pain and knee pain in this group of sailors, the low back pain data collected in this study had an additional purpose. Differences in the level of trunk muscle activation have previously been found in individuals with chronic low back pain and controls during sitting (Dankaerts, O'Sullivan, Burnett, & Straker, 2006). Therefore, a comparison between those with and without current low back pain was undertaken in this study to determine whether differences in the level of muscle activation existed in the strength and conditioning exercises and the HM₁₈₀ test. These analyses revealed that no differences in muscle activation existed. This may have been due to the relatively low levels of pain found in this study, while the individuals with chronic low back pain that Dankaerts and colleagues (2006) had examined, indicated relatively high pain and disability levels.

5.3 Level of Muscle Activation in Strength and Conditioning Exercises and the Maximal Hiking Test (HM₁₈₀)

Strength and conditioning exercises have been postulated by previous researchers as being a possible method to utilize for preventing and rehabilitating sailing-related injuries as well as improving performance (Legg, Mackie, & Slyfield, 1999; Legg et al., 1997; Wright et al., 1976). To date there have been no studies, that have examined the levels of muscle activation of such exercises and hiking itself. Hence, this study compared the level of muscle activation from selected lower limb and trunk muscles during four strength and conditioning exercises and a laboratory-based maximal hiking test (the HM₁₈₀ test).

The knee extensors have previously been identified as being an important muscle group in sailing (Boyas et al., 2009; Cunningham & Hale, 2007; Spurway, 2007; Vangelakoudi et al., 2007) and both the leg extension and back squat exercises are frequently used to develop knee extensor strength. In this study, these exercises showed similar levels of muscle activation in the vastus lateralis. Further, there was a greater level of muscle activation recorded for the concentric phase of these exercises. This is in contrast to previous studies that have examined eccentric isokinetic training and found

greater action-specific strength gains in muscle (Dudley, Tesch, Miller, & Buchanan, 1991; Hather, Tesch, Buchanan, & Dudley, 1991). Both the leg extension and back squat exercises elicited greater levels of muscle activation for the vastus lateralis when compared to the HM₁₈₀ test and this demonstrated that these exercises provide an overloading stimulus for this muscle in simulated hiking.

It has previously been suggested that the trunk muscles are of importance to sailors due to the extended position of the trunk when the long hiking position is adopted (Aagaard et al., 1998; Maisetti, Boyas, & Guevel, 2006; Menezes et al., 2007; Vangelakoudi et al., 2007). Therefore, these muscles should be conditioned as part of the sailor's physical preparation. Surprisingly, the superficial lumbar multifidus showed similar levels of muscle activation in the back squat and the back extension exercise. The back squat is an exercise that is used to primarily strengthen the quadriceps, hamstrings and the gluteal muscles (Gullett, Tillman, Gutierrez, & Chow, 2009). Whilst the angle of the trunk was not quantified in the back squat exercise, the superficial lumbar multifidus muscle may have been required to activate more than usual, as the trunk may have been excessively flexed during this exercise. It has been previously shown that increased trunk flexion in lifting result in higher levels of L5/S1 shear forces (Kingma, Staudenmann, & Van Dieen, 2007). This was also proven in other studies using biomechanical models (Arjmand, Shirazi-Adl, & Parnianpour, 2007; Briggs et al., 2007). Hence, excessive trunk flexion may overload passive structures of the lumbar spine like the posterior elements of the intervertebral disc (Granata, Lee, & Franklin, 2005). In junior athletes, where sailing performance may be improved via resistance training, this should not be at the expense of exercise technique. From the findings of this study, it is plausible that the leg extension exercise can be used to strengthen the quadriceps muscles whilst squatting technique is developed.

For the back extension exercise, it was found that the concentric phase showed a greater level of muscle activation when compared to the eccentric phase. This result is not surprising, as athletes must resist gravity whilst returning the trunk to the neutral (start) position. Also, contrary findings in this study included the significant difference found between-gender for the level of activation of the biceps femoris and the non-significant difference found between-gender for the lumbar multifidus for the back extension exercise. Males with greater body mass (as shown in this study – see Section 3.1) would have greater trunk mass, therefore, it would be expected that males have greater

activation and fatigability of the lumbar multifidus and biceps femoris when compared to females (Kankaanpää et al., 1998).

Whilst general strength exercises provide basic strength improvement in athletes, specific strength exercises are also used by the strength and conditioning coach. The 30 second hiking hold is an exercise prescribed as a hiking-specific exercise for junior sailors to provide overload for the abdominal muscles. The intention of this exercise was confirmed by this study, as there was a greater level of muscle activation of the rectus abdominus in the hiking hold exercise when compared to the HM₁₈₀ test.

