UNIVERSITY COLLEGE CHICHESTER

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The Physiological Demands of Elite Single-Handed Dinghy Sailing

by

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ABSTRACT

SCHOOL OF SPORT, EXERCISE AND HEALTH SCIENCES

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Dingy sailing has traditionally been thought of as a static sport, with hiking, involving considerable isometric muscle action in the quadriceps and to a lesser extent the abdominal muscle groups, the major physiological challenge. Relatively high heart rates (HR) have been reported in on-water studies, but as these were often mirrored with low values for oxygen consumption, little importance has been placed on aerobic training. Low oxygen consumption ($\dot{V}O_2$) during isometric exercise is well documented, but if the action is purely isometric, the elevated heart rates are difficult to explain. This thesis set out to investigate the physiological demands of elite single-handed dinghy racing by using a combination of on-water measures and simulations in the laboratory using sports specific sailing ergometers. The end goals were to establish the physical demands of the sport and the anthropometric and physiological characteristics required for success at the elite level, and offer appropriate assessment and training regimens. This work is aimed at changing practice based on scientific evidence rather than on belief.

On-water data, reported in chapter 4, was unanimous in establishing that the physical demands increased as wind speed increased and that upwind sailing was more strenuous than downwind sailing. Heart rates and blood lactates (La_{bl}) averaged 84% HR_{max} and 4.64 mmol.l^{-1} and 78% HR_{max} and 3.53 mmol.l^{-1} for Laser and Finn sailing in strong (9–15 m.s^{-1}) and moderate winds (5–9 m.s^{-1}) respectively. It has been suggested the elevated heart rates are caused by the isometric contractions involved with hiking, and is a misleading indicator of the overall energy demands. Chapter 5 investigated the physiological responses to a static 30 minute laboratory simulation of hiking. Blood pressure (BP) was markedly elevated peaking at 166/95 mmHg and hyperventilation was evident. But in spite of significant muscular discomfort, with rates of perceived exertion peaking at 15.3, HR and $\dot{V}O_2$ remained low and peaked at 101 ± 9 beats.min^{-1} and 7.1 ml.kg^{-1}.min^{-1} respectively. These results replicate the responses of isometric exercise reported in the sailing literature, and suggest that other mechanisms are responsible for the elevated values reported on the water.

Chapter 6 describes 30 minutes of simulated upwind sailing, on a purpose built Laser sailing ergometer, and was designed to mimic the dynamic movements of competitive sport. The main findings saw mean HR_{peak} of 160 beats.min^{-1} (87.4% Hr_{max}), a mean $\dot{V}O_2$ of 32.2 ± 3.0 ml.kg^{-1}.min^{-1} (58.1% $\dot{V}O_{2max}$), final La_{bl} of 4.47 ± 0.23 mmol.l^{-1}. Ventilatory equivalents for oxygen were higher than those obtained during a maximal cycle ergometer test, providing evidence of hyperventilation. This hyperventilation may indicate that even a dynamic simulation of single-handed sailing has an underpinning isometric contraction of the quadriceps and/or abdominals on which are superimposed a range of dynamic movements that typifies elite sailing. These results have been confirmed in a recent on-water study of elite French Laser sailors (Castagna and Brisswalter, 2004) when peak values of 78.5% HR_{max} and 68.4% $\dot{V}O_{2max}$ after 30 minutes of hiking were reported. It is argued that these elevated values indicate that the sport has elements of both aerobic and anaerobic metabolism. However, it seems that the competence level of the sailor and the duration of the hiking action are important factors considered.

The main findings reported in this thesis show that elite single-handed dinghy sailing is not a static sport as the majority of the previous scientific literature suggests, and oxygen uptake is taxed considerably. Thus, relevant aerobic training to facilitate both recovery and to underpin the dynamic activities of sailing are warranted as part of a training regimen. A sport-specific assessment of the sailors' physical characteristics by a coach and applied sports scientist with knowledge of the physiological demands of competitive single-handed dinghy sailing, together with an appropriate battery of fitness tests and a combination of aerobic and anaerobic training exercises would allow the sailors' physiological strengths and weaknesses to be evaluated. Based on this information data-base appropriate training programmes can be introduced that maximise sailing performance.

List of publications arising from this thesis:

Cunningham, P. (1995). The physiological demands of elite dinghy sailing in varying wind conditions. *Journal of Sports Sciences, (14) 1, 73.*

Cunningham, P., Hale, T. and Miles, H. (1998) Physiological responses to 30 minutes of static simulated dinghy sailing. *Journal of Sports Sciences, (16) 1, 43-44.*

Cunningham, P. and Hale, T. (2003). Physiological responses to 30 minutes of dynamic simulated dinghy sailing. *Conference proceedings. The 4th European Conference on sailing sports science and sports medicine, Auckland, New Zealand. January 2003, 19-24.* [full paper submitted to Journal of Sports Sciences, November 2003]

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List of Abbreviations

$\dot{V}O_{2max}$:	Maximal volume of oxygen consumption
$\dot{V}CO_2$:	Volume of carbon-dioxide
$\dot{V}_E$:	Minute volume
$\dot{V}_E / \dot{V}O_2$:	Ventilatory equivalent for oxygen
$\dot{V}_E / \dot{V}CO_2$:	Ventilatory equivalent for carbon-dioxide
EMG:	Electromyograph
IEMG:	Integrated electromyograph

Sailing terminology:

Finn:	Single-handed sailing dinghy
Laser:	Single-handed sailing dinghy
Europe:	Single-handed sailing dinghy
Upwind, beating or close-hauled:	Point of sailing that is as close as possible into the wind
Downwind, running or off-wind:	Point of sailing that is in the same direction as the wind
Reaching:	Point of sailing that is approximately at 90° to the wind direction
Sheet:	Rope controlling the sail
Mainsheet:	Rope attached to the mainsail and used for controlling the position of the mainsail
GRP:	Glass reinforced plastic – material used for boat construction
Sheeting:	Act of pulling in the mainsheet to increase the power in the sail
Cleating:	Act of fastening the mainsheet in a cleat
Hiking:	Act of supporting ones body weight over the side of a boat with the feet placed under a toe-strap (see figure 1.2)
Hiking strap:	Strap attached to the floor of a sailing dinghy and used to place ones feet under to allow hiking
Trimming:	Adjusting the angle of the sail to the wind so as to optimise power
Pumping:	The act of repeatedly fanning the sail by pulling on the mainsheet so as to create an apparent wind and increase forward propulsion

Declaration of Authorship:

DECLARATION OF AUTHORSHIP

I, PETER CUNNINGHAM ...., [please print name]

declare that the thesis entitled [enter title]

THE PHYSIOLOGICAL DEMANDS OF ELITE SINGLE-

HANDED DINGHY SAILING ....

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- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
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Signed: P. Cunningham ....

Date:..

Acknowledgements.

There seems to be a lot of people to thank, probably because this thesis has taken so long to come to fruition. First and foremost are my two supervisors, Professor Tudor Hale and Dr. Rosemary Dyson who have both been very supportive throughout the whole period. There were many occasions when it didn't look that it would ever get completed and without their encouragement, particularly that of Tudor, I don't think it would have. It was a challenge to find time to write up the thesis with the demands of a busy full-time job and their understanding of the situation was first class. John Harrison, although not a supervisor, gave plenty of his own time at the start of the research, his assistance in designing and building the ergometers was fundamental to the thesis.

Secondly, I would like to thank the elite sailors who have participated as subjects. Some 11 years ago these sailors were mere youngsters just embarking on their sailing careers and over the years that this work has been ongoing many of them have matured and gone on to win Olympic medals and make sailing their full time occupations. It's been a pleasure to work with them and in-particular, the likes of Iain Percy and Ben Ainslie, have in the process become good friends.

The Royal Yachting Association and in particular John Derbyshire have been supportive of this work from the very beginning. John was the National Racing Coach responsible for single-handed sailing at the commencement of this thesis in 1993, it was his intuition of single-handed sailing that led the direction of the work in the early years. It was rewarding for both of us to see the success of the British single-handed classes at the 2000 Sydney Olympic Games, particularly sweet for John given his role as Olympic Team Manager and his early roots coaching the single-handers.

Finally, a big thank-you must go out to my friends and family for their on going support. I apologise to my daughter Milly, for the many weekends that were disrupted, particularly of late, due to the writing up process taking much of my spare time and the mountain of papers that have lived on our dining room table for what must have seemed an age. Hopefully, one day she will realise what all the 'fuss' was about but I sincerely hope she never finds time to read it !!

CHAPTER 1

Chapter 1:

Introduction and statement of the problem.

1.1 Statement of the Problem.

Dinghy sailing is now one of Britain's most popular recreational activities (Spurway 1993a). At the Olympic level the sailing is split into categories where either one, two or three persons form the crew of each class of sailing boat. Olympic single-handed sailing takes place in three different types of sailing dinghies, the Laser, Europe, and Finn. Single-handed sailing was first introduced into the Modern Olympics in 1928 in France, and has grown in stature and importance over the intervening years. Fifty thousand dinghy sailors compete seriously in Britain annually (McCormack and Davis 1988). In spite of this level of participation, research into the physiological demands of the event has been scarce. What little has been undertaken is now irrelevant largely because of changes governing competitive events requiring the development of new techniques and skills. Also the sport of Olympic sailing has become much more professional with current sailors being full time rather than part time athletes. This change is important as the vast majority of the literature details the physiological attributes of these part-time athletes.

This thesis examines the physiological demands of elite level single-handed dinghy sailing focussing on the three Olympic classes. The principal philosophy underpinning this research is the need for sport specific ergometry that accurately reflects the sport being investigated. On-water measurements during racing in major International regattas are limited due to the risk of being too intrusive to the elite athlete, whereas measurements immediately post-race only accurately reflect on what has happened during the final stages of what could be a lengthy race. Race durations of between forty and eighty minutes are quite normal. Throughout this thesis a combination of on-water data coupled with laboratory simulations of single-handed sailing is used in order to establish the physiological demands of the sport.

The notion of 'sport specificity' and the need that the ergometer accurately reflects the nature of the task being undertaken is crucial for accurate assessment of training status and more importantly for monitoring changes in training status of the athlete concerned. This principle creates difficulties for sports such as dinghy sailing, which is a complex sport and one where the racing environment changes rapidly and is never exactly the same.

The major debate with single-handed dinghy sailing concerns the principal energy source required to maintain optimum speed in a variety of wind and water conditions at elite level. Based on this debate of the energy systems being utilised, the off-water training regimens have placed little importance on aerobic training but highlight the need for isometric type training. This thesis sets out to examine the interaction between aerobic and anaerobic metabolism in races that last between 40 and 80 minutes, in events that extend over seven days, with two or more races on any day. It does this in three major ways. Firstly, by monitoring technical and physiological responses on the water; secondly, by developing ecologically valid sport specific ergometry; and thirdly, using that ergometry to mimic on-water activities under controlled laboratory conditions. Based on these results detailing the physiological demands of the sport and on an appropriate assessment of both anthropometric and physiological characteristics of elite sailors, appropriate training regimes are recommended aimed at maximising sailing performance.

1.2 Introduction.

Yachts of some description have been dated back thousands of years, with one of the earliest recorded as long ago as 2,600 BC (Knox-Johnston, 1990). Yacht racing originated in the Netherlands during the early years of the 17th Century and the first yacht races in Britain took place in 1660 (Knox-Johnston, 1990). From these relatively casual beginnings of yacht racing some three centuries ago, yachting has developed to become one of the most highly sophisticated and competitive of modern sports. Sailing dinghies first competed in the Olympic Games in 1900 with the first single-handed dinghy appearing in 1928. The sport has grown steadily in popularity from these early origins. In dinghy sailing it has been estimated that 50,000 people compete seriously in Britain alone and that up to 500,000 people sail dinghies at some time each year (McCormack and Davis 1988).

Since yachting made its first Olympic appearance nearly 100 years ago it has grown into a major Olympic discipline. A record 436 sailors representing 77 countries participated in the 1996 Olympic sailing Regatta, where Hong Kong, Japan, Poland and the Ukraine won their first-ever yachting medals. In the Sydney 2000 Olympics there were 11 different sailing classes competing for 33 medals with 468 competitors covering some 69 competing Nations. At these Olympics Great Britain were the top sailing nation, winning all three gold medals in the single handed dinghy classes (Laser, Finn and Europe) and two silver medals in other classes (49'er and Star). Sailing was the most successful British sport at these Games. For the large International Olympic class regattas such as Le Hyeres in France, Medemblik in The Netherlands and Kiel in Germany, there are in excess of 1,000 dinghies/boards and around 1,600 athletes competing. Despite this level of competition and the prominence of sailing in the Olympic Games it is surprising that research into the physiology of dinghy sailing has been relatively scarce.

Stimulus for the thesis.

The driving force behind this thesis originated in 1993 with a half-time appointment of a Project Assistant on the Sports Science Support Programme (SSSP) for the Royal Yachting Association (RYA). This was the first formally established system of offering physiological support to sailing in Britain. The Project Assistant was encouraged to undertake a higher degree (M.Phil/PhD) whilst fulfilling the role of part-time physiologist, the only stipulation being that the higher degree had to be of benefit to the sport concerned. It was mutually decided that the research would be based on establishing the physiological demands of single-handed dinghy sailing and, centred on these findings, appropriate and relevant training programmes for elite dinghy sailors would be recommended. The RYA were keen to have some sports science support in the field setting. At the same time the physiology team (Tudor Hale, John Harrison and Peter Cunningham) held the belief that the effectiveness of the laboratory testing and the subsequent prescription of individualised training programmes would be greatly enhanced if the physiological demands of the sport were understood. Once the physiological demands of the sport were established it would be possible to mimic the sport by developing appropriate sport specific ergometry and, based on these findings, relevant training prescription could be recommended. At the onset of this thesis there were very few published papers that accurately stipulated either the physiological demands of single-handed sailing under racing conditions, or more importantly outlined specific training advice for the dinghy sailor based on scientific rationale.

In joint discussion with the National Racing Coaches at the Royal Yachting Association it was decided that there needed to be an emphasis on establishing the physiological demands of the sport during racing rather than just training, and it was clear that there was a need to be selective in deciding on which classes to work. Olympic competition is the pinnacle of dinghy sailing, so it was decided that the emphasis would be to investigate the physiological demands of Olympic sailing. However, there is still a wide spectrum of different sailing classes competing in the Olympics ranging from large keel-boats to the smaller dinghies and boardsailing. The varying Olympic sailing classes differ substantially in length, mass, sail-area, number of sails, number of sailors, method of keeping the boat upright and type of keel. Table 1.1 lists the various Olympic sailing classes.

Table 1.1. Description of Olympic sailing Classes.

Class	Olympic category	Physical feature	Number of sailors	Mass boat (kg)	Length (m)	Sail area (m^2)
Laser	Single-handed (Open)	Hiking	Skipper[1] only	59	4.23	7.06
Finn	Single-handed (Male)	Hiking	Skipper[1] only	144.7	4.50	10.6
Europe	Single-handed (Female)	Hiking	Skipper[1] only	45	3.35	7.2
Mistral	Windsurfer (male)	Pumping sail	Skipper only	15.0	3.72	7.5
Mistral	Windsurfer (female)	Pumping sail	Skipper only	15.0	3.72	7.5
470	Double-handed dinghy (male)	Hiking, trapezing	Skipper[1] & 1 crew[2]	120	4.70	12.7 + 14.0[3]
470	Double-handed dinghy (female)	Hiking, trapezing	Skipper[1] & 1 crew[2]	120	4.70	12.7 + 14.0[3]
Tornado	Double-handed multihull (open)	trapezing	Skipper[2] & 1 crew[2]	130	6.10	24.0 + 25.0[3]
49er	Double-handed high performance dinghy (open)	trapezing	Skipper[2] & 1 crew[2]	124.4	4.99	21.2 + 38.0[3]
Star	Double-handed Keelboat (male)	Hiking	Skipper[1] & 1 crew[4]	671	6.93	25.73
Yngling	Triple-handed Keelboat (female)	Hiking	Skipper[1] & 2 crew[5]	645	6.35	14.0 + 21.0[3]

[1] hiking, [2] trapezing, [3] spinnaker, [4] Star crew hiking assisted by harness, [5] Yngling crew hiking assisted by hobbles

In Olympic sailing there are five different dinghy classes (*470*, *49'er*, *Finn*, *Europe* and *Laser*), two classes of keel-boat (*Star* and *Yngling*), one catamaran class (*Tornado*) and the boardsailing class (*Mistral men* and *Mistral women*). Of the five dinghy classes the *470* is a double-hander (helm and crew) and there are separate racing disciplines for male and female in this class. The *49'er* is a double-handed skiff that made its Olympic debut in the 2000 Sydney Games and is classified as 'open' (can be crewed by male or female) but is primarily raced solely by males at the elite level. The three remaining dinghy classes are all single-handers, the *Finn* being sailed by males, the *Europe* being sailed by females in the Olympics, and the *Laser*, that made its debut in the 1996 Atlanta Games. The *Laser*, although classified as an open class, similar to the 49'er, is principally raced by males at Olympic level.

The inspiration for this thesis was, in the early stages, coach-led by the RYA. In 1993, the then National single handed racing coach at the RYA (John Derbyshire), having come from a single-handed sailing background held the assumption that single-handed sailors had increased physiological demands. The RYA wanted some training guidelines specific to the requirements of single-handed sailing rather than the sailors following generic training regimens from other sports. At the time the off-water training regimens were being coach- or sailor-led based on belief rather than being led by sports science knowledge. It was therefore decided that the three Olympic single handed dinghy classes (*Laser, Finn* and *Europe)* would be the classes to be investigated for this thesis.

Technical details of specific classes.

i) The Laser. The *Laser* class had only recently (November 1992) been selected as an Olympic class, being scheduled to make its debut in the 1996 Atlanta Olympic Games. It was at that time, and still is, the most popular single handed sailing dinghy ever built. There have been over 180,000 Lasers built to date in the world with racing taking place in around 120 countries (http://www.lasersailing.com). In the 1996 Atlanta Games, 48 countries competed in the Laser sailing regatta, more than in any other sport.