In the maximal hiking test (HM₁₈₀), the rectus abdominus muscle had the highest level of activation, followed by the activation from vastus lateralis muscle and the lumbar multifidus muscle respectively. The outcome of the muscle activation was anticipated due to the similar posture adopted, where the only differences were duration (180 seconds versus 30 seconds) and the nature of the exercise (dynamic versus isometric). Participants had to hike isometrically in a relatively static position for the hiking hold exercise, unlike the HM₁₈₀ test, where participants have the freedom of movement but are constantly encouraged to hike out for as long as they possibly can. Although rectus abdominus muscle has been revealed as the main protagonist for activation in short and long hiking, sailing literature shows otherwise. As in the study by (Aagaard et al., 1998), few correlations were observed for trunk flexor strength, while hiking performance correlated to knee extensor. For this reason, the difference in the outcome for the muscle activations could be due to the differences in hiking technique and the synergistic muscle recruitment pattern of each sailor. A repeated measure ANOVA with post-hoc comparison reveal that a fatigue effect for the HM₁₈₀ was observed for the lumbar multifidus (150-180s period, $p < 0.001$) and vastus lateralis muscles (90-120s period, $p = 0.001$). Additionally, muscle activations for the HM₁₈₀ test increased in the last time period (150s-180s). This would suggest that there should be emphasis to condition the lumbar multifidus and vastus lateralis muscles isometrically beyond 90 seconds.

The combination of these findings, provide support to Spurway's (2007) recommendation that hiking is deemed as quasi-isometric. In that hiking is not just a sustained static isometric activation, but bouts of isometric phases interspersed with dynamic movements of the lower limbs in response to the external conditions (i.e.

strong winds and rough seas). Therefore, strength and conditioning programs should not be focused on static hiking endurance alone, but incorporate exercises that conditions the body either laterally, vertically or torsionally. As a result, the sailor will have a better hiking endurance, and be able to respond and react quickly to variations of wind, sea and trimming of the dinghy as well.

5.4 Maximal Hiking Moment

The HM_{180} is a test designed to assess maximal hiking ability in sailors (Tan et al., 2006). In this study, the hiking dynamometer of Tan and co-workers (2006) was modified to suit the byte-class rather than the laser class. The significant difference found between-gender was consistent with previous work (Tan et al., 2006). The computation of the hiking moment is highly dependent on the participant's body mass and height, it is not surprising that the males, who were heavier, taller and had a greater BMI, produced superior HM_{180} when compared with their female counterparts. When translated to on-water racing, this would be of distinct advantage in combating strong winds that act upon the main sail during a race.

For between-ability group comparisons for the HM_{180} test, participants were classified into either the national byte class training squad or the high performance group. The difference found between-ability group for the hiking moment data was even more distinct than the between-gender effect. It could be speculated that greater values for the hiking moment in the national group may be due to a combination of superior hiking technique and conditioning. These sailors were probably able to maintain a long hiking position for longer periods of time when compared to the high performance group.

5.5 Limitations of the Study

There are a number of limitations in this study. These are listed below:

- i. Surface electrodes do not record precise differences between parts of a muscle as they record the neural activity of underlying muscles under the electrodes.

- ii. Due to the EMG equipment limitation, only four muscles can be bilaterally analyzed at any given time during the course of each test session.
- iii. Hiking performance was measured on a hiking bench rather than on-water; therefore, this study has reduced ecological validity.
- iv. The level of muscle activation was dependent upon the weight lifted during the strength and conditioning exercises examined in this study (back squat and leg extension) therefore, generalisation of findings to lower weight - higher repetition work should be made with caution.
- v. The level of muscle activation may be dependent upon the tempo with which exercises were executed (2-1-2). Therefore, generalisation of findings to other tempos (with longer or shorter eccentric and concentric phases) should be done with caution.

5.6 Conclusions

Although the incidence of low back and knee pain in these junior sailors are low, it will be vital to continue with injury surveillance as it has been found that pain prevalence increases with age and overuse. When comparing the level of activation for the strength and conditioning exercises to HM₁₈₀ test, it was evident that the level of muscle activation was greater for; 1) the superficial lumbar multifidus in back extension exercise, 2) the rectus abdominus in the hiking hold and 3) the vastus lateralis muscle in the back squat and leg extension exercises. This shows that these exercises are ideal training exercises to improve the strength / strength endurance base for hiking performance. Findings from this study revealed that rectus abdominus and vastus lateralis had the highest muscle activations while hiking. However, the trunk and knee stabilisers (biceps femoris and lumbar multifidus muscles) are not to be neglected due to its possible role in joint protection and prevention of injuries. These findings will be of interest to coaches and practitioners alike, so that more is understood about the use of strength and conditioning exercises in sailors. Furthermore, strength and conditioning programs need to comprise of dynamic and static components to provide sailors with a well-balanced physique for sailing.

5.7 Recommendations for Future Research

As a result of this study, there are several more studies that could be undertaken. These are summarised below:

- i. To examine mechanisms of low back pain in sailing, it would be of interest to examine the regional kinematics (upper lumbar and lower lumbar) of the lumbar spine during hiking postures.
- ii. It would be of interest to apply some form of coaching intervention to this group of sailors to improve squatting technique, and examine whether the activation of the lumbar multifidus muscle can in fact be decreased.
- iii. It would be interesting to utilize anthropometric measures of sailors (eg the moment of inertia of the trunk) and undertake a dynamic analysis of long and short hiking.

REFERENCES

- Aagaard, P., Beyer, N., Simonsen, E. B., Larsson, B., Magnusson, S. P., & Kjær, M. (1998). Isokinetic muscle strength and hiking performance in elite sailors. *Scand J Med & Sci Sports*, 8(3), 138-144.
- Allen, J. B., & De Jong, M. R. (2006). Sailing and sports medicine: a literature review. *Br J Sports Med*, 40(7), 587-593.
- Arjmand, N., Shirazi-Adl, A., & Parnianpour, M. (2007). Trunk biomechanical models based on equilibrium at a single-level violate equilibrium at other levels. *Eur Spine J*, 16(5), 701-709.
- Beachle, T. R., Earle, R. W. & Wathen, D. (2000). Resistance Training. In T. R. Beachle & R. W. Earle (Eds.), *Essentials of Strength Training and Conditioning* (pp. 392 – 404). Champaign, IL: Human Kinetics.
- Blackburn, M. (1994). Physiological responses to 90 min of simulated dinghy sailing. *J Sports Sci*, 12(4), 383 - 390.
- Bojsen-Møller, J., Larsson, B., Magnusson, S. P., & Aagaard, P. (2003). Strength and endurance profiles of elite Olympic class sailors. *Proceedings of the 4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference*, (Edited by S. J. Legg), pp. 97-111, Massey University.
- Bojsen-Møller, J., Larsson, B., Magnusson, S. P., & Aagaard, P. (2007). Yacht type and crew-specific differences in anthropometric, aerobic capacity, and muscle strength parameters among international Olympic class sailors. *J Sports Sci*, 25(10), 1117-1128.
- Bojsen-Møller, F., & Bojsen-Møller, J. (1999). Biomechanics of sailing. In G. Sjøgaard & J. Bangsbo (Eds.), *Sailing and Science* (pp. 77-93). Copenhagen: Institute of Exercise and Sport Sciences, University of Copenhagen
- Boyas, S., Maïsetti, O., & Guével, A. (2009). Changes in sEMG parameters among trunk and thigh muscles during a fatiguing bilateral isometric multi-joint task in trained and untrained subjects. *J Electromyogr Kinesiol*, 19(2), 259-268.
- Briggs, A. M., van Dieën, J. H., Wrigley, T. V., Greig, A. M., Phillips, B., Lo, S. K., et al. (2007). Thoracic kyphosis affects spinal loads and trunk muscle force. *Phys Ther*, 87(5), 595-607.
- Burton, A. K., Balague, F., Cardon, G., Eriksen, H. R., Henrotin, Y., Lahad, A., et al. (2005). How to prevent low back pain. *Best Pract Res Clin Rheumatol*, 19(4), 541-555.
- Castagna, O., & Brisswalter, J. (2007). Assessment of energy demand in Laser sailing: influences of exercise duration and performance level. *Eur J Appl Physiol*, 99(2), 95-101.