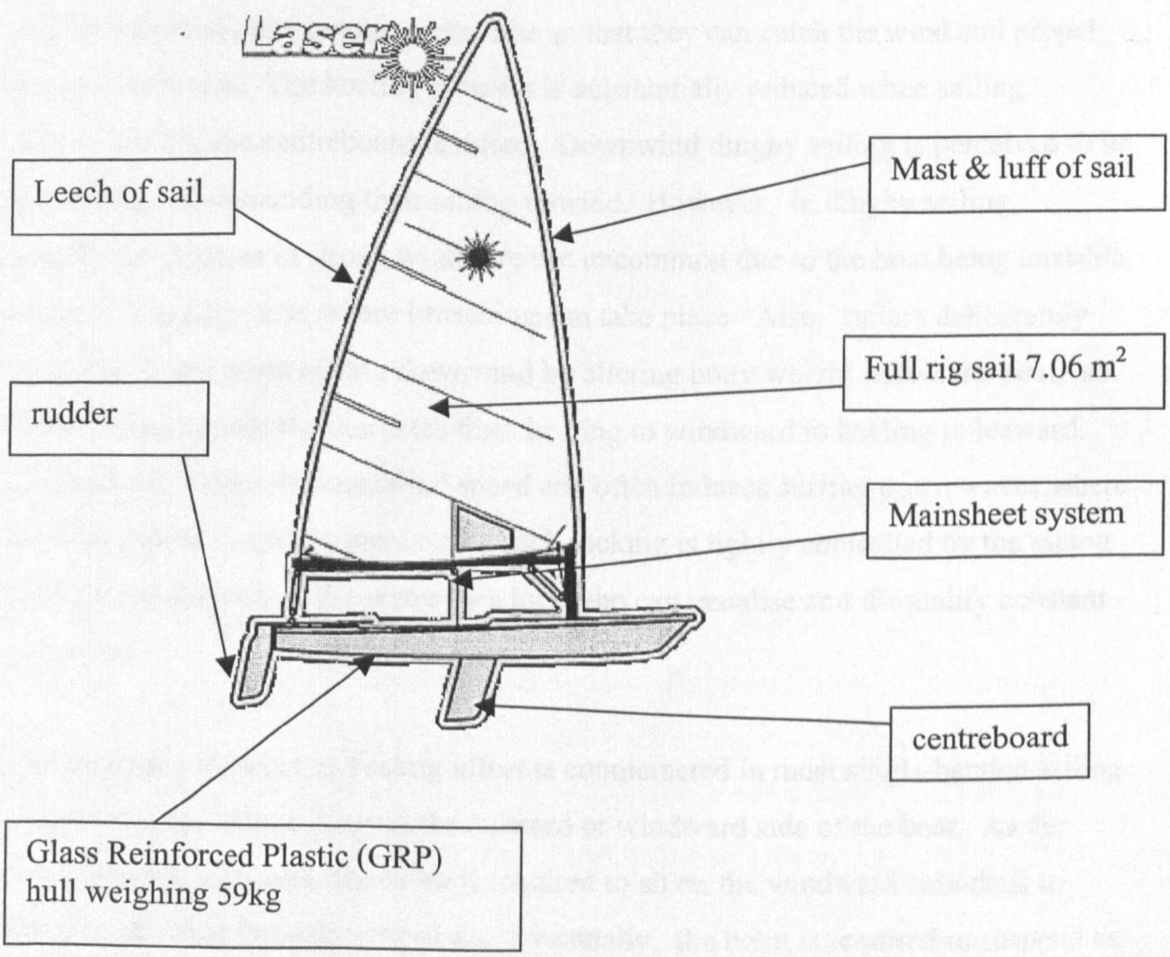
The popularity of the *Laser* dinghy in England, the close and competitive racing due to its strict one design nature, and its recent Olympic status, made it an ideal class of dinghy for investigation. The Laser National championship and weekend open meetings in Britain attract around 200 boats (100 standard rig Lasers and 100 Laser Radials) (http://www.yachtsandyachting.com/default2.asp?section=44). The strict one-design nature of the *Laser* dinghy means that no alterations can be made to the boat or the rigging; thus all the boats are identical which makes the racing close as no sailor has an equipment advantage over the other. The race winner is simply the better sailor where tactical prowess and physical fitness play a crucial part, as opposed to an advantage in boat or rig design as is seen in the other Olympic single-handed classes (*Finn* and *Europe*). The RYA had also planned to utilise the Laser class for developing sailing talent at youth and development level before facilitating sailor movements to other Olympic classes. The Laser is sailed at both senior and youth level, the only difference being that the seniors use the full sail which has a sail area of 7.06 m^2 and the youths can use a smaller sail of either 4.7 m^2 or a 5.76 m^2. At youth level the Laser is raced with the 5.76 m^2 sail, which is termed the Laser Radial class. The Laser is a light-weight boat, weighing only 59 kg and can be transported on top of a car. The ideal body weight for an elite Laser sailor using the full rig is approximately 80 kg (personal communication with John Derbyshire - RYA Olympic Team manager Sydney 2000). The boat's stability and the ease of handling make it ideal for both the novice and the expert alike; however, the boat responds well to careful sail tuning and sharp boat handling by the more experienced sailor.

ii) The Finn and Europe. The other two single-handed dinghies in the Olympics, the *Finn* and the *Europe*, are by contrast expensive classes where top Olympic campaigners spend thousands of pounds on mast and sail development, as these classes do not have such strict one-design status as that of the Laser class. This prohibitive cost often deters newcomers to the class and at the start of this thesis in 1993 the *Finn* and *Europe* classes had a very small following in the U.K. with fleet sizes commonly as small as three or four boats. The lack of racing in Britain in these two classes was a major influence in deciding to investigate the physiological demands of *Laser* sailing, which was thriving. During the course of this thesis the *Finn* class also came under some investigation in an attempt to distinguish the major differences in the physiological demands between *Laser* and *Finn* sailing. The *Finn* was first built in 1949 and has been an Olympic class since 1952. In contrast to the Laser, the Finn is a much heavier boat weighing 145 kg, it has a powerful rig which is characterised by its un-stayed wing mast coupled with a powerful 10 square metre sail. The un-stayed mast and sail combination requires considerable skill to set correctly and has undergone much development over the years. In a breeze the Finn is particularly demanding physically due to the powerful rig the helms tend to be at the heavier end of the scale weighing around 100 kg. During the course of this thesis the interest in Finn racing has increased, with numbers at the UK National championship increasing from 15 in 1993 to 40 in 2003 (http://www.yachtsandyachting.com/default2.asp?section=44). These numbers are still considerably less than the numbers for equivalent Laser regattas in the UK.

The technical challenge of single-handed sailing.

Every sailing craft is propelled forwards via the pressure of the wind in the sail or sails. More often than not the wind pressure creates a heeling or capsizing moment on the craft. This capsizing moment is increased when the wind strength increases and is also greatest when the vessel is sailing into the wind (upwind sailing or beating). Sailing upwind refers to sailing the boat as close as possible to the eye of the wind. It is not possible to sail directly into the wind as the sail would stall, but modern racing dinghies can get as close as 40° to the wind. When sailing upwind (a term also referred to as sailing 'close-hauled') the sail has to be pulled onto the centre line of the craft, this pulling in of the sail is termed 'sheeting'.

Figure 1.1. The Laser sailing dinghy.



The pressure of the wind in the sail not only produces forward motion but also produces a sideways force. The sideways force is counteracted by a centreboard with a dinghy and by a keel in a yacht or 'keelboat'. The centreboard or keel helps to prevent sideways drifting of the vessel by exerting pressure on the body of water. With all dinghy sailing it is necessary to keep the boat as upright as possible, particularly in the stronger winds, as boat speed is greatly reduced when heeling. Sideways slip is also increased when a boat is heeling over whilst sailing upwind as the centerboard is less effective due to a decreased lateral resistance of the tilted centreboard in the water. The other reason for keeping a boat like a *Laser* or *Finn* upright is that it has a small freeboard and the cockpit would soon fill with water which would also be detrimental to boat speed.

When sailing downwind, that is in the direction in which the wind is blowing, the sails are sheeted out from the centre line so that they can catch the wind and propel the boat forwards. The heeling moment is substantially reduced when sailing downwind and the centreboard is raised. Downwind dinghy sailing is perceived to be less physically demanding than sailing upwind. However, in dinghy sailing, downwind capsizes in strong winds are not uncommon due to the boat being unstable especially in large seas where broaching can take place. Also, sailors deliberately rock their boats when sailing downwind by altering body weight within the boat, so that the boat constantly alternates from heeling to windward to heeling to leeward. This rocking increases downwind speed and often induces surfing down waves where the boats speed is greatly increased – such rocking is tightly controlled by the racing rules and monitored on the water by a jury who can penalise and disqualify constant offenders.

The capsizing moment or heeling effect is counteracted in most single-handed sailing dinghies by the helm sitting on the outward or windward side of the boat. As the wind strength increases, the helm is required to sit on the windward side-deck to maintain the boat in an upright plane. Eventually, the helm is required to suspend as much of their body weight outboard as possible. This is achieved by hooking their feet under a strap that runs along the centreline of their boat and is attached to the hull. This allows the sailor to suspend the upper-body over the edge of the boat to balance the capsizing force of the wind, a term called hiking. Figure 1.2 shows a typical hiking posture for a single-handed Finn sailing whilst sailing upwind. In most modern single-handed dinghies, such as the Laser and Finn, it is necessary to hike to the full extent of the body in winds of approx 10 knots and above. It is argued that the hiking action is the main physiological demand of dinghy sailing.

Figure 1.2. The hiking posture for a Finn sailor whilst sailing upwind.

Other classes of sailing dinghy, normally double-handers, control this heeling moment by suspending their body over the windward side of the boat with the aid of a wire attached high up on the mast and attached to the crew via a harness. This technique is called trapezing – and the sailor basically stands against the side of the boat with all their body weight supported via the trapeze. Figure 1.3 shows the 470 crew trapezing whilst sailing upwind (also the helm can be seen hiking).

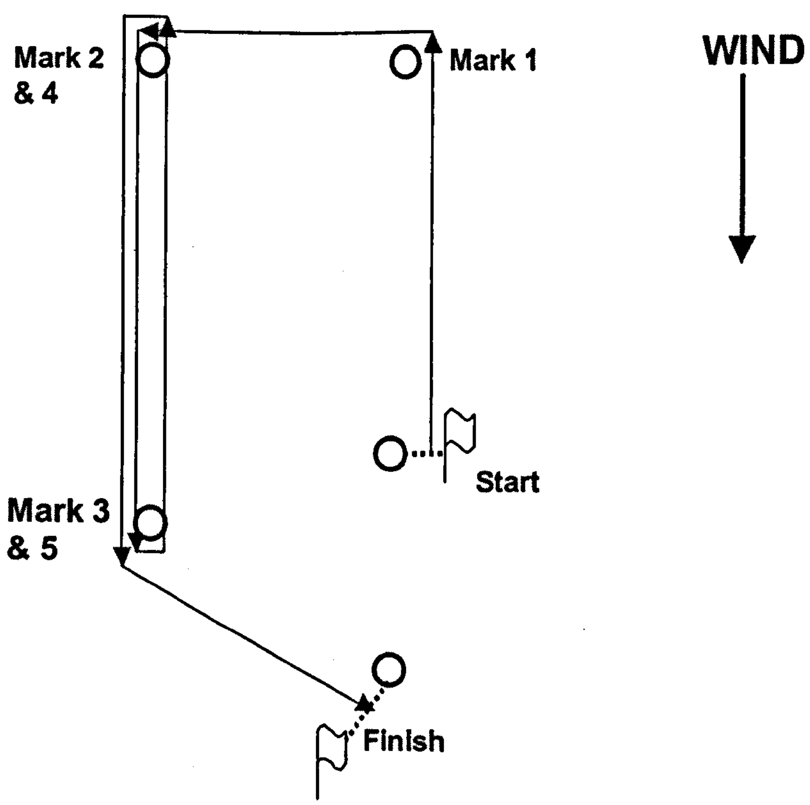
Figure 1.3. The trapezing position of a 470 crew and the hiking position of a 470 helm whilst sailing upwind.

Dinghy racing.

Dinghy races are held in varying wind conditions, with 5 knots (2 ½ $m.s^{-1}$) being the lightest condition and approximately 30 knots (15 ½ $m.s^{-1}$) being the upper wind limit. Racing takes place around a number of set marker buoys. The buoys have to be rounded in a set order as determined by the racing rules. Modern courses are predominantly trapezoid in shape and require the craft to sail into the wind, across the wind (reaching) and with the wind (downwind or running). Races are normally mass starts except where a fleet is so large that boat identification becomes a problem, particularly at the start. In this case the fleet will be divided so that there are normally about 50 craft in each fleet. The start takes place on an imaginary line between two points, which usually consist of a start boat (the committee boat) and a designated marker buoy. Warning signals are fired and flags are displayed to give notice of an approaching start. Each sailor synchronises their own watch with the starting sequence and then aim to be on the start line when the starting flag is lowered and the starting gun fired. Any craft that is over the line is disqualified unless they sail back and re-start.

The first leg is always an upwind leg to the first mark of the course, which requires the dinghy sailors to hike out in order to get maximal speed out of their boats. In Olympic sailing the subsequent legs of a course after the start are typically: upwind, reach, downwind, upwind, downwind, upwind, downwind and reach to the finish. Figure 1.4 shows a typical trapezoid sailing course with an outer loop. Hence it is clear that most of the activity for the sailor is spent sailing into the wind followed by sailing with the wind; there is normally only a limited amount of reaching (sailing across the wind). The aim of the race is to complete the set course and achieve the best possible finishing position in relation to your competitors. Maximal boat velocity is important – speed can be increased by working physically in the boat to get as much power as possible out of the sail. The most physically demanding parts of dinghy sailing are 'playing the mainsheet' that controls the sail, hiking to keep the boat flat, and using the body's kinetics to 'bounce' the boat through waves and to get the boat surfing when sailing downwind.

Figure 1.4. Trapezium Sailing Course (outer loop).



A scoring system is implemented where for 1st position 1 point is awarded, 2nd position 2 points, and so on. Hence, finishing time is not really important; it is simply necessary to beat the other competitors. A regatta is made up of a set number of races. In the 2000 Olympic regatta there was a total of 11 races for each class of boat (two races per day for five days followed by one final race on the last day of the regatta). During the Olympics rest days are included in the sailing programme, so a typical 11 race series will take up to 9 days to complete. It is common practice to allow the sailor to discard their worst two race results over a series of 11 races. The winner of the regatta is the sailor with the fewest points.

Course lengths can vary in distance (nautical miles) depending on the wind strength. In strong wind conditions, where the boats travel at faster speeds, the courses are lengthened by either increasing the number of laps sailed or by increasing the distance between the set marker buoys. Conversely, in light wind conditions the courses are shortened or the marker buoys are kept closer together to account for the reduced speed of the boats. Each class of boat normally has a 'target time' that each race should last and it is the job of the race officials to try to meet these target times. Target race lengths at the 2000 Olympics were 60 minutes for Lasers (with a maximal time limit of 90 minutes), and 75 minutes for Finns (with a maximal time limit of 120 minutes). Thus, given a standard two races a day along with time spent on the water between races, and time spent sailing to and from the race track, a typical sailing day on the water can last between 4-6 hours.

The sports scientist has largely ignored the physiological demands placed on the elite dinghy sailor. Some recent studies (Vogiatzis et al., 1995) have shed light on the physiological demands of dinghy sailing, but these studies were conducted on a sub-elite population during simulated racing, and are possibly not representative of an elite dinghy sailor racing in competitive regattas. The lack of research into the physical demands of dinghy sailing makes it difficult for sports scientists and coaches to implement appropriate training programmes, and also to advise accurately on dietary needs. General principles can be derived from the scientifically based regimens of other sports; however, the dinghy sailor has an unique posture and undergoes specific muscle movements that are both rapid and repeated for long periods in an attempt to get maximum speed out of their boats.

Spurway and Burns (1993) have suggested that elite dinghy sailors who hike should base their land training programmes around improving hiking endurance and as such their training should include:

> *"as much static exercise of the hiking muscles as the participants can tolerate." (p866)*

Blackburn (1994) and Shephard (1997) have also suggested that static training of the specific hiking muscles would be an essential part of a training programme in an attempt to elicit task specific adaptation of the circulation. Advice concerning the necessity for dinghy sailors to conduct aerobic training seems equivocal with some researchers suggesting that it should only form a small part of an elite dinghy sailors training programme (Shephard, 1990 and 1997; and Vogiatzis et al.,., 1995a). In contrast to this Blackburn (1994) concludes:

> *"Dynamic aerobic training by dinghy sailors seems warranted to develop cardiac endurance, facilitate recovery and help to support the dynamic activities in dinghy sailing." (p389).*

This thesis aimed to examine the physiological demands of single-handed dinghy sailing on the water during competitive regattas and then to use this information to construct ecologically valid ergometers in the laboratory where a full range of physiological parameters can be recorded during simulated racing. From this understanding of the physiological demands and the anthropometric profiles of sailors, exercise testing protocols relevant to dinghy sailing are suggested, along with relevant training regimens for elite sailors.

CHAPTER 2

Chapter 2:

Literature Review.

2.1 The physiological demands of Dinghy racing.

There are perceived to be two major physiological challenges to the single-handed dinghy sailor. Firstly, the physical effort required to extend the body outwards over the windward side of the dinghy in-order to keep the boat upright, a term called hiking. Secondly, there are the physical demands placed on the upper-body that are necessary to counteract and control the force exerted by the sail – this force being controlled by a rope system (termed the mainsheet) which is attached to the boom. The requirement for power in the arms and shoulders to 'pump' the mainsheet in order to assist the dinghy in accelerating down waves is greatest when sailing downwind (Legg et al., 1999). Despite the relative lack of research into the physiological demands underpinning dinghy sailing, a successful national dinghy sailor will rightly insist that sailing can be hard physical work, particularly in a high wind (Shephard 1990).

The physiological stress of dinghy sailing is influenced by various external factors such as the wind strength, sea state, wave height, temperature, humidity and whether 'free-sailing' or racing (Gallozzi et al., 1993). Physiological measurements taken under sailing conditions have provided valuable information on the various fitness parameters that are utilised in various sailing conditions. However, there are inherent problems with collecting a wide range of physiological measures in the field. There is a need to carry portable analysers on the water in support boats and such instruments are typically temperamental when used in low temperatures or where large temperature changes exist. In addition, salt water in the form of spray or from waves are damaging to such equipment. Electrical supply is also problematic and normally not available making some physiological measures, such as electromyography (EMG) or automated blood pressure readings inherently difficult. Any attempt at collecting expired gas or oxygen consumption would inevitably impair movement and competitiveness.

Previous research invariably concludes that the greatest physiological challenge for the modern, high performance dinghy sailor is the effort required to keep the boat upright in the stronger winds (Shephard, 1997; Felici et al., 1999). In racing, the sailor normally has one aim – to achieve maximal boat speed at all times. Subsequently, even in strong winds the sailor attempts to maximise the power produced by the sail into forward motion of the boat. Hiking clearly has an important role in keeping the boat upright and maximising the power produced from the sail into propelling the boat forwards as opposed to sideways or even capsizing the craft. If the sailor does not hike out hard when sailing upwind or reaching, the sail will have to be eased out and thus some of its power reduced; boat speed will inevitably suffer.

In addition to hiking, the other perceived physiological requirement is above average upper body strength, particularly in the arms and wrists. These muscles are used for playing the mainsheet that controls the position of the sail in relation to the centre line of the boat and thus optimises the power produced by the sail (Niinimaa et al., 1977, Shephard 1990). Flexibility, agility and balance are also considered to be important physiological attributes for a competitive dinghy sailor and it is suggested that these are:

> *"helpful when changing positions quickly, as the boat 'goes about' at the end of a tack" (Shephard 1990).*

It has been suggested that flexibility of the ankle joint was particularly important (Gourad, 1981, cited in Shephard, 1990), although no data have been offered to support this notion. Plyley et al., (1985) have provided evidence that sailors are more flexible around the hip joint than non-sailing counterparts of the same age. The importance of aerobic fitness for the dinghy sailor is a contentious issue and one that lies at the heart of this thesis.

2.2 The physiological demands of hiking.

Previous research is clear in outlining the muscles that play a major role in hiking. Predominantly these are the abdominals and the quadriceps (Wright et al., 1976; Plyley et al., 1985; Shephard, 1990; Spurway, 1993 and Vogiatzis et al., 1996). The hip flexors can also be expected to play a significant role in hiking (Bursztyn et al., 1988; Aagaard et al., 1998). Putnam (1979) produced a mathematical model of the hiking posture and suggested that large loadings are placed on muscles responsible for both knee extension and trunk flexion In addition, it has been suggested that during hiking, perceived to be static in nature, the rectus femoris exhibits the most pronounced activity of all the working muscles (Marchetti et al., 1980).

There is, however, some disagreement in the literature on the type of muscular contraction involved in performing the physiological role of hiking. Early research into dinghy sailing (Niinimaa et al., 1977; Putnam, 1979) highlighted the purely static nature of hiking. Shephard (1990) suggested that:

> *"hiking demands a sustained isometric contraction of muscles on the anterior side of the body" (p295).*

This purely isometric effort of the quadriceps and abdominals is also suggested by Gallozzi et al., (1993) and by Spurway (1993). Spurway (1993) suggests that hiking involves:

> *"essentially a static (isometric) stress, at a considerable percentage of the muscle's maximum, is imposed on quadriceps and abdominal muscles" (p846).*

Spurway goes on to add that:

> *"as to the muscular involvement, the key feature to recognise is that hiking, being more or less static, requires a diametrically opposite category of effort from the rapid, cyclic movements which are the essence of most other sports" (p846).*

However, truly static hiking would cause prolonged restrictions to blood flow, prevent the attainment of a steady state of blood pressure, and result in rapid muscle fatigue (Lind and McNicol, 1967; Shephard, 1990). More recently the dynamic nature of hiking has been recognised, and that it is only partially static in nature; it could not possibly be totally static because of the ever changing environmental conditions (wind strength and direction, waves and the swell) (Harrison et al., 1988; Aagaard et al., 1998; Castagna & Brisswalter, 2004).

Isometric contractions are commonly associated with increased intramuscular pressure, increased systolic and diastolic blood pressure and only small increases in heart rate (Petrofsky & Phillips, 1986). An isometric contraction equivalent to 15% of maximal voluntary contraction (MVC) can occlude blood supply (Lind and McNicol, 1967; Kahn et al., 1985) and the resulting ischaemia rapidly causes fatigue. The precise percentage of MVC at which blood occlusion, or indeed partial occlusion, takes place is a controversial point. Spurway et al., (2000) have recently suggested that an isometric contraction on the quadriceps at 25% MVC does not totally occlude blood flow.

The notion that hiking was not purely isometric in nature was originally made in Chichester back in 1988. Harrison et al., (1988), suggested that purely static hiking was exceptionally rare and would only apply if three conditions were met: conditions of steady wind speed and direction; a wind speed high enough to require hiking; and flat water conditions. They concluded that such a combination was improbable. Any variation in wind speed and/or direction and the presence of even small waves would require movement by the sailor to maintain optimum boat speed. The group went on to suggest that the extent of this movement, which was termed dynamic hiking, would increase in proportion to wind speed, extent and frequency of changes in wind direction, and height, period, variability and direction of the wave pattern. This was the first use of the term dynamic hiking in the literature. Blackburn (1994), has also criticised previous work, notably that of Niinimaa et al., (1977), because they took measurements during a completely static hiking effort which in his view was unrealistic. Blackburn (1994) suggests that:

> *"in races, hiking is made discontinuous by the whole body movements required to negotiate waves smoothly, and in boat trim and tacking" (p384).*

De Vito, (1993), has also been critical of previous simulations of dinghy sailing saying:

> *"they have taken into account only static postures" (p859).*

De Vito (1993) goes on to say that in competition, sailors – particularly in the single-handed classes – are required to perform fast flexor-extension movements at knee, hip and lumbar girdle and went on to investigate the muscle power required to perform these fast flexor-extension movements.

In more recent times the researchers who once suggested that hiking was purely isometric in nature have been forced to change their view and now suggest that hiking is pseudo-isometric in nature (Spurway, 1997). Spurway defines pseudo-isometric as implying that tension in the muscle is sustained at a high enough percentage of maximal EMG to occlude blood flow, even though some movement around the joint does occur. Recent research by Spurway et al., (2000) makes it clear that, even whilst maintaining a contraction on the quadriceps of 25% MVC, blood flow is not totally occluded. However, even at 25% MVC blood flow is seriously compromised. According to Hagen-Poiseville Law of flow in tubes, flow is a function of the radius (r) of the tube raised to the fourth power (r^4). Thus, doubling the radius increases flow 16 times; conversely halving the radius reduces flow to 1/16th of the original.

Marchetti (1997), suggests that:

> *"the sailor's posture is never really static, him having to adapt to waves and wind variation. Thus on a background of isometric contraction jerks are superimposed which approximate the Maximal Voluntary Contraction (MVC)" (p40).*

This sounds similar to the dynamic hiking as described some years earlier by Harrison et al., (1988). Spurway et al., (2000) have suggested that many sailors deliberately move the load from leg to leg, allowing the unloaded leg some recovery before returning it to work. They have gone on to conclude that:

"the addition of leg movement to a sustained hiking posture which maintained the same net load..... is clear cut: the movement adds markedly to the physical demand of hiking, as assessed by cardiovascular, respiratory and blood lactate parameters" (Spurway et al., 2000, p30).

The dynamic nature of sailing a small dinghy at an elite level and the attempts presently being made to control excess kinetics in sailing has recently been highlighted by a top Olympic sailor:

"body kinetics are part of the dynamic nature of the sport. You can not [sic] *just sit stiff in the boat. It makes a difference between a good talented sailor and a non-sailor, whether you can feel the boat or you're like a stone. It's not a sport for dead people, it's a sport for living athletes who want to move around" (in Cherrie 2002).*

2.3 Physiological profiles of dinghy sailors.

Muscular strength.

Muscular strength and muscular endurance are important aspects in determining sailing performance (Shephard, 1990). In his more recent paper Shephard (1997), suggests that:

> *"it is muscle strength that will facilitate competitive success .... moreover the programme should emphasise isometric endurance, focussing on the specific muscles involved in hiking" (p353).*

Lower-body strength, particularly in the quadriceps and abdominals, is also important for prolonged hiking performance (Niinimaa et al., 1977; Plyley et al., 1985). It is also suggested that upper-body strength, particularly in the wrists and arms, is important for adjusting the trim of the sail and for prolonged grasping of the mainsheet and tiller.

2.3.1 Isokinetic knee extension strength (quadriceps).

Probably the earliest suggestion that sailors exhibited greater quadriceps strength was presented by Niinimaa et al., (1977), where they reported greater eccentric knee extension strength in sailors (1044 ± 242 Nm) when compared to rowers (741 ± 208 Nm) and swimmers (720 ± 168 Nm) at $30°.s^{-1}$. Aagaard et al., (1998), have recently looked into the eccentric and concentric muscle movements involved in knee extension and have suggested that elite male sailors possess greater maximal eccentric quadriceps strength (347 Nm, at $30°.s^{-1}$) compared to matched control subjects (294 Nm at $30°.s^{-1}$). Further to this, these elite male sailors were split into sub groups of those who hiked (N=8) and those who did not (N=7); the mean maximal eccentric quadriceps strength was significantly greater ($P<0.05$) for the hikers (379 Nm at $30°.s^{-1}$) than the non-hikers (311 Nm at $30°.s^{-1}$). Maximal eccentric quadriceps strength for elite female sailors (246 Nm at $30°.s^{-1}$) was similar to those recorded for non-sailing male controls – suggesting the that the maximal eccentric quadriceps strength for the elite females was very high (Aagaard et al., 1998).

In contrast to this Plyley et al. (1985), measured peak isokinetic eccentric knee torques (at 180°.sec^{-1}) in 30 National level Canadian Olympic Class sailors and reported a mean value of only 107.7 ± 19.8 Nm, and suggested that although this is comparable with swimmers (108 ± 26 Nm) and orienteers (111 Nm), it is less than that for badminton players (117 ± 19 Nm) and much less than that measured for rowers (181 ±10 Nm) and alpine skiers (155 Nm). Some of the discrepancy between different researchers may be explained by the relevant methods used, especially the absence or presence of gravity correction procedures (Aagaard et al., 1998). Notwithstanding this word of caution, it is still clear that Plyley et al. (1985) recorded values for maximal eccentric knee extension for Olympic class sailors that were much lower than those recorded for other athletes. Some discrepancy can possibly be explained by the fact that Plyley et al. (1985) grouped Olympic sailors under one heading instead of splitting them into those who hike and those who trapeze. In their study 30 sailors from seven different Olympic classes (boardsailing, Finn, 470, Flying Dutchman, Tornado, Star and Soling) were analysed and data presented as one mean value. However, only the single-handed Finn sailor and the 470 skipper would hike out hard, and it would have been more useful if the data had been presented as class specific rather than averaged across all the different classes. The 470 crew and the boardsailor do not hike; the former trapezes and the latter stands, and although the Soling crew and the Star crew do hike they are greatly aided in the process by hobbles in the Soling and by a chest harness in the Star.

2.3.2 Isometric knee extension strength (quadriceps).

Blackburn (1994), reported a mean value of 270 ± 42 Nm for 10 Australian national and International standard Laser sailors when performing isometric knee flexion at a knee joint angle of 129 degrees [presumably the joint angle posterior to the knee between femur and tibia equivalent to 51 degrees if measured anteriorly as is the norm with zero degrees representing full extension]. This is slightly less than the values recorded by Aagaard et al., (1998) at 323 Nm and those from Shephard (1990) at 1044N (~ 305-325 Nm). This discrepancy may be due to the joint angles that Blackburn used. He tried to replicate joint angles at the knee (51 degrees measured anterior to the knee) and the hip (104 degrees) that were similar to those observed during mean hiking positions, whereas Aagaard et al. used a knee joint angle of 65 degrees. Aagaard et al. (1998) compared their results to the data they had recorded for similar aged male controls at 308 Nm, and to other athletes notably those of oarsmen at 741 N (~224 Nm) (Wright et al., 1975) and swimmers at 720 N (~ 217 Nm) (Shephard et al., 1990). Unfortunately, Aagaard et al. (1998) did not report any separate data for the two sub groups in their elite Danish sailors of hikers (N=8) and the non-hikers (N=7), but presumably there were no significant differences between the sub-groups otherwise they would have been reported. However, it seems that previous research indicates that peak isometric quadriceps strength is elevated in dinghy sailors.

Aagaard et al. (1998) suggest that difference in peak isometric quadriceps strength in elite male dinghy sailors compared to matched male controls (323 Nm and 308 Nm, respectively), is less pronounced than the corresponding difference in peak eccentric quadriceps strength (347 Nm and 294 Nm at $30°.s^{-1}$, 350 Nm and 291 Nm at $120°.s^{-1}$, and 341 Nm and 284 Nm at $180°.s^{-1}$ for the elite sailors and the controls, respectively). Thus, it seems that the most significant physiological attribute concerning leg strength in elite dinghy sailors is established during an eccentric contraction of the quadriceps. The noticeably higher values established are possibly a specific adaptive response to sailing itself. It is interesting to note that Aagaard et al. (1998) suggest that the eccentric quadriceps strength is an important factor due to the significant amounts of eccentric quadriceps loading imposed during hiking. This clearly suggests that hiking is not static or isometric in nature and as Aagaard suggests:

> *"small-amplitude dynamic movements are frequently incorporated during hiking" (p143).*

These movements are probably made in an attempt to prevent the occlusion of blood flow through the contracting quadriceps and also to compensate for the motions caused by the wind and waves. This seems to be in direct contrast to the work of Plyley et al. (1985) and Shephard (1990), where the latter stated that:

"dynamic force is less important to the sailor than a sustained isometric effort" (p296).

2.3.3 Isometric and isokinetic knee flexion strength (hamstrings).

Plyley et al., (1985) and Shephard (1990) also argue that maximal forces exerted by the hamstrings during knee flexion, albeit isometric or isokinetic in nature, have little relevance for the dinghy sailor. Plyley et al., (1985) reported peak isokinetic flexion torques of 85.7 Nm (measured at $180^{\circ}.s^{-1}$) for 30 Canadian Olympic class sailors (as discussed above these sailors covered a wide rang of different Olympic classes). Plyley et al., (1985) suggested these peak isokinetic values were similar to data he had collected for orienteers (87 Nm) and alpine skiers (89 Nm), but less than that reported for runners (90 Nm) and badminton players (95 ± 16 Nm) and much less than that for rowers (136 ± 8 Nm). Aagaard et al., (1998) suggested that the case concerning hamstring strength was not quite as clear cut at this. They also suggested that the peak concentric flexion torque around the knee joint (measured at 30, 120 and $180^{\circ}.s^{-1}$) was not a distinguishable attribute for elite dinghy sailors, and indeed reported greater values in the matched controls than in the elite sailors at two of the speeds (120 and $180^{\circ}.s^{-1}$). However, peak eccentric hamstring strength was notably higher in the elite dinghy sailors than the male controls at all three speeds measured (30, 120 & $180^{\circ}.s^{-1}$). The elite sailors recorded greater eccentric torques on average by 22.3 Nm over the three speeds measured (169 Nm against 146 NM at $30^{\circ}.s^{-1}$, 172 Nm against 149 Nm at $120^{\circ}.s^{-1}$ and 171 Nm against 150 Nm at $180^{\circ}.s^{-1}$, respectively for sailors and controls). Although the difference was not statistically significant it is an important finding and suggests, as pointed out by Aagaard et al., (1998), that elite sailors possess a greater capacity for muscular knee joint stabilisation. During an active quadriceps contraction, the involvement of antagonist hamstring co-contraction forces are likely to result in a reduction of the bone-on-bone stress forces and the anterior-posterior shear forces acting at the knee joint (Baratta et al., 1988).

There is very little literature detailing isometric knee flexion values in dinghy sailing. Aagaard et al., (1998), reported similar values between the elite male sailors and the matched controls for isometric knee flexion strength with mean values of 130 and 131 Nm, respectively. This may indicate that isometric knee flexion is not an important attribute to the physiological profile of an elite dinghy sailor. It can only be assumed that the importance of eccentric knee flexion rather than isometric knee flexion is a distinguishable trait due to the dynamic nature of dinghy sailing rather than the commonly purported isometric nature of the sport.

2.3.4 Trunk strength.

Both the strength of the trunk muscles and their muscular endurance are perceived to play an important role in hiking. Despite this only a few papers detail the strength and endurance of these muscles in sailors (Niinimaa et 1977, Plyley et al., 1985, Larsson et al., 1996, Aagaard et al., 1998). The work of Niinimaa and Plyley was quite limited; the only measures of trunk endurance were to record the number of sit-ups performed in one minute. The work of Larsson et al., (1996) and that of Aagaard et al., (1998), both working in the same laboratory with elite Danish sailors, is much more detailed and looks at both isokinetic and isometric performance using appropriate dynamometers.

Aagaard et al., (1998) measured isokinetic trunk extension and flexion strength using a Kin-Com dynamometer at angular velocities of 0, 15 and $50^{\circ}.s^{-1}$ over a -15° to $+30^{\circ}$ range of excursion (0 degrees = trunk vertical, positive degrees = movements in ventral plane, negative degrees = movements in the dorsal plane). Some subject pain and discomfort was reported during preliminary work whilst attempting to establish maximal eccentric trunk muscle strength so these measures were not obtained. Aagaard et al., (1998), reported that the elite male sailors exhibited very high levels of maximal trunk extensor strength which were significantly greater than their male controls for all measured conditions (isometric extension 386 ± 51 Nm against 330 ± 61 Nm, at $15^{\circ}.s^{-1}$ 352 ± 62 Nm against 288 ± 54 Nm, and at $50^{\circ}.s^{-1}$ 318 ± 65 Nm against 266 ± 46 Nm, respectively for male sailors and matched controls). In the sub-group of male hikers (N=8), Aagaard et al., (1998) went on to suggest that there was a much greater and significant relationship between hiking performance and maximal trunk extension strength than that recorded for the whole group of male sailors that included hikers and non-hikers (N=15).

Peak trunk extension values for female sailors were 296 ± 25 Nm (isometric), 263 ± 59 Nm (at $15^{o}.s^{-1}$) and 232 ± 60 Nm ($50^{o}.s^{-1}$) were statistically comparable to the male control subjects. It is usual to record much lower values for trunk extensor strength in females than for age matched males (Anderson et al., 1988; Thompson et al., 1985), thus, it is suggested that female sailors also possess notably high levels of maximal trunk muscle strength.

It does seem that the role played by the antagonist muscles involved in trunk and hip extension is important, probably to stabilise the lower back and spine. In conclusion Aagaard et al., (1998) suggested that there were:

> *"significant relationships between hiking performance and maximum trunk extension"....* and that *"even for highly skilled hikers a very strong quadriceps and trunk musculature thus seems to be important for an optimal hiking performance" (p143).*

Values for peak trunk flexion strength reported by Aagaard et al., (1998) for both sailors and controls during low velocity movements ($15^{o}.s^{-1}$) seem to be much greater than values reported elsewhere for non-sailors (Thorstensson & Nilsson, 1982). However, the values reported for fast trunk flexion (50 degrees.s^{-1}) for both sailors and controls by Aagaard et al., (1998) were somewhat less than that reported for well trained male and female athletes (Andersson et al., 1988; Davis & Gould, 1982; Thompson et al., 1985). Aagaard et al., (1998) explain that these discrepancies with previous published data are most likely to be caused by either differences in gravity correction procedures or from positioning of the subjects on the dynamometer with particular reference to hip joint angle. What is clear is that Aagaard et al., (1998) have suggested that the values recorded for peak trunk flexion strength between male sailors and male matched controls were not as high when compared to the corresponding differences for the same subjects for trunk extension. This suggests that trunk flexion strength is less important to the dinghy sailor than trunk extension strength.

2.3.5 Upper-body strength.

It is clear that sailors spend much time in trimming their sails to optimise the power generated by the wind in the sail. The position of the sail is controlled by a rope system, the mainsheet. The mainsheet is normally attached to the rigging via a pulley system and attached on the boom. Trimming of the sail (or sails) is virtually continuous during top racing; it takes place generally as the wind varies in speed or direction or when the course of the boat is altered. Changing wave patterns, altering course to round a race buoy, loss of apparent wind (particularly when sailing downwind), tacking the boat, heading tighter to the wind to get past an opponent, are all examples of when trimming the sail is essential in an attempt to keep up boat speed. Even when not trimming the sails, the elite sailor will only very seldomly cleat the sail; Laser sailors commonly remove the mainsheet cleat as it can accidentally cleat the sail. Thus a persistent isometric effort is required to maintain the grip on the sheet at all times. In the Laser and the Finn class the diameter of the mainsheet is 8 mm and 10 mm, respectively. It is difficult to maintain a grip on such small diameter ropes. Commonly, a wrap is taken around the hand; gloves are usually worn to protect from both rope burns and blistering, such is the loading on the sheet, particularly in stronger winds.

Blackburn (1994), has suggested that in winds of approximately 12 knots (6.2 $m.s^{-1}$) the static loadings on the Laser class mainsheet whilst sailing upwind are 98 N which are reduced to 59 N whilst sailing downwind. In contrast to this he has suggested that the dynamic loadings, when trimming or pumping the sail, are increased to 549 N and 294 N whilst sailing upwind and downwind, respectively. Mackie and Legg (1999) have reported average loadings of 111 N (35% MVC) for upwind Laser sailing in winds of 15-20 knots with peaks of 289 N (90% MVC) in the same conditions.

Niinimaa et al., (1977), were probably the first to suggest that upper-body strength was an issue in dinghy sailing. They looked at isometric forearm flexion and extension on the Ontario Sailing Team using a Clarke cable tensiometer. They reported that sailors scored poorly for both forearm flexion (452 ± 44 N) and forearm extension (374 ± 50 N), which was lower than values at the time reported for swimmers, oarsmen and paddlers. Niinimaa went on to highlight the five best members of the team, selected by the Captain's rating, and reported significantly higher values for forearm extension recorded at 463 N ($P<0.001$) but not significantly greater forearm flexion measured at 490 N ($P>0.05$).

Handgrip strength has been measured using a Stoeling handgrip dynamometer by Niinimaa et al., (1977), where they reported that sailors scored higher than most other sportsmen (610 ± 53 N, averaged for both arms). Plyley et al., (1985) reported slightly lower values of 558 ± 82 N (averaged for both arms) for 30 members of the Canadian Olympic sailing team, and suggested that their handgrip strength was only 6% above national norms. They went on to suggest that it is common for athletes who substantially use their hands to have localised development of the wrist muscles, and reported greater mean values for rowers (648 N), similar values for badminton players (545 N), and lower values for both orienteers (505 N) and swimmers (457 N).

Plyley et al., (1985) also measured general upper-body strength in their sailing population via a Biokinetic Swim Bench, which measures amongst other values peak power and peak force. No other studies have measured general upper-body strength for sailors in such a way so comparisons are not possible; also Plyley has not made comparisons in his paper between sailors and athletes from other sports. Peak power was measured at 589 ± 145 watts, with peak force measured at 346 ± 23 N. Peak force did not differ much amongst sailors from different classes or between helms and crews with the 470 crew recording the lowest value at 325 N and the Soling crew the highest at 363 N.

2.3.6 Muscular endurance.

The role of muscular endurance in sailing is clearly an important issue as certain muscle groups have to keep performing for prolonged periods. This is particularly so for the hiking muscles such as those responsible for knee extension and flexion, trunk extension and flexion, and muscles of the upper-body that are involved in trimming the sail. Shephard (1997) in his more recent review of sailing suggests that:

> *"the lesson that emerges strongly from recent physiological research is that the main determinant of performance in dinghy sailing is muscular endurance rather than aerobic fitness.....moreover, the programme should emphasise isometric endurance, focusing on the specific muscles involved in hiking" (p353).*

Various researchers have attempted to measure muscular endurance of sailors, these attempts vary from crude measures such as the number of sit-ups and chins performed in one minute (Niinimaa et al., 1977; Plyley et al., 1985) to more scientific measures working the specific sailing muscles at certain percentages of their MVC until exhaustion with time being the performance measure (Larsson et al., 1996).

Muscular endurance may well be more important than strength in determining dinghy sailing performance. As race times are relatively long (average 60 to 75 minutes for the single-handed Laser and Finn in the recent 2000 Olympics) the important point is not necessarily how great a sailor's MVC is for a certain muscle, but how long a certain percentage of that MVC can be held before the muscle fatigues. Clearly a high MVC on the sailing specific muscles may be beneficial as this would allow the sailor to work at a lower percentage of that MVC and still exert the same external loading. However, it is not necessarily the case that the sailor with the highest MVC can perform an endurance task, such as prolonged static hiking in the laboratory, for the longest time period (Larsson et al., 1996).