- Christou, M., Smilios, I., Sotiropoulos, K., Volaklis, K., Piliandis, T., & Tokmakidis, S. P. (2006). Effects of resistance training on the physical capacities of adolescent soccer players. *J Strength Cond Res*, 20(4), 783-791.
- Cockerill, S. (1999). No pain: how to develop a hiking style that avoids the knee problems, which put many out of the sport. *Aust Sailing*, 40-42.
- Cockerill, S., & Taylor, F. (1998). Hitch-hikers guide: ways we can improve our hiking-out style and avoid injury. *Yachts and Yachting*, 12, 11-15.
- Collins, S. L., Moore, R. A., & McQuay, H. J. (1997). The visual analogue pain intensity scale: what is moderate pain in millimetres? *Pain*, 72(1-2), 95-97.
- Cunningham, P., & Hale, T. (2007). Physiological responses of elite Laser sailors to 30 minutes of simulated upwind sailing. *J Sports Sci*, 25(10), 1109-1116.
- Dankaerts, W., O'Sullivan, P., Burnett, A., & Straker, L. (2006). Altered patterns of superficial trunk muscle activation during sitting in nonspecific chronic low back pain patients: importance of subclassification. *Spine*, 31(17), 2017-2023.
- Dankaerts, W., O'Sullivan, P. B., Burnett, A. F., Straker, L. M., & Danneels, L. A. (2004). Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *J Electromyogr Kinesiol*, 14(3), 333-342.
- De Vito, G., Di Filippo, L., Felici, F., & Marchetti, M. (1993). Hiking mechanics in laser athletes. *Med Sci Res*, 21, 859-860.
- Dudley, G. A., Tesch, P. A., Miller, B. J., & Buchanan, P. (1991). Importance of eccentric actions in performance adaptations to resistance training. *Aviat Space Environ Med*, 62(6), 543-550.
- Dyson, R., Buchanan, M., & Hale, T. (2006). Incidence of sports injuries in elite competitive and recreational windsurfers. *Br J Sports Med*, 40(4), 346-350.
- Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J., Jeffreys, I., Micheli, L. J., Nitka, M., et al. (2009). Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res*, 23(5 Suppl), S60-79.
- Felici, F., Rodio, A., Madaffari, A., Ercolani, L., & Marchetti, M. (1999). The cardiovascular work of competitive dinghy sailing. *J Sports Med Phys Fitness*, 39(4), 309-314.
- Freriks, B., Hermens, H. J., Disselhorst-Klug, C. & Rau, G. (1999). The Recommendations for Sensors and Sensor Placement Procedures for Surface ElectroMyoGraphy. In H. J. Hermens & B. Freriks (Eds.), *SENIAM 8: European Recommendations for Surface Electromyography* (pp. 12 – 20). Enschede, Netherlands: Roessingh Research and Development.
- Gale, T. J., & Walls, J. T. (2000). Development of a sailing dinghy simulator. *SIMULATION*, 74(3), 167-179.

- Granata, K. P., Lee, P. E., & Franklin, T. C. (2005). Co-contraction recruitment and spinal load during isometric trunk flexion and extension. *Clin Biomech*, 20(10), 1029-1037.
- Grimmer, K., & Williams, M. (2000). Gender-age environmental associates of adolescent low back pain. *Appl Ergon*, 31(4), 343-360.
- Gullett, J. C., Tillman, M. D., Gutierrez, G. M., & Chow, J. W. (2009). A biomechanical comparison of back and front squats in healthy trained individuals. *J Strength Cond Res*, 23(1), 284-292.
- Hather, B. M., Tesch, P. A., Buchanan, P., & Dudley, G. A. (1991). Influence of eccentric actions on skeletal muscle adaptations to resistance training. *Acta Physiol Scand*, 143(2), 177-185.
- Hestbaek, L., Leboeuf-Yde, C., Kyvik, K. O., & Manniche, C. (2006). The course of low back pain from adolescence to adulthood: eight-year follow-up of 9600 twins. *Spine*, 31(4), 468-472.
- Jones, G. T., Silman, A. J., & Macfarlane, G. J. (2003). Predicting the onset of widespread body pain among children. *Arthritis Rheum*, 48(9), 2615-2621.
- Kalogeromitros, A., Tsangaris, H., Bilalis, D., & Karabinis, A. (2002). Severe accidents due to windsurfing in the Aegean Sea. *Eur J Emerg Med*, 9(2), 149-154.
- Kankaanpaa, M., Laaksonen, D., Taimela, S., Kokko, S. M., Airaksinen, O., & Hanninen, O. (1998). Age, sex, and body mass index as determinants of back and hip extensor fatigue in the isometric Sorensen back endurance test. *Arch Phys Med Rehabil*, 79(9), 1069-1075.
- Kingma, I., Staudenmann, D., & Van Dieen, J. H. (2007). Trunk muscle activation and associated lumbar spine joint shear forces under different levels of external forward force applied to the trunk. *J Electromyogr Kinesiol*, 17(1), 14-24.
- Larsson, B., Beyer, N., Bay, P., Biond, L., Aagaard, P., & Kjaer, M. (1996). Exercise performance in elite male and female sailors. *Int J Sports Med*, 17(7), 504-508.
- Legg, S., Mackie, H., & Smith, P. (1999). Temporal patterns of physical activity in Olympic dinghy racing. *J Sports Med Phys Fitness*, 39(4), 315-320.
- Legg, S. J., & Mackie, H. W. (2000). Change in knowledge and reported use of sport science by elite New Zealand olympic class sailors. *J Physiol Anthropol Appl Human Sci*, 19(2), 83-92.
- Legg, S. J., Mackie, H. W., & Slyfield, D. A. (1999). Changes in physical characteristics and performance of elite sailors following introduction of a sport science programme prior to the 1996 Olympic games. *Appl Human Sci*, 18(6), 211-217.