Niinimaa et al., (1977) were probably the first to establish some measures for muscular endurance specific to sailing and reported findings for 10 male members of the Ontario sailing team. They measured the number of speed sit-ups performed in one minute from a bent knee position and found that sailors, recording on average 42.6 per minute, were significantly better than the normal values for men of that age which Plyley et al., (1985) reported as being 25 in 60 seconds (Canadian Fitness Survey values for 20-30 year olds). Plyley et al., (1985) reported a mean value of 51.7 ± 11.2 bent knee sit ups in 60 seconds for the 30 members of the Canadian sailing team in his study. Interestingly, in that study the sailors from the single-handed Finn class recorded the highest number of sit-ups, with a mean number of 62 performed in the 60 second period.

Niinimaa et al., (1977) found that sailors performed no better than non-sailors when performing isometric knee extensions at 50% MVC and 75% MVC with mean times to volitional exhaustion of 83.7 ± 12.6 seconds and 38.6 ± 13.4 seconds, respectively. However, when separating the five best sailors within the team (based on Captain's rankings) it was evident that the better sailors performed for a significantly longer time ($P<0.001$) when performing isometric knee extensions at 50% MVC with a mean time to exhaustion of 137.2 seconds. Niinimaa suggested that the 50% MVC contraction was the better indicator of sailing performance because it is rare that more than 50% of the quadriceps force is exerted in hiking.

Plyley et al., (1985), measured quadriceps endurance by recording the decrease in torque when performing 50 isokinetic knee flexions and extension (measured at 180 degrees.s^{-1}). They suggested that although the MVC values for knee flexion and extension were not particularly that high when compared to other sportsmen, the drop off in strength during both knee extension (50.0 %) and knee flexion (40.3 %) was considerably less than that recorded for other athletes.

Larsson et al., (1996) have probably produced the best study into muscular endurance, whilst working with elite Danish sailors. Not only did they record rather simplistic measures of muscular endurance but they also established functional tests for muscular endurance using a hiking bench. Measures of isometric endurance of the trunk flexors and back extensors were made by getting the sailors to lie prone and then raise the upper-body (above T12) off the floor and simply record the time that the subjects could hold the position before fatiguing. Isometric trunk endurance of the abdominal muscles were similar for the combined male sailors (60 ± 5 seconds), male controls (57 ± 10 seconds) and female sailors (58 ± 12 seconds). However, the 8 male hikers (69 ± 8 seconds) performed better than all the other groups and were significantly better ($P<.05$) than the non-hikers (50 ± 5 seconds). A similar pattern was established for isometric trunk endurance of the back muscles with hikers (138 ±

10 seconds) significantly better (P<0.05) than non-hikers (116 ± 6 seconds) but not significantly better (P>0.05) than male controls (123 ± 4 seconds) or female sailors (136 ± 7 seconds). Thus, it is clear that dinghy sailors who hike have superior muscular endurance in both the trunk flexors and extensors. In a similar fashion to the findings suggested a few years earlier by DeVito et al., (1993) Larsson et al., (1996) have speculated:

> *"that superior hiking endurance times could indicate that isometric endurance is high in knee extensors, hip flexors and abdominal muscles" (p507)*

The functional test of leg endurance was performed in a hiking bench. Initially the maximal hiking force was calculated by measuring the force exerted on the toe strap via strain gauges whilst hiking with a knee joint angle of 45 degrees and the trunk in a horizontal position. For the isometric endurance task the sailors kept the knee angle the same but adjusted the hip angle so that they hiked at 75% of the maximal force. Time to exhaustion was measured. Hikers (218 ± 38 s) were significantly (P<0.01) better than both male controls (107 ± 16 s) and non-hikers (98 ± 12 s), but were not significantly (P>0.05) better than female sailors (153 ± 21 s), [results are expressed as means ± SE]. A second evaluation of muscular endurance was conducted. This consisted of a dynamic hiking test conducted along the same lines as the isometric test with the exception that subjects had to hike with a cyclical hiking movement (1Hz) within a hip range of motion of 35-60 degrees of flexion (knees maintaining 45 degrees of flexion throughout). A similar pattern existed in the results with hiking sailors producing significantly better performance than other groups with the exception of female sailors who produced 50-60% better hiking endurance than both male controls and non-hiking sailors. The main difference between the dynamic hiking test and the isometric endurance hiking test was an overall reduction in hiking times for the dynamic test. This suggests that the added movement imposed by hip flexion at a strenuous rate adds significantly to the fatigue process.

Larsson et al., (1996) also measured arm endurance by connecting a mainsheet to the flywheel of an arm ergometer and then getting the subjects to perform maximal elbow flexions for 60 seconds by pulling the mainsheet; all this was conducted whilst hiking. Separate tests were conducted on the left and right arms. Sailors in general showed significantly ($P<0.05$) higher work outputs than controls for left arm only (737 ± 20 revs, against 679 ± 20 revs, respectively). Hikers were found to have markedly higher arm performance for both left and right arms when compared to male controls (left arm $P<0.01$, right arm $P<0.05$) and non hikers ($P<0.05$ for both left and right arms).

Larsson et al., (1996) make their concluding thoughts clear....:

> *"Elite sailors who perform hiking activity during sailing show higher isometric endurance in a hiking bench test and a better performance in an all-out arm test compared to non-hiking elite sailors and non-sailing controls matched for age, fitness [maximal aerobic capacity] and weight" (p508).*

2.3.7 Aerobic fitness.

Aerobic fitness, according to most of the literature, is of little importance to the sailor (Niinimaa et al., 1977; Plyley et al., 1985; Shephard, 1990; Gallozzi et al., 1993; and Vogiatzis et al., 1994). Vogiatzis et al., (1995a) even go so far as saying that:

> *"aerobic capacity is only moderately taxed in dinghy sailing [Laser class] and should not be emphasised in training..." (p 103).*

Indeed many papers have reported only modest maximal oxygen uptake ($\dot{V}O_{2max}$) figures for dinghy sailors. Niinimaa et al., (1977) reported a maximal oxygen uptake figure of 49.5 ± 6.7 ml.kg.$^{-1}$min^{-1} (4.16 ± 0.57 l.min^{-1}) for the Ontario Provincial Team. Plyley et al., (1985) reported even lower values for the Canadian National Team of 45.3 ± 8.4 ml.kg^{-1}min^{-1} (3.54 ± 0.70 l.min^{-1}), but these values were estimated from heart rate during sub-maximal cycle ergometry using the Åstrand and Åstrand nomogram (Åstrand, 1960). Vogiatzis et al., (1995a) reported $\dot{V}O_{2max}$ values of 52.0 ± 6.0 ml.kg^{-1}min^{-1} (3.84 ± 0.44 l.min^{-1}) for eight members of the Scottish National Laser Squad.

There are some reports of high maximal oxygen uptakes in elite sailors that are comparable to other elite athletes like soccer (Bangsbo et al., 1993), tennis (Bergeron et al., 1991), ice hockey (Resina et al., 1991) and alpine ski-ing (Rusko et al., 1978). However, in comparison with endurance sports like cycling and running, sailors have a markedly lower (by approximately 25%) aerobic capacity (Åstrand and Rodahl, 1986; Rusko et al., 1978). The highest recorded $\dot{V}O_{2max}$ values for dinghy sailors have been reported by Piehl-Aulin et al., (1977) for members of the Swedish Sailing Squad at 62.0 ± 8.0 $ml.kg^{-1}min^{-1}$, by Blackburn (1994) for members of the Australian National Laser Squad at 62.3 ± 8.2 $ml.kg^{-1}min.^{-1}$ (4.71 ± 0.62 $l.min^{-1}$), and more recently by Larsson et al., (1996) who recorded mean values of 61.4 ± 2.0 $ml.kg^{-1}min^{-1}$ for elite Danish sailors. In the latter study, the authors reported that hikers (N=8) had significantly greater $\dot{V}O_{2max}$ values of 63.8 ± 1.7 $ml.kg^{-1}min^{-1}$ than non hikers (N=7) at 58.6 ± 3.8 $ml.kg^{-1}min^{-1}$ ($P<0.05$). Larsson et al., (1996) reported the highest individual $\dot{V}O_{2max}$ figure of 71.0 $ml.kg^{-1}min^{-1}$ for one of the male hikers. Measures of aerobic power for female sailors are scarce. Larsson et al., (1996) reported a mean value for elite female Danish sailors of 50.1 ± 1.4 $ml.kg^{-1}min^{-1}$ (N=6), with a range of 46-55 $ml.kg^{-1}min^{-1}$.

Indeed, some of the more recent research findings (Devienne & Guezennec 2000) have suggested that:

> *"aerobic capacity could be considered as a factor of performance for competitive sailors....moreover, we have observed a very high energy expenditure..." (p237).*

Increasingly, researchers who were originally adamant believers that hiking was isometric in nature and thus diminished the importance of aerobic capacity are now suggesting that, if counter movements are added to the hiking action, this will add markedly to the physical demand of hiking including respiratory and cardiovascular parameters (Spurway et al., 2000).

Laboratory measured fitness parameters of elite sailors are useful indicators into the necessary physiological attributes of the sport. However, it is necessary to examine exactly what happens in the boat to get an understanding of the true physiological demands of the sport, hence physiological measurements during sailing are warranted.

2.4 Review of on-water studies in dinghy sailing.

The collection of physiological data in the field is comparatively scarce when compared to data available from laboratory simulations of dinghy sailing. In-addition, such investigations during International competition are very limited. There are two main reasons. Firstly, the collection of physiological data in the field is inherently difficult to obtain and standardise due to the challenging environmental conditions and the nature of the sport. Secondly, limitations with analytical equipment have accounted for the lack of physiological measurements other than heart rate trends. However, such information is an important feature for any applied sports scientist where the prescription and optimisation of a training program must be based on the physiological demands that the athlete undergoes during competition and training.

Durnin and Passmore (1967) issued the statement that:

> *"we know of no-one who has measured the energy cost of any of the different activities in which a yachtsman is employed. Most yachtsmen probably find that their recreation provides them with exercise of a light grade, but with occasional periods of moderate or heavy exercise" (p88).*

The lack of interest possibly stems from the fact that the activity seems to have a supposedly low energy cost. Harrison and Coleman (1987) also suggested that the physiological demands of dinghy racing had been largely ignored by the sports scientist and that there was no background to enable coaches to plan appropriate training or dietary regimens. Shephard (1990) suggested that the statement made by Durnin and Passmore some 23 years earlier still seemed true. However, in more recent times there have been a few studies conducted on the water that have looked into the energy cost of sailing (Gallozzi et al., 1993; Vogiatzis et al., 1994; Vogiatzis et al., 1995a; Devienne & Guezennec, 2000). However, only the measurements of Gallozzi (1993) and that of Devienne & Guezennec (2000) were conducted during a competitive regatta, and only the former dealt with dinghies (and then with only one subject in each sailing class), whereas the latter was based on larger keel-boat yachts.

Originally the measurement of heart rate during sailing was the only way of assessing the physiological stress of the various activities that the sailor undertook. Early work suggested three main findings: that sailing upwind was considerably harder physically than sailing downwind; the physical demands increased as the wind speed increased; and that single-handers were physically more demanding than double-handers even in the same wind conditions (Cudmore, 1969; Piehl-Aulin et al., 1977; Dierck and Rieckert, 1980; Pudenz et al., 1981; and Harrison & Coleman, 1987).

2.4.1 Cardiovascular measurements from on-water studies.

In one of the initial studies on the water Dierck and Rieckert (1980), looked at the heart rates and blood glucose levels in Optimist sailors. Optimists are sailed by youngsters aged between the ages of 8 to 14 years. Dierck and Rieckert recorded heart rates that were so low that they advocated that the youngsters should adopt a second sport to maintain cardiovascular fitness. Bachemont et al., (1984), recorded heart rates in the double-handed 470 class (still an Olympic class today) during on-water training sessions in moderate winds. They concluded that heart rates remained below 120 beats.min^{-1} for 75% of the time and never exceeded 140 beats.min^{-1}. Marchetti et al., (1980), recorded heart rates for three Laser sailors whilst sailing in a steady winds and flat water, so that the hiking posture was isometric in nature. At the end of a 30 second bout of hiking, heart rates had risen from a resting mean value of 63 beats.min^{-1} to a mean value of 148 beats.min^{-1}. The duration of this hiking effort was far shorter than in races which typically last approximately 60-75 minutes for single-handers, and the hiking posture was unrealistic in that it was totally isometric in nature and the subjects had greater extension of the body than normally takes place when racing. Harrison & Coleman (1987) presented their initial findings into racing from the single-handed Europe class dinghy and suggested that heart rates vary depending on both the wind strength and angle of sailing in relation to the wind direction. The lowest heart rates were recorded whilst sailing downwind in light conditions (wind speed 1-3 $m.s^{-1}$) where the readings only amounted to 14% of the sailors' heart rate reserve (HRR). In stronger wind conditions (10-12 $m.s^{-1}$) the peak reading occurred whilst reaching (sailing across the wind) and amounted to 86% of the HRR. These findings were indeed tentative and limited by the fact that the data reported only accounted for two subjects.

The difference in heart rates between sailing upwind and downwind does seem more pronounced in the single-handers. Pudenz et al., (1981), reported data for Laser sailors in strong winds (8.1 to 13.8 $m.s^{-1}$) where upwind heart rates averaged 168 ± 12 $beats.min^{-1}$; in moderate winds (3.4 to 8.0 $m.s^{-1}$) heart rates were lower with upwind averages of 143 ± 9 $beats.min^{-1}$. Pudenz also highlighted the difference between upwind and downwind heart rates and reported that average downwind heart rates in the stronger winds were 138 ± 8 $beats.min^{-1}$. The difference in mean heart rates from upwind and downwind of 30 $beats.min^{-1}$ may be very significant for the sailor, suggesting that downwind sailing offers a period of relative recovery. Indeed, Laser sailors commonly report that the most difficult part of downwind sailing is a combination of tactics and ability to steer effectively down the waves, whereas the physical effort of playing the mainsheet is quite small due to the lack of power generated by the relatively small Laser sail when sailing downwind. Downwind hiking is quite minimal in most single-handers, as the righting moment is greatly reduced as the sailor lets the sail out, thus reducing the force in the mainsheet, in order to catch more wind.

For the crews of a 470 (trapezing) it is a case of a complete reversal where downwind heart rates are higher than upwind heart rates. This is possibly related to the fact that the trimming of a spinnaker increases heart rates by about 30-40% (Piehl-Aulin, 1977). Bachemont et al., (1984) also noticed a difference in heart rates between crew and helm in the 470 class when sailing in strong winds, and suggested that 15% of the heart rate readings for the helm exceeded 130 $beats.min^{-1}$ as opposed to 25% for the crews.

There is little in the research detailing any heart rate data for Finn sailors. One of the first studies into the physiological demands of dinghy sailing was by Cudmore (1969) who concentrated solely on changes in the cardiovascular system of the Finn helmsman in different wind speeds. He suggested that the most physical effort was in launching the boat:

> *"the heart rate was greatest in taking the boat from the dinghy park, some 75 yards to the water for launching. This pushed the heart rate up to 120 beats per minute and was the period of greatest cardiovascular activity" (p804-805)*

Cudmore (1969) also reported constant heart rate values of approx 68 beats.min^{-1} in wind speeds of 2-5m.s^{-1}, and slightly higher recordings in wind speeds of 7-10 m.s^{-1} where average values were a constant 85 beats.min^{-1} for sailing upwind and 95-100 beats.min^{-1} for sailing downwind. Cudmore explained the steadiness in heart rates whilst sailing upwind as a reflection of the isometric nature of 'sitting out' that the helmsman developed in these winds. Interestingly, an increase in heart rates of approximately 10-15 beats was reported just prior to the start and explained as nervous excitement affecting the sympathetic nervous system and the release of adrenaline. Cudmore suggested that in winds above 7m.s^{-1} the most physical challenge to the Finn sailors was overcoming local muscular fatigue in the upper limbs, stomach, back and quadriceps group of muscles and recommended that these areas should be the focus of the sailors off-water training program.

Gallozzi et al., (1993) looked at one Finn sailor in rather non-demanding light wind conditions and reported that the mean heat rate during a race was 106 beats.min^{-1}, with maximum and minimum value of 156 and 81 beats.min^{-1}, respectively. They have not broken the data down into upwind/downwind figures but from his graphical presentation (p852) there is no obvious difference in the heart rate trend between upwind and downwind sailing. The only noticeable point is that both heart rate and oxygen uptake were elevated during race manoeuvres such as tacking and mark rounding. The lack of any obvious trend in the heart rates for this Finn sailor has two possible explanations. Firstly, it could be due to the undemanding conditions. Secondly, it could simply be that Finn sailing downwind is more demanding (also supported by Cudmore, 1969), possibly due to the extra power generated by the more sophisticated and powerful rig in comparison to the Laser.

The analysis of heart rates in dinghy sailing and the varying trends during a race have been heavily criticised as a misleading method for measuring the physical demands of the sport. In some cases the strong emotional aspect of the sport have been used to explain why the elevated heart rates distort the true physiological meaning (Bachemont et al., 1984; Gallozzi et al., 1993). The complex reasoning required by the helm, which has at times been likened to a game of chess (Shephard, 1990), certainly requires sustained attention (Gouard, 1981). However, it is doubtful whether this cognitive challenge to the dinghy sailor is responsible for heart rates as high as 168 beats.min^{-1}, as reported by Pudenz et al., (1981) for Laser sailors. If the cognitive demands were so high it is difficult to explain the relatively low heart rates observed by Bachemont et al., (1984) for 470 sailors, as the cognitive demands should be roughly the same for each class and should be unrelated to wind speed.

Other researchers, notably Vogiatzis et al., (1995); and Spurway (1997), have suggested that the elevated heart rates observed for dinghy sailing are directly related to the major challenge of hiking, which they allege is isometric or pseudo-isometric in nature. It is difficult to understand why such isometric hiking would increase heart rates so markedly whilst only moderately increasing oxygen consumption ($\dot{V}O_2$). Indeed, if hiking is isometric in nature the latter may well be true, as it is well documented that $\dot{V}O_2$ only increases modestly during isometric exercise despite marked increases in ventilation (Lind and McNichol, 1967; Myhre & Anderson, 1971; and Petrofsky & Phillips, 1986). However, it is also well documented that:

> *"the heart rate response during isometric exercise is very modest in nature and rarely exceeds 120 beats/min" (Petrofsky & Phillips,1986, p27).*

Thus, it seems logical that the elevated heart rates are not a reflection on the alleged isometric activity of hiking but more likely a result of the dynamic nature of hiking. This was first suggested by Harrison et al., (1988) and later by Cunningham (1995) and by Cunningham et al., (1998). Larsson et al., (1996), have suggested that fatigue is heightened whilst performing dynamic hiking tests in the laboratory as opposed to isometric hiking tests. Spurway et al., (2000) have, in their preliminary findings, suggested that a repeated leg movement of as little as 5 degrees (0.087 rad) on top of a sustained isometric contraction can significantly increase the physiological cost of the activity as measured by cardiovascular, respiratory and blood lactate parameters. It is very likely that much greater movement takes place than this during racing at the top level and this dynamic movement is responsible for the elevated heart rates. Gallozzi et al., (1993), have made it clear that induced body movements in a Finn, where they simulated frequent tacking as if match racing a competitor during tactical stages of a race, markedly increase both the cardiovascular and respiratory responses.

2.4.2 Oxygen measurements from on-water sailing.

The Marchetti et al., (1980) study, although partly constrained to laboratory measures, was also one of the earliest studies to look deeper into the physiological demands of dinghy sailing by collecting data on the water. In addition to heart rate data they also reported minute volume ($\dot{V}_E$), frequency of respiration (fr), oxygen uptake ($\dot{V}O_2$), blood lactate (La_{bl}), and systolic blood pressure (mmHg) for three sailors. The subjects were required to hold the hiking posture for only 30 seconds, after which the physiological measures were taken, except for $\dot{V}O_2$ which was assessed continuously. The wind conditions were 10-12 $m.s^{-1}$ but Marchetti claims that the lake surface was practically wave-less and the wind steady, thus the hiking postures were substantially isometric in nature. Heart rates averaged 148 $beats.min^{-1}$, frequency of ventilation 15 $breaths.min^{-1}$, blood lactates were barely elevated above resting values (14.6 $mg.100ml^{-1}$ [1.61 $mmol.l^{-1}$] at rest and 16 $mg.100ml^{-1}$ [1.77 $mmol.l^{-1}$] after hiking), and systolic blood pressure was 155mmHg. From the paper it is difficult to establish what the oxygen uptake values were. However, in the conclusions Marchetti et al., (1980) suggests:

> *"From the energy expenditure point of view, under actual sailing conditions, 30 seconds of such an exercise corresponded to about 1 litre O2 consumption...." (p331)*

It is difficult to assess how the oxygen consumption was measured but it seems that it must have been collected via a Douglas bag system, as portable gas analysers such as the Cosmed K2 were not available in 1980, although the paper does not make this clear. It also seems that the gas collection was based on a five minute continuous collection. The oxygen consumption measured equates to approximately 2 $l.min^{-1}$; given the mean body weights of 64.5 kg, this translates into an oxygen consumption of approximately 31 $ml.kg^{-1}.min^{-1}$. Furthermore, although this research is 20 years old, it remains the only one that has reported blood pressures from on-the-water as opposed to simulations.