- Legg, S. J., Miller, A. B., Slyfield, D., Smith, P., Gilberd, C., Wilcox, H., et al. (1997). Physical performance of elite New Zealand Olympic class sailors. *J Sports Med Phys Fitness*, 37(1), 41-49.
- Legg, S. J., Smith, P., Slyfield, D., Miller, A. B., Wilcox, H., & Gilberd, C. (1997). Knowledge and reported use of sport science by elite New Zealand Olympic class sailors. *J Sports Med Phys Fitness*, 37(3), 213-217.
- Lin, H. T., Hsu, A. T., Chang, J. H., Chien, C. S., & Chang, G. L. (2008). Comparison of EMG activity between maximal manual muscle testing and Cybex maximal isometric testing of the quadriceps femoris. *J Formos Med Assoc*, 107(2), 175-180.
- Loud, K. J., Micheli, L. J., Bristol, S., Austin, S. B., & Gordon, C. M. (2007). Family history predicts stress fracture in active female adolescents. *Pediatrics*, 120(2), e364-372.
- Luhmann, S. J., Schoenecker, P. L., Dobbs, M. B., & Eric Gordon, J. (2008). Adolescent patellofemoral pain: implicating the medial patellofemoral ligament as the main pain generator. *J Child Orthop*, 2(4), 269-277.
- Mackie, H., Sanders, R., & Legg, S. (1999). The physical demands of Olympic yacht racing. *J Sci Med Sport*, 2(4), 375-388.
- Mackie, H. W., & Legg, S. (1999). Preliminary assessment of force demands in laser racing. *J Sci Med Sport*, 2(1), 78-85.
- Maisetti, O., Boyas, S., & Guevel, A. (2006). Specific neuromuscular responses of high skilled laser sailors during a multi-joint posture sustained until exhaustion. *Int J Sports Med*, 27(12), 968-975.
- Maisetti, O., Guevel, A., Iachkine, P., Legros, P., & Briswalter, J. (2002). Sustained hiking position in dinghy sailing. Theoretical aspects and methodological considerations for muscle fatigue assessment. *Sci Sports*, 17, 234-246.
- Mayhew, J. L., Hill, S. P., Thompson, M. D., Johnson, E. C., & Wheeler, L. (2007). Using absolute and relative muscle endurance to estimate maximal strength in young athletes. *Int J Sports Physiol Perform*, 2(3), 305-314.
- Menezes, F., Schutz, G. R., Cerutti, P. R., Carneiro, L. C., Fontana, H. B., & Roesler, H. (2007). Biomechanical analysis of spine movements in hiking on sailing: A preliminary study. *Proceedings of the 25th International Symposium on Biomechanics in Sports*, (Edited by H. J. Menzel & M. H. Chagas), pp. 125 – 128, Congress Center of Ouro Preto.
- Mohr, K. J., Pink, M. M., Elsner, C., & Kvitne, R. S. (1998). Electromyographic investigation of stretching: the effect of warm-up. *Clin J Sport Med*, 8(3), 215-220.
- Moraes, J., Nery, C., Fontel, E., Morais, E., Cosendey, F., Rossatto, S., et al. (2003). Multidisciplinary assessment of the Brazilian Olympic sailing team. *Proceedings of the Human Performance in Sailing Conference Preceedings*:

Incorporating the 4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference, (Edited by S. J. Legg), pp. 92-95, Massey University.

- Nadler, S. F., Malanga, G. A., Feinberg, J. H., Prybicien, M., Stitik, T. P., & DePrince, M. (2001). Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes: A prospective study. *Am J Phys Med Rehabil* 80(8), 572-577.
- Neville, V., & Folland, J. P. (2009). The epidemiology and aetiology of injuries in sailing. *Sports Med*, 39(2), 129-145.
- Ng, J. K. F., Kippers, V., & Richardson, C. A. (1998). Muscle fibre orientation of abdominal muscles and suggested surface EMG electrode positions. *Electromyogr Clin Neurophysiol*, 38(1), 51-58.
- Ogon, M., Krismer, M., Sollner, W., Kantner-Rumplmair, W., & Lampe, A. (1996). Chronic low back pain measurement with visual analogue scales in different settings. *Pain*, 64(3), 425-428.
- Perich, D., Burnett, A., & O'Sullivan, P. (2009). An examination of low back pain in adolescent schoolgirl rowers. Submitted, *Clin J Sports Med*.
- Putnam, C. A. (1979). A mathematical model of hiking positions in a sailing dinghy. *Med Sci Sports Exerc*, 11(3), 288-292.
- Ranson, C., Burnett, A., King, M., O'Sullivan, P., Cornish, R., & Batt, M. (2008). Acute lumbar stress injury, trunk kinematics, lumbar MRI and paraspinal musclemorphology in fast bowlers in cricket. *Proceedings of the XXVI International Conference on Biomechanics in Sports*, (Edited by Y-H Kwon, J. Shim, J-K Shim, I-S Shin), pp. 233-236, Seoul National University.
- Reynolds, J. M., Gordon, T. J., & Robergs, R. A. (2006). Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res*, 20(3), 584-592.
- Ruschel, C., Menezes, F. S. D., Haupenthal, A., Hubert, M., Schütz, G. R., Cerutti, P. R., et al. (2009). Incidence of injuries in Brazilian sailors of different technical levels *Rev Bras Med Esporte* 15, 268-271.
- Sato, T., Ito, T., Hirano, T., Morita, O., Kikuchi, R., Endo, N., et al. (2008). Low back pain in childhood and adolescence: a cross-sectional study in Niigata City. *Eur Spine J*, 17(11), 1441-1447.
- Sekulic, D., Medved, V., & Rausavljevi, N. (2006). EMG analysis of muscle load during simulation of characteristic postures in dinghy sailing. *J Sports Med Phys Fitness*, 46(1), 20-27.
- Shephard, R. J. (1990). The biology and medicine of sailing. *Sports Med*, 9(2), 86-99.
- Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychol Bull*, 86(2), 420-428.

- Spurway, N. C. (1999). Sailing physiology. In G. Sjøgaard & J. Bangsbo (Eds.), *Sailing and science* (pp. 95-117). Copenhagen: Institute of Exercise and Sport Sciences, University of Copenhagen
- Spurway, N. C. (2007). Hiking physiology and the "quasi-isometric" concept. *J Sports Sci*, 25(10), 1081-1093.
- Spurway, N. C., & Burns, R. (1993). Comparison of dynamic and static fitness-training programmes for dinghy-sailors and some questions concerning the physiology of hiking. *Med Sci Res*, 21, 865-867.
- Spurway, N. C., Legg, S., & Hale, T. (2007). Sailing physiology. *J Sports Sci*, 25(10), 1073-1075.
- Tan, B., Aziz, A. R., Spurway, N. C., Toh, C., Mackie, H., Xie, W., et al. (2006). Indicators of maximal hiking performance in Laser sailors. *Eur J Appl Physiol*, 98(2), 169-176.
- Tse, M. A., McManus, A. M., & Masters, R. S. (2005). Development and validation of a core endurance intervention program: implications for performance in college-age rowers. *J Strength Cond Res*, 19(3), 547-552.
- Vangelakoudi, A., Vogiatzis, I., & Geladas, N. (2007). Anaerobic capacity, isometric endurance, and Laser sailing performance. *J Sports Sci*, 25(10), 1095-1100.
- Vera-Garcia, F. J., Elvira, J. L., Brown, S. H., & McGill, S. M. (2007). Effects of abdominal stabilization maneuvers on the control of spine motion and stability against sudden trunk perturbations. *J Electromyogr Kinesiol*, 17(5), 556-567.
- Vogiatzis, I., Spurway, N. C., Jennett, S., Wilson, J., & Sinclair, J. (1996). Changes in ventilation related to changes in electromyograph activity during repetitive bouts of isometric exercise in simulated sailing. *Eur J Appl Physiol Occup Physiol*, 72(3), 195-203.
- Walls, J., Bertrand, L., Gale, T., & Saunders, N. (1998). Assessment of upwind dinghy sailing performance using a virtual reality dinghy sailing simulator. *J Sci Med Sport*, 1(2), 61-72.
- Watson, K. D., Papageorgiou, A. C., Jones, G. T., Taylor, S., Symmons, D. P., Silman, A. J., et al. (2003). Low back pain in schoolchildren: the role of mechanical and psychosocial factors. *Arch Dis Child*, 88(1), 12-17.
- Winter, D. A. (2005). *Biomechanics and Motor Control of Human Movement* (pp. 34 - 50). New Jersey: Wiley.
- Wright, G., Clarke, J., Niinimaa, V., & Shephard, R. J. (1976). Some reactions to a dry-land training programme for dinghy sailors. *Br J Sports Med*, 10(1), 4-10.
- Zheng, N., Fleisig, G. S., Escamilla, R. F., & Barrentine, S. W. (1998). An analytical model of the knee for estimation of internal forces during exercise. *J Biomech*, 31(10), 963-967.