With the advent of portable gas analysers such as the Cosmed K2 in the late 1980's (Dal Monte et al., 1989), the ease of continuous measurement of oxygen consumption in the field setting was enhanced. Gallozzi et al., (1993), performed simultaneous readings of heart rate and oxygen consumption in four Olympic class sailors whilst competing in an International regatta. The highest oxygen uptakes (and heart rates) were recorded in the single handed Finn class as opposed to those in the double handed classes (Tornado helmsman, Star crew and Star helm). Average oxygen uptakes for a whole race ranged from 10.4 $ml.kg^{-1}.min^{-1}$ recorded for the Star crew to 20.5 $ml.kg^{-1}.min^{-1}$ for the Finn helmsman. A peak oxygen consumption of 45.3 $ml.kg^{-1}.min^{-1}$ was recorded for the single-handed Finn. The mean $\dot{V}O_2$ measures may have been affected by the rather undemanding wind conditions where light winds prevailed for the testing (4-6 $m.s^{-1}$). Oxygen consumptions were generally higher when sailing upwind as opposed to sailing downwind. However, the oxygen consumptions were not expressed as percentages of each individuals $\dot{V}O_{2max}$. Gallozzi et al., (1993) also conducted an on-water simulated race on the Finn helmsman, which replicated upwind sailing but required tacking every 10 seconds as if covering an opponent during a tight tactical finish. During this simulated race the oxygen uptake was elevated and averaged approximately 30 $ml.kg^{-1}.min^{-1}$. This study was the first to report values for oxygen consumption during racing; the undemanding wind conditions and in particular the case study nature of the research were weaknesses of this work.

Vogiatzis et al., (1994) reported oxygen consumption values for semi competitive sailing from six members of the Scottish National Laser squad. These oxygen uptakes were recorded using the portable telemetric Cosmed K2 system in moderate winds (5 to 7 $m.s^{-1}$) and in strong winds (8 to 9 $m.s^{-1}$). All physiological measurements ($\dot{V}O_2$, $\dot{V}_E$, tidal volume and heart rate) were elevated in both strong winds and when sailing upwind. Mean (± s.d.) $\dot{V}O_2$ values and heart rates for moderate and stronger winds were 20.9 ± 2.7 $ml.kg^{-1}.min^{-1}$ and 145 ± 17 $beats.min^{-1}$, and 23.1 ± 0.3 $ml.kg^{-1}.min^{-1}$ and 153 ± 20 $beats.min^{-1}$, respectively. They argued that, given the peak readings for $\dot{V}O_2$ and heart rate of 23.3 $ml.kg^{-1}.min^{-1}$ and 175 $beats.min^{-1}$ respectively, the sport is not aerobically taxing and that cardiac function is challenged by other factors. Subsequently they have suggested that these factors are primarily related to the isometric nature of hiking. In a similar fashion to Gallozzi et al., (1993), Vogiatzis et al., (1994) also failed to measure maximal oxygen consumption ($\dot{V}O_{2max}$) of their subjects so it is not possible to express on-water $\dot{V}O_2$ as a percentage of their $\dot{V}O_{2max}$.

Vogiatzis et al., (1995a) replicated their 1994 study with one major exception that they also established maximal oxygen consumptions for the sailors in the laboratory via cycle ergometry. Mean maximal oxygen consumption for the eight subjects (again members of the Scottish National Laser squad) was recorded at 52.0 ± 6 $ml.kg^{-1}.min^{-1}$. All physiological data on the water were measured in winds that ranged from 4 to 12 $m.s^{-1}$ whilst sailing on one tack, upwind for 10 minutes. Mean oxygen uptakes, again measured via the Cosmed K2 system, were slightly lower than the mean values expressed in his 1994 paper at 20.3 ± 3.0 $ml.kg^{-1}.min^{-1}$. This equated to a mean value of 39 ± 6 % of the subjects $\dot{V}O_{2max}$, again suggesting that aerobic capacity is unlikely to be of great important to a single-handed dinghy sailor. Mean heart rates recorded at 145 ± 21 $beats.min^{-1}$, were also lower than had been reported in their 1994 paper. Vogiatzis et al., (1995a) concluded that:

> *"training regimes for dinghy sailors should involve a limited number of aerobic activities ...." (p 107).*

In contrast to the findings of Gallozzi et al., (1993) and Vogiatzis et al., (1994 and 1995a), a very recent conference presentation and subsequent abstract published in the proceedings suggests that on-water oxygen uptakes for elite French Laser sailors is considerably higher than this (Castagna and Brisswalter, 2004). This research has some important findings that puts this thesis into context. Firstly, they reported that oxygen uptake increased with time. Secondly as the time elapsed there became an increasing difference in oxygen uptakes between sailors of different skill levels. Thirdly, after 30 minutes of upwind sailing oxygen uptakes in the high skill group was recorded at 68.4% of $\dot{V}O_{2max}$. During the 30 minute sailing task oxygen uptakes and heart rates were recorded between the following time periods and averaged; the 6^{th}–10^{th} (T10), 16^{th}–20^{th} (T20) and the 26^{th}–30^{th} (T30) minutes. Throughout the hiking period the sailors were required to tack at 2 minute intervals. Oxygen uptakes in the lower skill group increased slightly ($p>0.05$) during the 30 minutes from 45.1% $\dot{V}O_{2max}$ (T10), 51.7% $\dot{V}O_{2max}$ (T20) to 51.3% $\dot{V}O_{2max}$ (T30). In contrast to this the oxygen uptakes in the high skilled group started from an almost identical point as the lower skilled sailors at 45.4% $\dot{V}O_{2max}$ (T10) but increased significantly ($p<0.05$) throughout and were also significantly greater ($p<0.05$) 61.5% $\dot{V}O_{2max}$ (T20) and 68.4% $\dot{V}O_{2max}$ (T30) than the values recorded for the lower standard sailors. The most significant findings from the work of Castagna and Brisswalter (2004) are that in a group of elite Laser sailors oxygen uptake can reach approximately 70% $\dot{V}O_{2max}$ after hiking for 30 minutes; this is considerably higher than previous findings. It is possible that the discrepancy between these values and the lower values reported by Vogiatzis et al., (1995a) may be due to the lower standard sailors, the short hiking period of only 10 minutes and the lack of tacking in their study.

Castagna and Brisswalter (2004) also reported heart rates that followed a similar trend to the oxygen uptake data. Heart rates for the high skilled group increased throughout and were recorded at 64.7%, 73.5% and 78.5% of maximum at T10, T20 and T30, respectively. Heart rates for the lower skilled group started off similar to the high skilled sailors at 65.2% max (T10) but were significantly lower at both T20 and T30 with values of 70.7 and 70.7% of heart rate maximum. They offer no explanations for the differences between the two different skill groups or for the increases in the skilled group with time. They suggest that future EMG study would be useful to ascertain muscular activity.

Devienne & Guezennec (2000) also highlighted the aerobic demands of sailing. They proposed that sailing a first class 8 (a large 8 metre keel boat) was heavily aerobic in nature and at certain times, such as mark roundings, this could be a limiting factor on performance. The degree of physiological measures varied depending largely on each crew member's role on the boat. For the harder worked individuals on board (the bow person for example), oxygen uptakes averaged in excess of 80% of $\dot{V}O_{2max}$ and at times heart rates reached maximal values as measured in the laboratory during maximal treadmill running. Also the individual who managed the mainsail in addition to doing the racing tactics at times reached 92% of $\dot{V}O_{2max}$. As Devienne & Guezennec (2000) concluded:

> *"It seems important for him to keep a good vigilance for sailing tactics despite his energetics fatigue. So, a good aerobic capacity could be considered as a factor of performance for competitive sailors." (p237)*

2.4.3 Metabolic measurements from on-water studies.

Blood lactate responses can give an indication into the metabolic demands placed on the body. However, if the sport essentially involves a static contraction of one major muscle mass, such as the quadriceps, as suggested by some researchers then whole blood measures of blood lactate may be misleading and may not be reflective of what is happening in the working muscle. Indeed, results from various on-water studies have not been directly comparable with each other. Piehl-Aulin et al., (1977) have reported the highest values where blood lactates ranged between 4 to 8 $mmol.l^{-1}$ after a demanding 40 minute sailing test. Vogiatzis et al., (1995a) reported mean values of 2.3 ± 0.8 $mmol.l^{-1}$ immediately after 10 minutes of upwind sailing in wind conditions of between 4 – 12 $m.s^{-1}$. Marchetti et al., (1980) have reported the lowest values of 1.8 ± 0.4 $mmol.l^{-1}$ following a 5 minute hiking period. It is hard to quantify the blood lactate response and draw any conclusions on the metabolic demands. Probably the biggest problem in making conclusions from any of the on-water data is inherently the lack of standardised sailing conditions. Vogiatzis et al., (1995a) gives some detailed information about climatic conditions (humidity, ambient temp, very vague wind speed and barometric pressure) but fails to make any comment on sea state and wave height. The latter is as important as wind speed in changing the physiological demands of the sport. It is not surprising that the available research detailing metabolic responses from on-water studies all suggest that there is a big inter-subject variability; this is probably due to non standardised climatic conditions during their research. It is for this reason that many researchers have opted to conduct laboratory simulations rather than attempt to collect data from an on-water setting.

Despite the popularity of dinghy sailing, there are relatively few on-water studies detailing the physiological demands of dinghy sailing. In contrast to this there has been considerable interest in trying to replicate dinghy sailing in the laboratory. These studies have ranged from very basic and crude simulations where the static nature of hiking has been highlighted (Niinimaa et al., 1977) to the quite sophisticated and elaborate mock up of sailing dinghies where the dynamic nature of the sport have been replicated (Blackburn, 1994).

2.5 Review of laboratory simulations of dinghy sailing.

The number of studies that have simulated dinghy sailing in a laboratory significantly outweigh the number of studies conducted on the water. This is primarily due to the ease of collecting physiological data in a laboratory environment and the ease of standardising conditions between subjects. Most of the laboratory simulations have concentrated on the physiological demands of hiking as most researchers have seen this as being the major physiological challenge to a dinghy sailor (Felici et al., 1999; Shephard, 1997; & Blackburn 1994). However, most of the simulations have portrayed dinghy sailing as being primarily static in nature and have subsequently not replicated what occurs on the water. In producing a simulation it is of paramount importance that it both accurately replicates the real situation (ecologically valid) and that it is reliable when subjected to a test/re-test situation. The reliability has probably been achieved with the static simulations but it is questionable whether the validity has been achieved as most simulations have failed to account for the dynamic nature of the sport.

The earliest simulation of dinghy sailing in a laboratory was conducted by Niinimaa et al., (1977). This simulation was totally static in nature and simply required the sailors to counter-balance their own weight whilst leaning out from a simulated deck with their ankles fastened under a strap. The trunk was inclined to 45 degrees to the horizontal. The simulation lasted 5 minutes, during the first two minutes the trunk was supported just by the thigh and abdominal muscles, but during the last three minutes the subjects were allowed to clasp their hands around the knees. They recorded a steady state heart rate of 137 $b.min^{-1}$, a peak systolic and diastolic blood pressure of 177 and 109 mmHg (after the fourth minute), respectively, a rise in blood glucose from 5.0 $mmol.l^{-1}$ to 6.5$mmol.l^{-1}$, and a decrease in serum bicarbonate from 27.4 $mE.l^{-1}$ to 21.9 $mE.l^{-1}$. This early simulation is undermined by its dependence on a totally static approach, and the lack of any upper-body activity as would be the case in steering and trimming the sail.

Marchetti et al., (1980), assessed both biomechanical measures (EMG and muscular moments) and physiological measures (blood lactate, oxygen consumption, blood pressure, heart rate and breathing rate) during simulated hiking (and trapezing) for three experienced sailors. In a similar fashion to the work of Niinimaa et al., (1977) the simulation was totally static in nature as the subjects hiked for a period of just 30 seconds. However, Marchetti et al., (1980), did suggest that hiking can be considered as a heavy exercise where the quadriceps are engaged nearly to maximum. They go on to state that the elevated heart rate (averaged 146 $b.min^{-1}$) and systolic blood pressure (averaged 149 mmHg) recorded at the end of the 30 second hiking effort is a result of the large isometric contraction in a number of big muscles as measured by EMG. They suggested that this is indicative of an impeded blood flow. It is difficult to clarify the results as far as oxygen consumption is concerned as they measured oxygen uptake with Douglas bags continuously over the whole five minute period, but the hiking posture was performed only over the first 30 seconds. A mean gross oxygen uptake of approximately 660 $ml.min^{-1}$ can be calculated from the table of results on page 329; thus it is possible to estimate an average gross oxygen uptake relative to body weight of 10.2 $ml.kg^{-1}.min^{-1}$. This estimated oxygen uptake is not representative of the energetic cost of static hiking as it includes a large proportion of time (4 ½ minutes) where the sailors simply sat on the side deck and recovered from the 30 second bout of hiking.

A more recent study that carries much merit was conducted by Vogiatzis et al., in 1993. They looked at the physiological responses during two sub-maximal and one maximal hiking effort, that were performed consecutively on a specifically constructed laboratory simulator. However, the paper again concentrated on the static nature of dinghy hiking. Indeed the experimenters went to great lengths to make sure that the simulation was as static as possible:

> *"Moments about the foot straps and angles generated about the knee joints were continuously controlled, thus confirming a near isometric contraction of the muscles which surround the knee joint" (Vogiatzis et al., 1993, p 861).*

They reported a mean heart rate over the three bouts of hiking of 125 ± 15 beats.min^{-1}, and suggested, in contrast to the earlier work of Niinimaa et al., (1977), that heart rate continuously increased without stabilising at any stage and peaked at 140 beats.min^{-1}. The group believed that the continual increase in heart rate was normal with static exercise where a muscular contraction is sustained isometrically at more than 15% of MVC. There seems to be some confusion about the trends in heart rate during static hiking simulations with Vogiatzis (1993) claiming that:

> *"Studies in the past have shown that heart rate and blood pressure rise steadily throughout 5 minutes of simulated hiking (Niinimaa et al., 1977; Marchetti et al., 1980)" (Vogiatzis et al., 1993, page 862).*

However, Niinimaa et al., (1977) concluded:

> *"The heart rate and blood pressure rose to a plateau during simulated hiking" (p90).*

The work of Marchetti et al., (1980) only looked at hiking over a brief 30 second interval when clearly heart rates would still have been increasing rather than obtaining a plateau. Clearly Vogiatzis et al., (1993) have interpreted the heart rate findings from the earlier studies incorrectly.

Vogiatzis offers no evidence to suggest at what percentage of MVC the quadriceps were being recruited but suggests (from an earlier unpublished Masters thesis) that it is likely to approximate 38% MVC. If this is the case the resulting ischaemia is likely to result in rapid fatigue; in this experiment the mean time to exhaustion was 16.45 ± 9.4 minutes. If such an ischaemia does exist it could explain the continuous increase in heart rate for as long as the muscular contraction can be maintained. This increase in heart rate results in an increased cardiac output which in turn is associated with large increases in blood pressure during such isometric exercise (Petrofsky & Phillips, 1986). Increased blood pressure may lead to an increased amount of blood perfusing the active muscle (Lind & McNicol, 1967).

It is unlikely that there is a total occlusion in blood flow across the working muscle, even with static hiking as simulated by Vogiatzis et al., (1993). This is supported by Vogiatzis et al's. own work where they measured blood flow through the femoral artery (via continuous wave Doppler ultrasound) throughout the three consecutive bouts of hiking. Blood flow through the femoral artery, like heart rate, increased continuously throughout the three consecutive efforts of hiking and was approximately two to three times greater during hiking than at rest (Vogiatzis et al., 1993). Vogiatzis goes on to suggest that blood flow through the femoral artery increased progressively throughout the three consecutive bouts of hiking, thus suggesting that the intramuscular pressure developed in the quadriceps during simulated hiking was not sufficient to totally occlude blood flow. This by itself is a crucial finding. If blood flow is not occluded during purely static hiking, where it is claimed that the rectus femoris is activated at approximately 38% MVC, it is very unlikely that significant vascular occlusion occurs on the water where hiking is much more dynamic in nature.

Vogiatzis et al., (1993) also reported that individual blood lactate values increased steadily throughout the three bouts of hiking, reaching the highest at the end of the 3rd hiking effort with a mean value of 4.0 ± 1.5 $mmol.l^{-1}$. However, it is interesting to note that the peak blood lactate values were recorded in the 5th minute after the hiking test had finished with a mean value of 5.7 ± 1.3 $mmol.l^{-1}$. This possibly suggests that some blood pooling occurred in the working muscle and that the intramuscular pressure was too great for some of the waste products of metabolism to be returned in the normal way by the venous return. This produced a build up of waste products in the working muscle that were only released once the exercise bout was terminated.

The other explanation for the peak lactate values being recorded five minutes post exercise could simply be due to the fact that the muscular effort was continuously increased throughout the bouts of exercise and there is a natural time lag for any waste product produced in the working muscle to be seen in a capillary blood sample taken in the finger. The continuous increase in muscular effort throughout the bouts of hiking is well reported by Vogiatzis et al., (1993), where they suggest that the integrated EMG (IEMG) of the rectus femoris muscle increased continuously throughout all bouts of hiking with the greatest value being recorded at the end of the final effort (exhaustion). This finding has another implication in that it makes it clear that to maintain the same static hiking posture for a given period of time there is a need for greater muscle activation, which is probably achieved via recruiting additional motor units.

The only simulation looking at the effect of dietary manipulation on hiking performance was conducted by McLoughlin et al., (1993) in the laboratories at Chichester. Subjects consumed either a high carbohydrate or a low carbohydrate diet prior to commencing the sailing task. This simulation was primarily static in nature, although the sailors were much less constrained than previous laboratory studies as they were trying to replicate the field setting. The six sailors were allowed to change position and alter the level of isometric force applied by each leg at will throughout the 30 minute simulation. Although the study failed to establish any significant differences in performance from ingesting a high carbohydrate diet and a low carbohydrate diet, the results had a trend towards a better hiking performance following the high carbohydrate diet with 5 of the 6 subjects showed an improved hiking performance. Although the nature of the task was quite demanding it is clear that the isometric contraction of the exercising muscles (primarily the quadriceps) was less than the 60% of MVC adopted in other studies (Maughan, 1988) otherwise fatigue would have been established before completing the 30 minute task. Despite the physical effort involved heart rates only averaged 109 beats.min^{-1} throughout the task with a peak of 124 beats.min^{-1}.

Possibly the first attempt to replicate a dynamic simulation was conducted at Chichester in collaboration with Southampton University (Burstzyn et al., 1988) following the development of a sailing ergometer. In contrast to earlier simulations the notable difference here was that the ergometer was constructed from a single-handed dinghy (Europe) that was free to pivot at the ends (i.e. heel 30 degrees to windward or to leeward). The ergometer simulated three main physical activities, namely, hiking, trimming and steering. A micro computer was used to assess errors for hiking, steering and trimming. Hiking could be dynamic in nature where in addition to the weights stacked on the leeward side to cause a constant heeling moment, water could also be pumped randomly in and out of a ballast tank again stored on the leeward side. This was the first attempt to simulate dynamic hiking and take some account of the ever-changing wind and wave conditions. This dinghy ergometer was the first laboratory tool capable of investigating a range of physiological and mental responses that a dinghy sailor would face in an on-water situation.

Following on from the work of Burstzyn et al., (1988), Blackburn (1994) replicated a 90 minute Laser race on a specially constructed ergometer. In a similar fashion to the ergometer used by Burstzyn et al., (1988), the subjects (top Australian Laser sailors) had to steer and trim the sail in addition to hiking. Blackburn, an Olympic medallist himself in the Laser (fourth Atlanta 1996 & third Sydney 2000), attempted to achieve the dynamic nature of hiking by allowing the hull to move freely in both horizontal and vertical planes through the use of springs. The subjects hiked from only one side of the boat but were required to replicate tacking during the simulation by sitting in from the hiking position, reaching over and touching the opposite gunwale of the boat with one hand. Unlike previous studies Blackburn attempted to simulate true sailing movements by getting his subjects to watch a specially edited video during the simulation. The video depicted close up action of a Laser sailor sailing on the water during racing, and the subjects were required to mimic all the body movements depicted in the video. It was envisaged that the simulation was replicating a Laser dinghy race in winds over 12 knots, thus requiring continuous upwind hiking.

One of the main findings from the Blackburn (1994) study was that sailing upwind was significantly more demanding than sailing downwind. Heart rates, blood pressure and oxygen uptake were greater for upwind sailing as opposed to downwind reaching with mean values of 118 ± 25 beats.min^{-1}, 172 ± 18/100 ± 14 mmHg, and 1.12 l.min^{-1} recorded for upwind sailing, with 94 ± 13 beats.min^{-1}, 150 ± 19/92 ± 12 mmHg and 0.81 l.min^{-1} to for downwind reaching. Oxygen uptake which rarely exceeded 30% of maximum and averaged only 14.8 ml.kg^{-1}.min^{-1} for upwind sailing suggests that there is only a relatively low rate of energy supply. Mean blood lactate levels taken one minute after completing the upwind legs were 2.32 ± 0.81 mmol.l^{-1}, suggesting only a small anaerobic demand. Clearly from these findings it would seem that simulated dinghy sailing could be sustained largely from aerobic metabolism. Blackburn goes on to suggest that the muscular discomfort felt by the subjects during the simulation would indicate that the muscular contraction during hiking is inhibited before a peak in energy supply, by both aerobic and anaerobic metabolism, is reached. From this statement Blackburn concludes that, although dynamic aerobic training is warranted in the training schedule of a dinghy sailor, primarily to facilitate recovery, static training is essential for task specific adaptation of the circulation.

One problem with the Blackburn (1994) study is that, although he attempted a dynamic simulation, he seems to have underestimated the physiological stress of Laser sailing. The heart rates he recorded for the simulation are considerably lower than the on-water heart rates recorded by Pudenz et al., (1981), where average heart rates for upwind and downwind sailing were 168 and 138 beats.min^{-1}, respectively. Blackburn also makes reference in his discussion to unpublished work conducted by Sandstrom et al., (1985) on behalf of the Australian Yachting Federation:

> *"Oxygen uptake during the simulated sailing was considerably lower than during a 10 minute hiking test reported by Sandstrom et al., (1985), i.e. 1.12 l.min^{-1} (upwind mean) v's 1.82 l.min^{-1} (10 min average). Thus, here, simulated sailing involved exercise of a lower intensity compared with the study of Sandstrom et al., (1985). Sandstrom and co-workers' simulation was subjectively designed to mimic the demands of strong-wind dinghy sailing and involved a large dynamic component consisting of repeated movements of the body between sitting in and hiking out and a pumping action on a simulated mainsheet." (Blackburn 1994, p388).*

Assuming that the subjects in the Sandstrom et al., (1985) study were similar in weight to those in Blackburn's study, which is a valid assumption given the fact that they were also Laser sailors, they would have had an oxygen consumption relative to body weight of approximately 24 $ml.kg^{-1}.min^{-1}$, compared to the 14.8 $ml.kg^{-1}.min^{-1}$ reported by Blackburn. The crux of the issue is that it has been shown that oxygen consumption during combined static and low level dynamic exercise may be as much as four times greater than that of static exercise alone (Kilbom and Brundin, 1976). Thus, it seems that the elevated oxygen consumptions that reached 60% of maximum ($\dot{V}O_{2max}$) during the 10 minutes of simulated hiking in the Sandstrom et al., (1985) paper were probably due to extra dynamic activities particularly flexion and extension around the hip joint, and upper-body movements in pumping the sail. Unfortunately, the work of Sandstrom et al., (1985) is unpublished and is only cited in the Blackburn (1994) paper, where no further reference is made to other physiological measures recorded.

Ioannis Vogiatzis has over the past decade been one of the main researchers looking into the physical demands of single-handed dinghy sailing, with a particular emphasis on Laser sailing. In addition to his two on-water studies (Vogiatzis et al., 1994 and Vogiatzis et al., 1995a) and the laboratory simulation mentioned earlier in this review (Vogiatzis et al., 1993), he conducted another study looking into changes in both ventilation and EMG activity during simulated Laser sailing (Vogiatzis et al., 1996). In this study measures were taken during and after four bouts of hiking activity with each bout lasting three minutes and separated by a 15 second rest period. As with their earlier simulations (Vogiatzis et al., 1993), the hiking posture was static in nature, indeed this is reflected in the title of his more recent study:

> *"Changes in ventilation related to changes in electromyography activity during repetitive bouts of* ***isometric*** *exercise in simulated sailing." (Vogiatzis et al., 1996, p195)*

Although it is an excellent study with useful findings, it is not an accurate representation of what happens on the water as the dynamic nature of the sport has been neglected. The main findings from the study are that ventilation and intergrated electromyographic (IEMG) increased throughout the four bouts of hiking from 19.8 to 37.5 $l.min^{-1}$ and from 31 to 39% MVC (quadriceps), respectively. Such progressive hyperventilation, commonly associated with isometric exercise (Petrofsky and Phillips, 1986; Poole et al., 1988), was also related with a decrease in mean end tidal partial pressure of CO_2 from 37.7 mmHg to 32.4 mmHg, during the four hiking bouts. Interestingly, blood lactate concentrations did not increase significantly during the simulation. Heart rate and rate of perceived exertion (RPE) increased significantly throughout all four bouts of hiking from 95 to 125 $beats.min^{-1}$ for heart rates and from 10 to 15.7 for RPE. Vogiatzis et al., (1996), goes on to suggest that the increasing fatigue that the subjects experienced was likely to be caused by the level of isometric contraction of the quadriceps muscle restricting perfusion by mechanically compressing the intra-muscular blood vessels, although this was not measured. They highlight the agreement between their findings and those presented in the Blackburn (1994) simulation of Laser sailing where $\dot{V}O_2$, heart rate and post lactate were 1.12 $l.min^{-1}$, 118 $beats.min^{-1}$, and 2.3 $mmol.l^{-1}$, respectively. However, Vogiatzis et al's., claim that the real hiking effort was well simulated because the post lactate sample at the end of the fourth hiking bout was identical to the lactate recorded after a 10 minute hiking test in sailors under sailing conditions (Vogiatzis et al., 1995a), cannot be sustained. Furthermore, based on this claim Vogiatzis et al., (1996) go on to conclude that in accordance with others (Blackburn, 1994; Vogiatzis et al., 1995a):

> *"The major factor which dominates the physiological responses during hiking is the degree of isometric tension developed in the quadriceps muscle" (p202).*

Felici et al., (1999), in his introduction described hiking as having a common feature:

> *"the common feature of hiking is that an isometric* ***(or a quasi isometric)*** *effort is performed" (p 309).*

The use of the term quasi-isometric was not new, [Spurway (1997) described hiking as pseudo isometric in nature], but it is clear that in the last few years most dinghy sailing researchers are distancing themselves from the purely static notion that had previously existed (Niinimaa et al., 1977; Marchetti et al., 1980). Felici et al., (1999) went on to suggest:

> *"In actual sea conditions the continuous variations in wind force and direction and the effect of waves call for continuous modifications of the sailor's posture. Thus dynamic activity is superimposed upon the static effort. Furthermore, the sailor has to pull on the sail ropes (hauling haft) and steer. Therefore arm muscles are also involved in dynamic muscle actions" (p309).*

Despite the appreciation by Felici et al., (1999) of the dynamic nature of dinghy sailing, their simulation was primarily static in nature where the sailors were required to hike statically till exhaustion. Three hiking postures were used, including one that elicited a maximal hiking torque (MHT). For this the body was outstretched in the hiking position with the trunk fully extended, with the head in a line with the trunk, and the hands placed close to the chin. The other two hiking positions were evaluated so that 85% and 60% of MHT were exerted. EMG activity measured on the quadriceps (presumably on the rectus femoris but this is not stated) was approximately 60% MVC to achieve 100% MHT, 30% MVC for 60% MHT and at values of less than 40% MHT the sailors simply sat on the side of the simulator and were not required to hike.

The main findings from the Felici et al., (1999) study were elevated heart rates (141 and 138 beats.min^{-1}), blood pressure (195/110 and 183/117 mmHg) and blood lactate (3.9 and 3.1 mmol.l^{-1}) in both the 85 % MHT and the 60% MHT conditions, respectively. Despite these physiological increases, the energy cost of hiking was very low compared to other forms of activity (Felici et al., suggested it is comparable to level walking at 1-1.5 m.s^{-1}). Net oxygen intakes were recorded at 0.95 and 0.87 l.min^{-1}, for the 85% MHT and 60% MHT conditions, respectively. At 85% MHT the time to exhaustion was 188 seconds whereas at 60% MHT it was 896 seconds. The respiratory exchange ratio (RER) increased from a resting value of 0.80 to 0.98 and 0.91 during the 85% and 60% MHT conditions, respectively. Given the low energetic cost of the activity it is clear that there is a large degree of hyperventilation, especially during the 85% MHT condition. During the 60% MHT trial cardiac output doubled with respect to resting values (10.4 $l.min^{-1}$ compared to 5.9 $l.min^{-1}$ at rest), unfortunately cardiac outputs for the 85% MHT condition are not reported.

Felici et al., (1999) go on to speculate that fatigue was unlikely to have been caused by muscle glycogen depletion, which seems to be a logical conclusion. They suggest that, from a metabolic energy point of view, hiking seems to be only light exercise, with limited oxygen deficit as indicated by lactates lower than the anaerobic threshold. The findings of this study are in accordance with results reported from other simulations, notably, Niinimaa et al., 1977, Vogiatzis et al., 1993, Blackburn, 1994, and Vogiatzis et al., 1995. It seems that the fatigue was being caused by the isometric compression of the leg muscles. Lind (1983) has highlighted that any isometric contraction greater than 15% MVC induces a partial muscular ischemia. In this study the quadriceps were statically contracted at MVC's in excess of 30% but less than 60% in both hiking conditions. The question of what is exactly happening in the contracting muscle is not totally clear. One logical explanation is that the contraction-induced ischemia has been shown to increase lactic acid production which leads to a diminished muscle pH (Sahlin et al., 1975) and a decreased contractile force in the muscle (Sahlin, 1986). Other chemical reactions inside the muscle and substances released by active fibres, such as potassium ions, are trapped within the muscle interstitial fluid and contribute to force decline (Hnik et al., 1986). An increase in potassium ions coupled with a decreased pH have been shown to have functional connections with the respiratory centre (McCloskey & Mitchell, 1972) and could also be responsible for the ventilations often found with such static hiking simulations.

The physiological debate into what is causing the fatigue during simulated dinghy hiking, principally seen as fatigue of the quadriceps, is likely to continue. Also the debate on blood perfusion during a static contraction will continue. The amount of blood perfusion taking place during isometric dinghy hiking has only received attention in one study (Vogiatzis et al., 1993), and they have suggested that even during a static contraction of the quadriceps of approximately 38% MVC there is still a two to three fold increase in arterial blood flow through the activated muscle compared to resting values. There is not one laboratory simulation of dinghy sailing that has taken either muscle biopsies or directly measured muscle metabolites in the working muscle. Needless to say, subject recruitment from an elite sailing population for such a study would be hard to find. However, such a micro view of what is happening in the working muscle may provide a useful explanation of the fatigue being experienced. It is possible that, when reporting whole body measures such as capillary blood lactates or pH values, the more specific details are being missed. This may particularly be the case considering the relatively small amount of muscle being activated during simulated static hiking. A washing out or diluting of what is occurring in the muscle is a distinct possibility when using whole body measures.

However, it seems far more crucial to establish whether the laboratory simulations are accurately mimicking dinghy sailing as it happens on the water. It is doubtful that this has been achieved yet. Until a true replication of the dynamic actions that occur during sailing is achieved it is difficult to debate what is causing the fatigue during on-water sailing. Most of the simulations have been to static in nature, possibly the only exception is the unpublished work of Sandstrom et al., (1985) [cited in Blackburn, 1994] where they attempted to replicate the true dynamic nature of dinghy sailing. Even the relatively recent work of Felici et al., (1999) has failed to mimic the dynamic nature of the sport, although they fully appreciate there is a dynamic component and indeed mentioned it in their introduction. In their discussion they admitted that they had failed to accurately simulate the real on-water situation:

> *The static hiking exercise we adopted was quite different from hiking in real sea conditions where the torque is continuously varied according to waves and wind and is interrupted for a few seconds at each tack" (Felici et al., 1999, p314)*

Very recently (Saunders et al., 2003; and Saunders et al., 2004) have developed a completely new type of sailing ergometer. This ergometer has been years in the making and is based on earlier models (Harrison et al., 1988; Walls et al., 1998), with the initial working idea originating from John Harrison, a former colleague at University College Chichester. Professor Norman Saunders has taken John Harrison's initial ideas and added a sophisticated set of electronic devices all operated by an impressive software control programme and truly developed an innovative sailing ergometer. This ergometer could revolutionise laboratory based exercise testing of elite sailors. The dynamic nature of the simulation is provided by computer controlled pneumatic rams to create the correct righting moments, depending on the wind strength that has been pre-selected in the software. It can discriminate between different standards of sailor and does offer a true dynamic simulation with the added bonus that each simulation can be exactly reproduced which is impossible on the water. This tool is also useful in teaching novices or youngsters to sail in the safe and pleasant surroundings of a classroom. Saunders et al., (2004) have produced evidence that youngsters who are first introduced to sailing on the ergometer have a lower drop-out rate and a significantly quicker uptake of sailing itself when they transfer to the water. The product will soon be commercially available at a cost of approximately Aus$ 20,000. Further improvements are planned to add additional pneumatic rams to create a tilting movement in the fore and aft plane. This looks like being the first commercially available ergometer that is capable of simulating the true dynamic nature of dinghy sailing.

2.6 Experimental order for this thesis.

The experimental order for this thesis was firstly to establish the anthropometric profiles of the elite single handed sailors forming the British Olympic squads. This was felt necessary to give a good grounding on the typical body profiles of top class single-handed sailors before starting the subsequent experimental chapters. The experimental chapters follow a logical sequence of on-water data analysis followed by two laboratory simulations on sailing specific ergometers to establish the physiological demands of the sport. The concluding experimental chapter combines these physiological demands of the sport with an appropriate battery of fitness tests presently being used by the Royal Yachting Association's exercise physiologists on the elite British sailors. This mix of data permits the exercise physiologist to make an assessment of the sailors' physiological strength and weaknesses and to offer appropriate advice on training regimes that will enhance sailing performance. A knowledge of the correct anthropometric profiles, and in particular body weights, for each of the single-handed classes is an essential part of the information needed to prescribe suitable applied training advice.

CHAPTER 3

Chapter 3:

Class specific anthropometric profiles of elite dinghy sailors.

3.1 Introduction.

The typical body profile of dinghy sailors has been extensively researched but there is still a lack of information about the physiological and anthropometric profiles of elite Olympic class sailors (Legg et al., 1997). Plyley et al., (1985) have suggested that there is no one perfect profile as the optimal requirements differ between different classes of boat and also between skipper and crew. They go further to suggest that there is no evidence linking individuals who match an assumed 'perfect profile' with those being selected for national teams. The advantage of height in creating an increased righting moment is obvious, particularly if this additional height is linked to a higher centre of gravity. In addition to an increased height or raised centre of gravity, greater body mass in any boat will help the righting moment. However, an increased body mass will also increase the area of the boat in contact with the water as the displacement is increased and the frictional resistance increases. For this reason it seems logical to speculate that each Olympic class has an optimal crew weight that provides an adequate righting moment in strong winds but does not overly increase frictional resistance in light winds.

Optimal crew weights of elite sailors in each Olympic sailing class have not been detailed in recent scientific papers. Crew weights have been reported (Plyley et al., 1985; Blackburn, 1994; Shephard, 1990; Gallozzi et al., 1993; Shephard, 1997 and Legg et al., 1997), but these are now dated and not representative of present day sailing of Olympic classes. Plyley et al., (1995) hypothesised that the successful sailor should be light and tall and have a high centre of gravity. This theory is logical but both Niinimaa et al., (1977) and Plyley et al., (1985) failed to establish any supporting evidence linking body mass, increased height or raised centre of gravity to successful sailing performance. Shephard (1990) argued that the tall thin person may lack the abdominal musculature to be able to hold themselves in the hiking position and that they may also be disadvantaged when tacking and gybing in a small racing dinghy.

There are 11 Olympic sailing classes encompassing 9 different types of sailing craft (the same crafts are used by both male and female sailors in both the 470 and windsurf classes). The various Olympic classes differ substantially in length, mass, sail area, rig, type of keel and the number of sailors in the craft – (see Table 1.1 in chapter 1 for details of the Olympic sailing classes). The smallest boats such as the Europe and Laser, only weigh 45 and 59 kg and have relatively small sail areas of 7.2 m^2 and 7.06 m^2, respectively. In contrast to these small dinghies the largest two Olympic classes are the Yngling and Star, which are much heavier boats with fixed keels (keelboats) and weigh 645 kg and 671 kg, respectively, and have sail areas of 14.0 m^2 and 28.0 m^2. To generalise one typical body profile is virtually meaningless. Additionally, the problem with choosing a perfect profile is that the physiological demands of each class are different (Plyley et al., 1985; Gallozzi et al., 1993).

Body mass of the sailor is particularly important in the smaller dinghies. For any sailing vessel there is a complex set of mechanics involving forward propulsion. Of particular importance are the rather complex mechanics that concern the resistances to forward propulsion (Shephard, 1990). Probably the most dominant form is viscous resistance, which largely comes from the friction of the wetted hull through the water. Overall resistance increases approximately as the square of the mass of the boat combined with the mass of the crew (Shephard, 1990). Thus, in the light weight single-handed dinghies such as the Europe (45 kg), Laser (59 kg), and Finn (145 kg) and in the light weight double-handed 470 class (120 kg) the weight of the crew has a large effect on the overall resistance. In the large keelboat classes such as the Yngling (645 kg) and Star (671 kg) the combined crew weight has less impact on overall weight and as such the crew weight has less influence on the frictional resistance resisting forward propulsion. This results in a narrow band for crew weights in the smaller dinghy classes, particularly in the Laser, Europe and 470 classes, and more variance in crew weight in the larger keelboat classes. Legg et al., (1997) have suggested that:

> *"there were clear and logical differences between body mass and both class of vessel and the position of the sailor i.e. crew or helmsman. Lighter sailors sailed lighter craft whilst heavier sailors sailed heavier classes. Crew members were generally heavier than helmsman" (p41).,*

They go on to add that optimal requirements differ between different classes of boat and between the skipper and crew. The early work of Niinimaa et al., (1977) suggested that the more successful Canadian sailors had an above average body mass and also had strong leg and abdominal muscles. Shephard (1990) concluded that Canadian sailors were somewhat taller and heavier than the average person. They were also heavier than other International sailors (Japanese, Czechoslovak and Italian) with most of this additional weight being carried as fat with body fat percentages being higher than those recorded for other classes of athletes. Plyley et al., (1985) have also found that the Canadian national team sailors had higher body mass and were taller than the general Canadian population. They analysed 30 Canadian Olympic class sailors and concluded that:

> *"successful sailors in general have above-average height and body mass, well developed abdominal and wrist muscles, 18% ± 4% body fat, and a perceived aerobic power of 45 ± 8 ml.kg^{-1}min^{-1}" Plyley et al., 1985 (p152).*

Shephard (1990) has suggested that the only distinguishing physical characteristic between successful and unsuccessful Canadian sailors was a lower percentage of body fat (in the latter group). Legg et al., (1997) have proposed that age appeared to be related to on-water sailing performance with the older sailors forming the elite New Zealand Olympic squads being more successful internationally. They also highlighted that the 31 sailors forming the elite New Zealand Olympic squads tended to be both younger and lighter than sailors from other nations. However, such grouping of different classes of sailors into one generic group as conducted by Legg et al., (1997) and then to compare mean anthropometric data with that of other countries Olympic sailing squads is virtually pointless. Before making any comparisons the profiles have to be specific to each sailing class. If the profiles are not class specific there is the danger of not comparing like with like as the numbers of sailors in each class will be different with big differences in the anthropometric profiles between sailing classes (Legg et al., 1997).