APPENDIX A

SUBJECT INFORMATION FORM

Subject Information Form

- Title of Project:** An examination of high-level junior Singaporean sailors: An injury survey and biomechanical analysis of hiking
- Principal Investigator:** Associate Professor Angus BURNETT
(School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Western Australia)
- Associate Investigator:** WEE Wing Kuen
(School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Western Australia)

Background

In the sport of sailing, many actions involve explosive movements and physically demanding postures. One such posture as you will be aware is called "hiking". It is of importance for sailors to keep themselves injury free (e.g. no low back pain or knee injury) whilst maximizing performance. This is especially important for junior sailors who form the competitive base of the sport and who have the potential to be the next generation of elite athletes.

In the current literature, there is still a lack of clear understanding of low back and knee injury patterns in junior sailors and there is little literature pertaining to the examination of strength and conditioning exercises prescribed to sailors. By examining key exercises prescribed to junior sailors in their strength and conditioning programs, and comparing them to the levels of muscle activation experienced in simulated long- and short-hiking, this may improve knowledge to enhance performance and prevent injury in the sport. Such a study would be of significance to athletes, coaches, sports scientists and rehabilitation professionals.

Aims of Study

There are two aims of this study. Firstly, it is to determine the incidence of back and knee pain in a group of high level junior Singaporean sailors. Secondly, to compare muscle activation patterns of selected lower limbs and trunk muscles in simulated short and long hiking, and selected strength and conditioning exercises prescribed to junior sailors.

Participants

Subjects in this study will consist of male and female high-level junior Singaporean sailors aged between 14 and 16 years. Subjects will be recruited from the Singaporean National Byte Class training squad and High Participation Group

Procedures

Testing will involve two sessions, with the first session lasting 30 minutes. Subjects will complete two sets of exercises; squats and leg extension, to obtain the maximum weight the subject can lift in six repetitions. The second session will last 90 minutes and consist of two distinct parts. In the first part, a questionnaire pertaining to subject demographics and injury status (low back pain and knee pain) will be completed. Prior to the second (physical) part of testing, subjects will warm up by cycling for approximately 5 minutes on an exercise bike and will then perform their usual

stretching routine. Subjects will go through a short familiarization period of hiking on a hiking simulator.

In this study, there will be a couple of pieces of biomechanical measuring equipment being used. A technique called electromyography (EMG) will be used to assess how much of the subject's muscles are activated during selected tasks. The muscles we will be testing are the quadriceps/hamstrings (front/back of your thighs) and two areas of your trunk muscles (abdominal and back muscles). EMG of these muscles will be collected whilst you perform static simulated long and short hiking positions, and four strength and conditioning exercises. Each of these tests will consist of three trials with the order of testing being randomized. You will also perform a single, three-minute maximum hiking moment test. In order to calculate your muscle action to a percentage of your maximum, we will require you to do four tests to obtain what your maximum strength is in these muscles before the hiking testing. Prior to application of the EMG electrodes to your skin, we will need to clean your skin with an alcohol type substance. There are no side effects of this. To allow us to attach the EMG electrodes as easily as possible and secured well during testing, we will require you to wear specific clothing. Males and females will both need to wear loose fitting shorts (eg. running shorts) and females will be required to wear a tight fitting half sports top and males should wear a loose fitting singlet. Your dignity will be considered at all times.

In addition, we will need to use a digital video camera to determine the phases of movement whilst you perform the hiking movements and the above exercises. This video footage is for research purposes only.

The associate investigator has had a working with children police check done in Australia (Clearance Number: 341174) due to being involved in a large cohort study, which involved testing children under the age of 18 years. This was a requirement of Edith Cowan University to work in that study.