It is difficult to disagree with the statement made by Shephard (1990) that:

> *"as with many sports, it is wrong to look for a single optimal physiological profile" (p290).*

Despite this statement many researchers, including Plyley et al., (1985), Shephard (1990); Shephard (1997) and Legg et al., (1997) have spent time in attempting to find a physiological and anthropometric profile of a dinghy sailor that correlates with performance.

Any investigation into optimal anthropometric profiles of sailors needs to be related to a specific class of boat and not just generalised. The aim of this chapter is to present anthropometric profiles of the elite British Olympic sailing squads. These data will be presented in a generic fashion so as to allow general comparisons with previous studies (Plyley et al., 1985; Shephard, 1990; Shephard, 1997; and Legg et al., 1997). In addition the profiles will be split into class specific and where relevant split further into profiles for helms and crews. Given the recent success of British Olympic sailing, particularly in the single handed classes where Britain claimed all three gold medals at the 2000 Sydney Olympics, these profiles may be considered as the 'gold standard' for each of the single-handed classes.

3.2 Method.

All subjects completed consent forms (see appendix A) prior to taking part in this testing. The anthropometric profiles reported in this chapter and the physiological profiles outlined in chapter 7 have been established during routine exercise testing of the elite British sailing squads and funded through the National Governing Body's (Royal Yachting Association) World Class Performance Programme (WCPP). The data forming these profiles are the most recent data recorded for each individual sailor with all of the data coming since the Sydney 2000 Olympics and the majority of it dated since June 2003.

Anthropometric data. Body mass was measured with an electric balance (Seca model Sa337). Height was measured with a Holtain stadiometer (Holtain Ltd). Body fats were estimated by the equations of Durnin and Womersley (1974), using four skinfolds sites (biceps, triceps, subscapular, and suprailiac) measured using Harpenden calipers. Body mass index (BMI) were calculated and presented in the results section. Means and standard deviations are reported for each class and for male and female sailors. Paired t-tests with two tails have been used to compare the means. Levels of significance were set at $p<0.05$.

3.3 Results.

All raw data relevant to this chapter are shown in appendix B of the second volume of this thesis.

Table 3.1 shows the mean (± s.d.) anthropometric data for male and female members of the British Olympic sailing squad during the period 2003-2004. The age of male and female sailors were similar ($p>0.05$), but statistically, males were typically heavier, taller, and had lower skinfold sums (from 4 sites) than the female counterparts ($P<0.01$).

Table 3.1. Mean (± s.d.) anthropometric data for male and female members of the elite British Olympic sailing squad 2003-2004.

Variable	**Male (N=65)**	**Female (N=32)**
Age (years)	23.7 ± 4.8 years	24.6 ± 5.3 years
Body mass (kg)	79.4 ± 13.8 kg	64.8 ± 7.2 kg
Height (m)	1.82 ± 0.07 m	1.69 ± 0.06 m
BMI	23.8 ± 3.1	22.7 ± 1.6
Sum of 4 skinfolds	37.1 ± 14.4 mm	52.4 ± 12.9 mm
* Percentage body fat	14.6 ± 4.2 %	27.1 ± 3.9 %

*Skinfolds taken at 4 sites (biceps, triceps, subscapular and suprailliac) - Durnin and Womersley, 1974

Table 3.2 details the class specific anthropometric profiles for the Olympic single-handed classes – the male classes of Laser and Finn and the female Europe class. Finn sailors were significantly heavier ($p<0.01$) and taller ($p<0.05$) than both Laser and Europe class sailors. Laser sailors had significantly ($p<0.01$) lower skinfolds than both Finn and Europe sailors. Finn sailors had significantly less ($p<0.01$) body fat than Europe sailors when the skinfolds were converted to percentages (Durnin and Womersley, 1976), but the absolute values for the sum of the four skinfolds expressed in mm were similar ($p>0.05$). Europe sailors were significantly shorter than Laser sailors ($p<0.01$). There were no significant differences ($p>0.05$) between the ages of the three classes of sailors.

Table 3.2. Mean (± s.d.) anthropometric data for male Laser and Finn sailors and female Europe sailors who were members of the elite British Olympic sailing squad 2003-2004.

Class	**Age (years)**	**Mass (kg)**	**Height (m)**	**Sum of 4 skinfolds (mm)**	*** % body fat**
Laser (n=12)	22.0 ± 4.0	79.9 ± 4.2	1.83 ± 0.05	33.6 ± 8.4	13.7 ± 3.1
Finn (n=8)	22.5 ± 3.1	95.9 ± 4.1	1.89 ± 0.08	50.0 ± 11.8	18.6 ± 3.0
Europe (n=10)	24.1 ± 3.5	66.5 ± 3.8	1.69 ± 0.05	54.6 ± 8.4	28.0 ± 2.3

*Skinfolds taken at 4 sites (biceps, triceps, subscapular and suprailliac) - Durnin and Womersley, 1974

Table 3.3 details the anthropometric data for the elite British sailing squads 2003-2004 for the remaining eight Olympic sailing squads and where appropriate split into helm and crew positions. It was considered unwise to establish statistical significances between the classes as in some cases the sample size is small (n=3).

Table 3.3. Mean (± s.d.) anthropometric data of elite British sailors for remaining Olympic sailing classes - detailing breakdowns between helm and crew where appropriate.

Class	Age (years)	Mass (kg)	Height (m)	* % body fat
470 female helm (n=5)	23.6 ± 2.2	54.3 ± 4.0	1.63 ± 0.05	24.7 ± 5.5
470 female crew (n=3)	22.6 ± 1.5	68.1 ± 3.4	1.76 ± 0.01	26.3 ± 4.3
470 male helm (n=4)	23.0 ± 2.4	62.6 ± 2.5	1.74 ± 0.01	11.5 ± 2.6
470 male crew (n=6)	21.3 ± 2.7	68.8 ± 2.2	1.80 ± 0.04	10.5 ± 1.7
Boardsailor female (n=4)	23.2 ± 5.0	63.2 ± 5.8	1.70 ± 0.08	23.7 ± 4.1
Boardsailor Male (n=6)	20.5 ± 4.2	68.4 ± 3.6	1.76 ± 0.05	12.7 ± 2.3
Yngling helm (n=4)	31.8 ± 11.1	62.2 ± 3.3	1.65 ± 0.04	29.0 ± 3.2
Yngling bow (n=3)	24.0 ± 3.5	66.0 ± 8.4	1.68 ± 0.07	27.4 ± 3.7
Yngling middle (n=3)	24.7 ± 2.5	77.0 ± 2.5	1.78 ± 0.03	30.8 ± 2.2
49er helm (n=7)	26.0 ± 6.8	73.2 ± 5.0	1.77 ± 0.06	15.8 ± 3.0
49er crew (n=8)	23.3 ± 4.0	76.3 ± 3.5	1.85 ± 0.03	12.7 ± 3.3
Star helm (n=4)	32.3 ± 3.1	86.6 ± 13.0	1.81 ± 0.04	16.4 ± 3.6
Star crew (n=4)	29.5 ± 5.1	111.8 ± 12.3	1.93 ± 0.11	22.0 ± 2.6
Tornado helm (n=3)	26.3 ± 5.5	69.9 ± 4.0	1.76 ± 0.08	12.3 ± 2.0
Tornado crew (n=3)	24.7 ± 1.2	75.2 ± 9.4	1.82 ± 0.08	13.2 ± 1.3

*Skinfolds taken at 4 sites (biceps, triceps, subscapular and suprailliac) - Durnin and Womersley, 1974

3.4 Discussion.

The mean data for the combined male and female members of the British Olympic sailing squads 2003-2004 are comparable to those reported for elite New Zealand sailors by Legg et al., (1997) for age and height but not for body mass. Legg reported a mean age, height and body mass of 23.6 ± 5.7 years, 1.779 ± 0.65 m and 73.0 ± 8.1 kg for the 25 members of New Zealand's Olympic sailing squads. In comparison, the British Olympic sailing squads (n=97) were similar in age at 24.0 ± 5.0 years; similar in height at 1.780 ± 0.10 m; and slightly heavier at 74.6 ± 13.9 kg (see table 3.1). Legg et al., (1997) also presented anthropometric data for Olympic class sailors from a combined 10 other nations. Their mean age was 30.4 ± 8.1 years (n=85) with a mean body mass of 82.4 ± 13.4 kg (n=77); no data were reported for height.

The similarity in the mean ages and heights reported for the Olympic sailing squads of New Zealand and Britain are of interest. The similarity in the ages is particularly interesting as Legg et al., (1997) have suggested that the New Zealand sailors tended to be younger in comparison with sailors from other nations. This is true for the age data that Legg reported for the 85 sailors from other nations in their paper but not for the British sailors reported here who are almost identical in age to the elite New Zealand sailors. Legg et al., (1997) declared at the time the New Zealand data were collected, that the young age of the nation's Olympic sailing squad coupled with their success at international level would bode well for further success. This assumption was based on the premise that the sailors remained in the sport and that they continued to improve with experience. This notion of successful young sailors developing into more successful older sailors is a policy that holds true for British sailors with the most successful Olympians also being previously successful at international level as youth sailors. The present British Olympic sailing squad is young and this is in agreement with the data reported by Legg et al., (1997) for other nations Olympic sailors where the average is around the 30 years of age mark (30.4 ± 8.1 years reported by Legg).

The slight difference in body weight between the New Zealand sailors and the heavier British counterparts may be due to the eight star sailors (four helms and four crews) in the British figures, who between them average almost 100 kg and have thus raised the overall average. The New Zealand data did not include any Star sailors. It is clear to see from table 3.3 that Star class sailors, particularly the crews, tend to be the heavy weights in the sailing world. For this reason it is difficult to make direct comparisons between one Nation's Olympic sailing squad and that of another. The mean body mass data reported by Legg for other nations' sailors were 82.4 ± 13.4 kg (n=77); this is approximately 7.8 kg and 9.6 kg heavier than the data reported here for the respective British and the New Zealand Olympic sailors respectively. However, the exact breakdown of classes sailed by these 77 sailors will influence this mean figure. The only meaningful way to compare anthropometric data, possibly with the exception of age, is by being specific to each sailing class as listed in the tables 3.2 and 3.3 of this chapter.

From table 3.2 it is evident that the most notable difference between the three single-handed classes is the difference in body mass. Europe class sailors were the lightest at 66.5 ± 3.8 kg, Laser sailors at 79.9 ± 4.2 kg and the heavy weight Finn sailors weighing 95.9 ± 4.1 kg. There were also similar differences in height with Europe sailors having the shortest stature at 1.69 ± 0.05 m, Laser sailors at 1.83 ± 0.05 and Finn sailors being the tallest at 1.89 ± 0.08 m. These differences in height and body weight between the classes were statistically significant ($p<0.05$). There is little literature detailing such data for both Finn and Europe sailors. This is surprising since the Finn has been an Olympic class since 1952 and the Europe since 1992. The Laser class, though the youngest Olympic single-handed class making its first Olympic appearance in Atlanta in 1996, has been widely discussed in the scientific literature.

3.4.1 Laser class profiles.

Legg et al., (1997) reported mean ages, body weights and heights for elite New Zealand Laser sailors of 21.6 years, 77.5 kg and 1.792 m. In comparison the British Laser sailors reported here were of a similar age, on average 2.4 kg heavier and approximately 4 cm taller. Bojsen et al., (2003) reported values collected during 2002 for 8 elite Danish Laser sailors that were, with the exception of age, almost identical to the British data. These Danish sailors were approx 2 years older at 23.9 ± 2.6 years, but had similar weight (80.3 ± 2.7 kg), height (1.81 ± 0.05 m) and body fats (12.8%). Blackburn (1994) reported data for 10 Australian Laser sailors (all ranked in the top 30 Laser sailors in Australia) who had mean ages, body weights and heights of 26.9

years, 75.6 kg and 1.795 m. These elite Australian Laser sailors were considerably older than both British and New Zealand Laser sailors, lighter than both, being some 4.3 kg less, than the British Laser sailors, and 3.5 cm shorter than the British but similar in stature to the New Zealanders. Legg et al., (1997) also found that a mixed group of elite Laser sailors from other nations were considerably older than the British and New Zealanders at 27.5 years (n=17) and were heavier than the New Zealand sailors but similar in body weight to the British sailors at 79.8 kg. Vogiatzis et al., (1995a) reported mean age, body weight and height for eight Scottish National squad sailors of 23 ± 5 years, 74 ± 14 kg and 1.78 ± .08 m. Age and height are similar but body mass is considerably lower than other values reported with a large standard deviation for a group of eight subjects. Felici et al., (1999) reported mean values of 17 ± 2.1 years, 69.0 ± 3.8 kg and 1.79 ± 0.04 m for age, mass and height of seven junior Italian Laser sailors. The junior nature of these sailors accounts for the low age and the lowest body weight mentioned to date which is approx 9.9 kg lighter than the body weights reported here for the British Laser sailors.

In addition to these values the British Laser sailors had a body fat percentage of 13.7 ± 3.1%. Body fat measurements for specific sailing classes are rare in the literature. Bojsen et al., (2003) reported mean values of 11.4% (n=5) and 12.8% (n=8) for Danish Olympic squad Laser sailors collected during the period 1991-1995 and 2002. Blackburn (1994) reported body fats for elite Australian Laser sailors. He used 8 skinfold sites (Telford et al.,., 1988) but reported the data – a mean vale of 71.9 mm – as the sum of the eight skinfolds. Due to the different methods for assessing body fat percentage by skinfolds it is not possible to make any comparisons. Plyley (1985) has reported that elite Canadian sailors in general tended to have relatively large amounts of body fats with values of 17.7 ± 4.3 % being reported for 30 male members of the Canadian National team. These data are not class specific but values were considerably greater than those reported here for the British Olympic Laser squad. From the data present here and that reported recently by other authors, notably Bojsen et al., (2003), it would seem that a typical elite Olympic Laser sailor is ranging from 22-26 years of age, weighs approx 78 to 80 kg, has a height of 1.80 m and a body fat between 12-14%.

3.4.2 Finn class profiles.

There are only a few studies in the scientific literature detailing anthropometric profiles for Finn sailors. The British Olympic Finn sailing squad had a mean (± s.d.) age of 22.5 ± 3.1 years, height of 1.89 ± 0.08 m and a body weight of 95.9 ± 4.1 kg. In comparison the New Zealand Finn sailors were 2.4 years older at 24.9 years (n=3), very similar in height at 1.88 m (n=2), but considerably lighter weighing some 7.5 kg less at 86.6 kg (n=3) (Legg et al., 1997). They also reported a similar trend in the data for Finn sailors from other nations who were again older at 32.8 ± years (n=28) and noticeably lighter than the British sailors at 87.8 kg (n=28). Data for Canadian Finn sailors were also similar in height to the British and New Zealanders at 1.877 m, but approx 10.3 kg lighter than the British and 1.0 kg lighter than the New Zealanders at 85.6 kg. Bojsen et al., (2003) has reported data for Finn sailors covering two periods 1991-1995 (n=4) and 2002 (n=5). In their data there is a notable increase in body weights where the 1991-1995 data reported a mean body weight of 87.8 ± 4.4 kg compared to 93.5 ± 10.8 kg for the 2002. The latter figures are only 2.4 kg less than the British data. Bojsen et al., (2003) data for the 2002 group of Finn sailors reported that they were 5 cm shorter at 1.84 ± 0.04 m, almost 3 years older at 25.3 ± 4.8 years, and had greater body fats at 21.8% than those reported here for British Finn sailors. Bojsen's data for the 1991-1995 Danish Finn sailors suggested that they were not only lighter but some 4 cm taller at 1.88 ± 0.03 m, considerably older at 29.1 ± 2.5 years and carried significantly less body fat at 15.3% than the subsequent 2002 group.

With the exception of the recent data reported by Bojsen et al., (2003) there seems to be a consistent discrepancy in the literature where the body weights of the current British Finn sailors are approx 8-10 kg heavier than any other reported mean data. This difference can be explained by the fact that in November 1995 the International governing body for sailing [International Yacht Racing Union – now superseded by the International Sailing Federation (ISAF)] implemented an International rule change affecting the weight of sailing clothing. Prior to the rule change sailors were allowed to wear clothing weighing up to 8kg and an additional weight jacket that could weigh up to 15 kg in some classes. The weight jackets were worn whenever the wind was strong enough to warrant hiking. Finn sailors were allowed compete wearing weight jackets that weighed up to 10 kg, whilst the limit in the Laser class was set at 4 kg. The Finn sailor in the Gallozzi et al., (1993) case study only weighed 80 kg but wore a 15 kg weight jacket when sailing in winds sufficient to promote hiking. These weight jackets were considered to be detrimental to health, particularly on the knees and lower backs (http://www.sailing.org/meetings/minutes/1993_YS_31_10.PDF) and the International Yacht Racing Union, under the guidance of its medical advisor Dr Frank Newton, amended the racing rules, and banned weight jackets in November 1995. Hence, body weights reported in the scientific literature, with the exception of the Bojsen et al., (2003) data, for Finn sailors are out dated and are from the weight jacket era. Even the data presented by Legg et al., (1997) were collected during 1994 so that is also now dated. The change in sailors clothing and weight jackets although approved in November 1995 didn't come into force till 1st January 1997.

The mean body weight of 95.9 ± 4.1 kg (n=8) for elite Finn sailors of the British Olympic squad includes the data for the 2000 Olympic champion and also that for a triple World champion (2001-2003) and should now be considered the norm for sailors of that class. Since the 2000 Sydney Olympic Games, the British Finn sailors have dominated the class and it would seem that a typical elite Olympic Finn sailor is between 22-26 years of age, weighs approximately 96 kg and has a height of approx 1.90 m. Body fats were recorded at 18.6 ± 3.0 %, which are significantly greater ($p<0.01$) than the values reported for elite British Laser sailors but are similar to the values of 17.7 ± 4.3 % reported for members of the Canadian National sailing team (Plyley 1985) but less than the values of 21.8% for Danish Finn sailors (Bojsen et al., 2003).

3.4.3. Europe class profiles.

As with the Finn class there are only limited scientific studies detailing anthropometric profiles for Europe Sailors. The British Europe sailors (n=10) forming the Olympic squad had a mean (± s.d.) age of 24.1 ± 3.5 years, height of 1.69 ± 0.05 m, a body weight of 66.5 ± 3.8 kg and a body fat of 28.0 ± 2.3%. Comparison with the New Zealand Europe sailors reported by Legg et al., (1997) is problematic as that study only contained two Europe sailors who were younger than the British sailors at 19.7 years (n=2), and considerably shorter and lighter at 1.605 m (n=2) and 58.8 kg (n=2). The data reported by Legg et al., (1997) for international Europe sailors from other nations were similar in age to the British sailors at 24.8 years (n=8) and were closer in body weight than the New Zealand sailors at 62.4 kg (n=7). Probably the most recent and relevant data detailing the body profiles of Europe sailors have been reported by Bojsen et al., (2003). They reported data for six elite Danish Europe sailors collected during 2002 who had mean age, height, body weight and body fat percentage of 21.8 ± 4.1 years, 1.70 ± 0.03m, 69.6 ± 7.2 kg, and 23.6%. These Danish sailors were younger than the British data reported here, 3.1 kg heavier, very similar in height, and had less body fat. Larsson et al., (1996) reported anthropometric details for six female sailors from the Danish Olympic squads. Their mean age, weight, height and body fat were 20 ± 2 years, 67 ± 3 kg, 1.72 ± 0.03m and 29 ± 1%. Due to the small subject size the data were not sub-divided into separate classes and the six sailors were from the Europe, 470 and Sailboard classes. They were four years younger than the British sailors but had similar body weights (0.5 kg heavier), heights (3 cm taller) and body fats (1 % more fat).

As there are so little data specific to Europe sailors it is hard to suggest an ideal anthropometric profile. Britain's most successful Europe class sailors have been in their early 30's, almost 1.70m tall, a body weight of approximately 68 kg and body fats of approximately 25%. With the exception of age the data are similar to the results recently reported by Bojsen et al., (2003) for the elite Danish sailors who are also successful international sailors. It is suggested that an elite female Europe sailor should have an anthropometric profile where they are approx 1.70 m tall, 68-70 kg in weight, and approx 23-25% body fat. Age of successful Europe sailors seems to cover a wide banding from 20-32 years.