Confidentiality

All recorded data will be entered into a database using your assigned subject number only, no names will be used. Access to the stored data will be restricted by a password known only by the investigators. All data collected and consent forms will be stored safely in a locked cupboard at Edith Cowan University.

The results will be reported on, but it will be impossible to identify individual subjects as no identification numbers or names will be included in report material. On completion of the study, all data will be stored in a secure and confidential location with the investigators for five years.

Request for Further Information:

You are encouraged to discuss and/or express any concerns or questions regarding this study with the investigators at any time. You should feel confident and secure about your involvement in the study.

Refusal or Withdrawal:

You may refuse to participate in the study and if you do consent to participate, you may withdraw from the study at any time without fear or prejudice. If you do decide to withdraw from the study please contact the investigators at the earliest possible convenience. All data will be destroyed if you do decide to withdraw. Please contact the

following people if you have problems or concerns at any stage during your participation in this project:

Wee Wing Kuen

w.wee@ecu.edu.au

[REDACTED]

Assoc. Prof. Angus Burnett a.burnett@ecu.edu.au

[REDACTED]
+61 8 6304 5416

Approval

This study has been approved by the Edith Cowan University Human Research Ethics Committee. If you have any concerns or complaints about the research project and wish to talk to an independent person, or if you require verification of approval you may contact:

Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP, WA, 6027
Phone: +61 8 6304 2170
Email: research.ethics@ecu.edu.au

APPENDIX B

SUBJECT WRITTEN CONSENT FORM

Subject Written Consent Form

Title of Project: An examination of high-level junior Singaporean sailors: An injury survey and biomechanical analysis of hiking

Principal Investigator: Associate Professor Angus BURNETT
(School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Western Australia)

Associate Investigator: WEE Wing Kuen
(School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Western Australia)

You are of your own accord making a decision whether or not to participate in this research study. You and your parent/guardian's signature verifies that you have decided to participate in the study, having read and understood all the information accessible. Your signature also officially states that you have had adequate opportunity to discuss this study with the investigators and all your questions have been answered to your satisfaction. You will be given a copy of this consent document to keep.

I, _____ [the undersigned]

Of _____ [Please PRINT]

Postcode _____ Phone _____

consent to involvement in this study and give my authorisation for any results from this study to be used in any research paper, on the understanding that confidentiality will be maintained. I understand that I may withdraw from the study at any time without discrimination. If so, I undertake to contact the respective person at the earliest opportunity:

Wee Wing Kuen w.wee@ecu.edu.au

Assoc. Prof. Angus Burnett a.burnett@ecu.edu.au +61 8 6304 5416

Subject

Name: _____ Signature: _____ Date: _____

Parent/Guardian

Name: _____ Signature: _____ Date: _____

I have explained to the subject the procedures of the study to which the subject has consented their involvement (in writing) and have answered all questions. In my appraisal, the subject has voluntarily and intentionally given informed consent and possesses the legal capacity to give informed consent to participate in this research study.

Signature: _____ Date: _____

APPENDIX C

PARTICIPANT QUESTIONNAIRE

Participant Demographics

Name: _____

Gender: _____

Age: _____ years old

Ethnicity: _____

Height: _____ cms

Weight: _____ kg

Do you *currently have* any low back trouble (ache, pain or discomfort)?

_____ Yes

_____ No

If you answered Yes to the above question, is your low back pain brought on, or exacerbated by sailing, or sailing-related training? (eg. weights sessions, cross-training?)

_____ Yes

_____ No

Have you *ever had* any low back trouble in the past (ache, pain or discomfort)?

_____ Yes

_____ No

Do you *currently have* any knee trouble (ache, pain or discomfort)?

_____ Yes

_____ No

If you answered Yes to the above question, is your knee pain brought on, or exacerbated by sailing, or sailing-related training? (eg. weights sessions, cross-training?)

_____ Yes

_____ No

Have you *ever had* any knee trouble in the past (ache, pain or discomfort)?

_____ Yes

_____ No

APPENDIX D

VISUAL ANALOG SCALE

(ONLY IF SUBJECT HAS EXPERIENCED LBP)

The following questions on this page are asking about your *low back pain*.

- 1) Please use a vertical line to indicate your level of pain *at this moment*

no pain |—————| severe pain

- 2) Please use a vertical line to indicate your level of usual pain *in the last week*

no pain |—————| severe pain

- 3) Please use a vertical line to indicate your usual level of pain during your *last episode*

no pain |—————| severe pain

- 4) Please use a vertical line to indicate your usual level of pain during your *worst episode*

no pain |—————| severe pain