3.4.4. Anthropometric profiles for other Olympic sailing classes.

There are some notable trends within the anthropometric profiles for the elite British sailors forming the other Olympic sailing classes (see table 3.3). Without exception all the mean values for both body weight and height would suggest that the crews are normally both heavier and taller than the helms. Additionally, the helms are typically older than the crews, the only exception here being the Star class. Legg et al., (1997) found crew weights to be greater than that for helms but found similar statures. They summarised the difference in crew and helm weights as being logical:

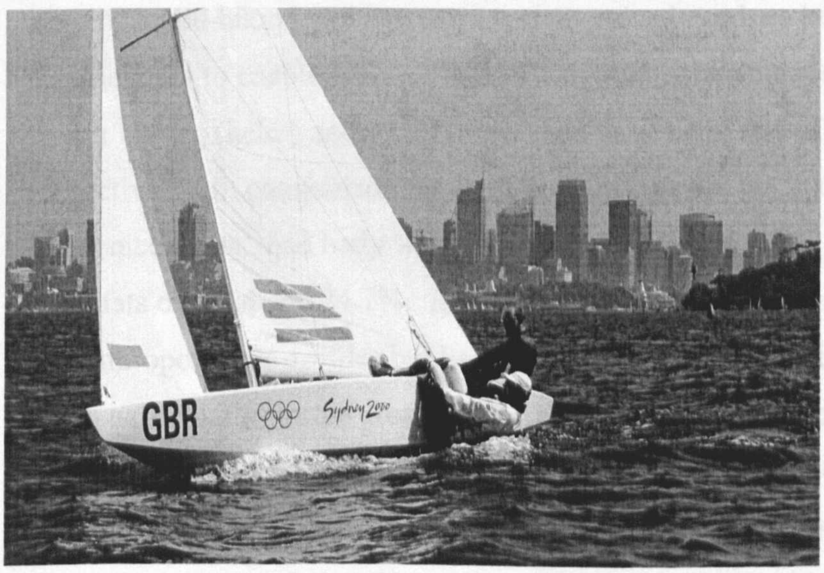
> *"This is in keeping with the different roles required of each sailor. One of the primary tasks of the crew member is counterbalancing the boat, so high body mass is an advantage." (Legg et al.,., p48)*

They also recognised that the difference between the crew and helm weights increased as the weight and size of the vessel increased. They reported differences of 10 kg and 6 kg for female and male 470 sailors, respectively. Although, they draw attention to the very small sample sizes, they advocated a difference between helm and crew weights of 7 kg in the Tornado class, 30 kg in the Star class and 12 kg in the Soling class (the Soling is no longer an Olympic class). In comparison the British class profiles suggested differences in body weights for crews and helms of 13.8 kg for female 470, 6.2 kg for male 470, 3.1 kg for 49'er, 5.6 kg for Tornado and 25.2 kg for Star. These results are similar to those reported by Legg et al., (1997), particularly in the 470, Tornado and Star classes. Bojsen et al., (2003) has combined the data for the helms of the 49'er and Tornado classes and compared them to the combined crew data for the same two classes. The results differ from those reported by Legg et al., (1997) and those reported in this chapter with the helms being both heavier (76.2 kg) and taller (1.85m) than the crews (72.0 kg and 1.78 m). This is surprising and difficult to explain.

Some of the other sailing classes are new to the Olympic arena such as the Yngling that debuts in Athens 2004 and the 49'er that made its debut in Sydney in 2000. There are no anthropometric profiles presented for Yngling class sailors in the scientific literature and only one limited publication concerning 49'er sailors (Bojsen et al., 2003). Body weight in the Yngling class is tightly controlled by international racing rules where the three female crews undergo a daily weigh-in prior to racing, and where the combined weight must not exceed 205 kg. Crews try to get as close as possible to the 205 kg weight limit. The combined mean weights for the three Yngling crew reported in table 3.3 amount to 205.2 kg. There are very little data concerning the 49'er class as it is also a relatively new Olympic class. Body weights are also controlled in this class with a one off pre-regatta weigh-in taking place. The optimal weight for the combined crew and helm is 148 kg, the crew and helms combined weight reported in table 3.3 amounts to 149.5 kg. As the 49'er class only has a pre-regatta weigh-in, normally at least 24 hours before the regatta starting, the sailors tend to be slightly over the weight limit and then dip on the day to make the weight.

The data reported both in this chapter and by Legg et al., (1997) suggest that in the Star class there is a big discrepancy between helm and crew profiles, with the most notable difference being the body weights. The hiking position for the Star crew is typically a dropped legged hiking position where the crews weight is supported by a harness (see figure 3.1 below).

Figure 3.1 Typical dropped legged hiking position for Star crew – hiking being aided by a harness.

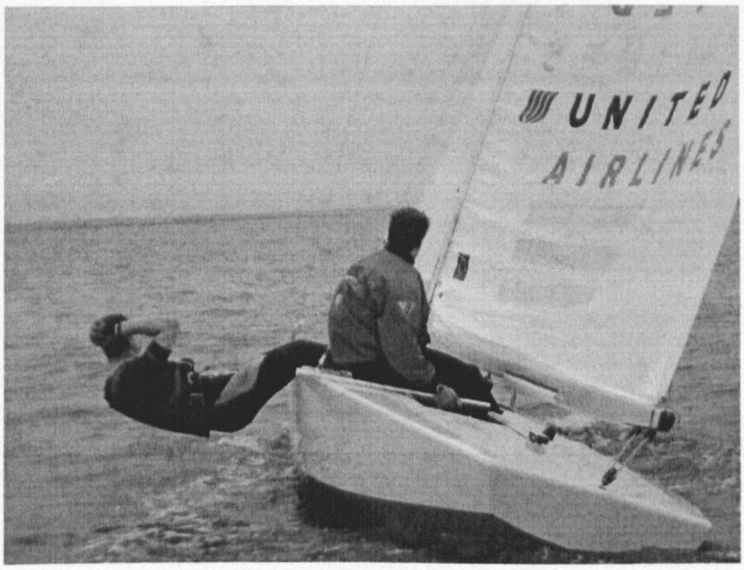


Traditionally the Star was sailed with heavy crews as the more weight in the boat the faster it would be in stronger winds due to the increased righting moment. This extra crew weight only had a minimal negative effect on boat speed in light winds. As the Star is a heavy boat (671 kg) an extra 30 or 40 kg in crew weight would have minimal effect on the frictional resistance through the water as that approximately equals the square of the mass of the boat combined with the mass of the crew (Shephard, 1990). Legg et al., (1997) reported helm crew weights of 90.1 and 119.3 kg, respectively for data collected during 1994. After the 2000 Olympics ISAF were keen on introducing a control or upper limit on Star crew weights. They wanted to implement a control on Star crew size because most of the crews were obese or close to be classified as obese and the image this portrayed on the International stage was not good for the image of sailing as an athletic sport. There were also potential long-term health issues at stake for the crew concerned. The mean body fats for the Star crews in this thesis are 22 ± 2.6 % (n=4) with the range being from 18.5 to 24.5%. In an attempt to reduce crew weights ISAF introduced a complex weight ruling into the class on the 1st January 2002. The weight rule, presented below, is presently being used in the class running up to the 2004 Olympics and is based on a crew/helm ratio:

$$\text{Star crew weight (kg)} = \frac{(100\text{ kg} - \text{helm weight})}{2} + 100\text{ kg}$$

Crew size has decreased considerably since this weight rule was implemented. There is a danger that it encourages heavy weight helms but the Star helm does not wear a harness to aid hiking and any extra weight gained needs to be supported by an adequate muscle mass to enable hiking. The British Star sailors competing at the 2004 Olympics weigh 102 kg (helm) and 99 kg (crew) and have body fats of approx 15 and 18%, respectively. In comparison the British Star sailors at the 2000 Olympics, who were silver medallists, had body weights of 72 kg (helm) and 129 kg (crew) and respective body fats of 10.6 and 24.7%. Implementing a weight rule change has not only altered the anthropometric profiles but has also altered the physical demands of sailing the boat, particularly for the crew. With the modern Star crew being approx 25 kg lighter, their role is now much more physical in nature. Figure 3.2 below depicts the new straight legged hiking posture being adopted by Star crews as opposed to the old and more conventional dropped legged position being aided with a harness shown in figure 3.1. The Star crew now has an enhanced physical role with emphasis being placed on the strength and endurance of the leg and abdominal muscles which is more akin with single-handed hiking sailors.

Figure 3.2 Modern day 'straight legged' hiking position for the new light-weight Star crews.



Conclusions.

Anthropometric profiles, and in particular body weights, are an important issue within the Olympic sailing classes. When comparing such profiles it is necessary to break the data down into specific classes and then a further split into helm and crew where appropriate. As stated by Bojsen et al., (2003) the problem then is that the sample size is normally small, particularly when presenting profiles from an elite population. Olympic sailing is continually evolving and over the past 10 years alone there have been major changes. The types of boat being sailed at the Olympics have changed, materials have advanced making the boats more powerful and there have been some influential rule changes pertaining to weight of sailors clothing and some changes directly to the weights of the sailors themselves. For these reasons comparisons to previous data, especially dated studies, should be treated with care.

CHAPTER 4

Chapter 4.

Physiological measures from on-water studies of single-handed dinghy racing.

4.1 Introduction

On-water investigations into the physiological demands of dinghy sailing are scarce, primarily due to the challenging environmental conditions and limitations with using analytical equipment on the water. The majority of the early investigations conducted on the water were confined to the measurement of heart rates alone using short range telemetric devices. These provide some insight into the physiological stress dinghy sailors experience during actual sailing conditions (Cudmore 1969; Piehl-Aulin 1977; Marchetti et al., 1980; Pudenz et al., 1981; Bachemont et al., 1984; Harrison & Coleman 1987). Some of the research is dated (Cudmore, 1969; Marchetti et al., 1980) and at times confusing as different classes of dinghy have been considered in the same paper and the roles of the skipper and the crew intermingled (Marchetti et al., 1980). Despite the possible effect of some non-physiological factors on heart rate, it can still be considered to be a relevant indicator of the involvement of aerobic metabolism during exercise (Åstrand and Rodahl, 1986).

Early work suggested three main findings: that sailing upwind was harder physically than sailing downwind; the physical demands increased as the wind speed increased; and that single-handers were physically more demanding than double-handers even in the same wind conditions (Cudmore, 1969; Piehl-Aulin et al., 1977; Dierck and Rieckert, 1980; Pudenz et al., 1981; and Harrison & Coleman, 1987). Some authors have been critical of using heart rate alone as indicating the physiological stress of dinghy sailing (Gallozzi et al., 1993; Vogiatzis et al., 1994; Vogiatzis et al., 1995a; Spurway 1997). Vogiatzis et al., (1994) suggests that aerobic capacity is not particularly taxed in Laser sailing despite cardiac function being challenged by other factors. These 'other factors' were not elaborated upon. The disparity between heart rates and oxygen uptakes measured on the water may be due to various factors. Psychological or emotional factors associated with sporting competitions in general may lead to somatic anxiety leading to tachycardia (Bachemont et al., 1984; Gallozzi et al., 1993). Vogiatzis et al., (1995a) suggests that the isometric contractions of principally the quadriceps is responsible for the elevated heart rates but not oxygen uptake as the cardiovascular system attempts to maintain perfusion in the working muscles. This explanation is difficult to understand. Indeed oxygen uptake only increases modestly during isometric exercise despite marked increases in ventilation (Petrofsky & Phillips, 1986; Wiley & Lind, 1971; Myhre & Anderson, 1971) but it is also well documented that heart rate response during isometric exercise is modest in nature and rarely exceeds 120 $b.min^{-1}$ (Petrofsky & Phillips, 1986).

Marchetti et al., (1980) and Vogiatzis et al., (1994) are the only ones to report oxygen kinetic data measured on the water with conventional Douglas bags. With the advent of portable gas analysers such as the Cosmed K2 in the 1980's (Dal Monte et al., 1989), the ease of measuring oxygen consumption in the field setting was enhanced. Subsequent oxygen uptake data has been reported for sailors from various classes (Gallozzi et al., (1993) Vogiatzis et al., 1995a; Devienne & Guezennec, 2000; Castagna & Brisswalter, 2004). The results from these studies, as reported in chapter 2 of this thesis, are equivocal in nature with some authors reporting low oxygen uptakes (Gallozzi et al., 1993; and Vogiatzis et al., 1995a) whereas others have reported significantly higher values (Devienne & Guezennec, 2000; and Castagna & Brisswalter, 2004). Some of this discrepancy has probably resulted from; undemanding weather conditions, use of sub-elite sailors, short hiking periods, different classes of sailing boats, and training situations opposed to racing situations. Recent findings by Castagna and Brisswalter (2004) during training highlights the differences in oxygen uptakes and heart rates between sailors of varying abilities and highlights the importance of the hiking duration. They reported oxygen uptakes and heart rates of 68.4% $\dot{V}O_{2max}$ and 78.5% heart rate max, respectively, for elite sailors during 30 minutes of hiking.

It is surprising that given the ease of use, the relative low cost and the sophistication of modern heart rate monitors that there have been so few recent investigations detailing heart rate response from regattas. To date the work by Gallozzi et al., (1993) and the very recent preliminary findings of Castagna and Brisswalter (2004) remain the most up to date research in this area. At the commencement of this thesis, in October 1993, it was proposed that a sensible starting point in determining the physiological stress placed on elite single-handed sailors would be a comprehensive collection of field data detailing heart rate response during racing in major regattas along with blood lactates immediately on finishing racing as it seemed there was a void of data in this area in the literature. The high cost of purchasing a state of the art Cosmed K2 (approx. £25,000) along with potential inaccuracies (Peel and Utsey, 1993; Lothian et al., 1993), the fact that it is not waterproof, and the possibility that it could disrupt the whole nature of the sailors movement patterns, made that option not feasible. This present study details heart rates and blood lactates for single-handed dinghy sailing in the Laser and Finn classes during major regattas.

The hypothesis for this chapter are fourfold:
Firstly, heart rates will increase as the wind speed increases.
Secondly, there will be no differences between the two classes.
Thirdly, that heart rates from upwind are higher than those for downwind sailing.
Fourthly, blood lactates will be elevated for both classes.

4.2 Method.

4.2.1 Subjects.

Twenty male Laser sailors and eight male Finn sailors volunteered to take part in this study. Anthropometric data for the subjects can be seen in tables 4.1 and 4.5 in the results section. The percentage of body fat reported are from skinfolds (Harpenden callipers) taken at the biceps, triceps, sub-scapular and supra-iliac sites (Durnin and Womersley, 1974). The majority of the Laser data were collected between October 1993 and June 1996 and during one International regatta during April 2002. The bulk of the Finn data was collected between April 1998 and March 2001. All the sailors were linked to the Royal Yachting Association's (RYA) Olympic Squad or Olympic Development Squad and were routinely fitness tested in the sports science laboratories at University College Chichester (UCC). Prior to any testing on the water all subjects were fully briefed about the experiment and informed consent forms completed (see appendix A). The study had ethical approval from University College Chichester's ethical committee.

4.2.2 Heart rate collection.

Heart rates were continuously recorded during sailing using short range telemetry (Polar Electro, Finland). Each subject wore a Polar wireless heart rate transmitter underneath their sailing clothing. The heart rate receiver unit (Polar Sports Tester, Polar Vantage Night Vision or Polar S610) was watch size and fastened onto the back of the elastic strap holding the heart rate transmitter in place underneath the sailing clothing. An earlier investigation into the on-water demands of windsurfing highlighted problems with wearing the watch receiver on the wrist whilst competing on the water (Cunningham et al., 1994). The receiver unit was set to record at either 15 second intervals for data collected prior to 1998 or at 5 second intervals for data collected post 1998. The recording process started at the time of donning the heart rate monitor. All heart rate receiver units were time synchronised with the experimenters watch and an accurate time activity log detailed during sailing. The time activity log recorded activities such as race start, upwind sailing, rounding marker buoys, downwind sailing, any capsizing moments and race finish time. After sailing the heart rate monitors were electronically downloaded using the Polar interface unit and the Polar software programme. Using the time activity log heart rates were averaged for the whole race and also for upwind and downwind legs of the course.

The heart rates reported for the 20 Laser sailors covers six regattas ranging from British championship regattas to a European championship and other grade one International regattas. In total data from 142 races have been analysed (59 races in light winds, 48 races in moderate winds and 35 races in heavy winds). For classification purposes wind conditions have been split into the following three conditions:

Light wind conditions:	2 – 4.5 $m.s^{-1}$ (4 – 9 knots)
Moderate wind conditions:	5 – 9 $m.s^{-1}$ (10 – 17 knots)
Heavy wind conditions	9 – 15 $m.s^{-1}$ (18 – 30 knots)

The splitting of the wind conditions into three categories is slightly arbitrary as the wind commonly changes both speed and direction during the time course of a race (approx. 60 minutes). Indeed, during data collection many races started in light conditions (2 – 4.5 $m.s^{-1}$) but finished in moderate conditions (5 – 9 $m.s^{-1}$). In wind speeds of 2 – 4.5 $m.s^{-1}$, continuous and maximal hiking is not required in order to keep the boat upright as the capsizing moment caused by the wind is not large enough and the sailor, at times, simply has to sit on the windward side to keep the boat balanced.

Heart rate data for the Finn class were collected during training regattas in Palma (Majorca) and Hayling Island (England) during April and August 2001, during International grade one regattas in Medemblik (Holland) and Le Hyeres (France) during 1998 and from the Finn class World Championship in Athens (Greece) during August 1998. Heart rates were collected in exactly the same manner as for the Laser class sailors as previously detailed. For classification purposes wind conditions have been split in a similar fashion as used with the Laser data with the exception that there are no data for the heavy wind conditions.

4.2.3 Blood sampling.

Finger tip capillary blood samples were taken as soon as possible on completion of each race. This involved waiting at the finish line in a support boat and taking the blood samples whilst on the water. Most blood samples were taken approx 1 –5 minutes after finishing the race, problems arose when the sailors being monitored all finished the race within a minute of each other as is typical with elite racing in the Laser class. The sailors on finishing the race would immediately sail alongside the support boat, have their hands thoroughly dried before having their finger pricked with a spring loaded monojet lancet. Fifty micro-litres of capillary blood were drawn into a heparinised capillary tube and immediately analysed for blood lactate concentration on a battery powered lactate analyser – YSI Sport 1500 (Yellow Springs International, Ohio, USA). Blood sampling in light and moderate winds and in smooth sea states was relatively straight-forward. Sampling in strong winds and in rough sea conditions with waves was not so straight-forward with the biggest problem being caused by both excessive boat movement and from sea spray impregnating the capillary tubes. The YSI Sport 1500 lactate analyser is a robust machine but is not water-proof and is temperamental to changes in ambient temperature. In an attempt to enhance its stability a waterproof box was made to keep both water out and direct sunlight off. The latter proved the biggest problem with blood samples being rejected as the YSI commonly became 'temperature unstable' due to sunlight shining on the outer casing of the box. At the onset of this research blood samples were taken from the sailors immediately prior to going sailing so that a pre-race versus a post-race blood lactate analysis could be established. However, there seemed little point in taking the pre-race sample as it was common to have large time lapses between taking the this sample and the race start. In such cases an analysis of pre-race versus post-race samples was meaningless, pre-race samples on the water were impractical as it was deemed to be too invasive immediately before the commencement of racing.

4.2.4 Statistical Analysis.

Means and standard deviations are reported for each wind condition and have been averaged between subjects. Paired t-tests with two tails have been used to compare the means for heart rates and blood lactates from different wind conditions. Levels of significance were set at $p<0.05$.

4.3 Results.

All raw data relevant to this chapter are shown in appendix C of the second volume of this thesis.

4.3.1 Laser sailing results.

The physical characteristics for the Laser sailors are in table 4.1 below:

Table 4.1. Anthropometric data for Laser sailors (n=20).

Variable	Mean ± s.d.	Range
Age (years)	22.9 ± 5.4	17.1 – 32.6
Height (m)	1.81 ± 0.04	1.73 – 1.90
Mass (kg)	79.1 ± 3.3	71.8 – 88.1
Body fat %	13.0 ± 2.3	9.0 – 16.2
HR_{max} (beats.min^{-1})	195 ± 7.3	182 – 214

Mean (± s.d.) heart rates (HR) for light, moderate and heavy wind Laser sailing can be seen in table 4.2 below. In all three conditions mean heart rates for upwind sailing were significantly greater ($p<0.01$) than those for downwind sailing. Upwind Laser sailing in heavy winds (9-15 m.s^{-1}) produced the highest heart rates which averaged 163 ± 10 beats.min^{-1}, and equated to 83.6% of maximum heart rate.

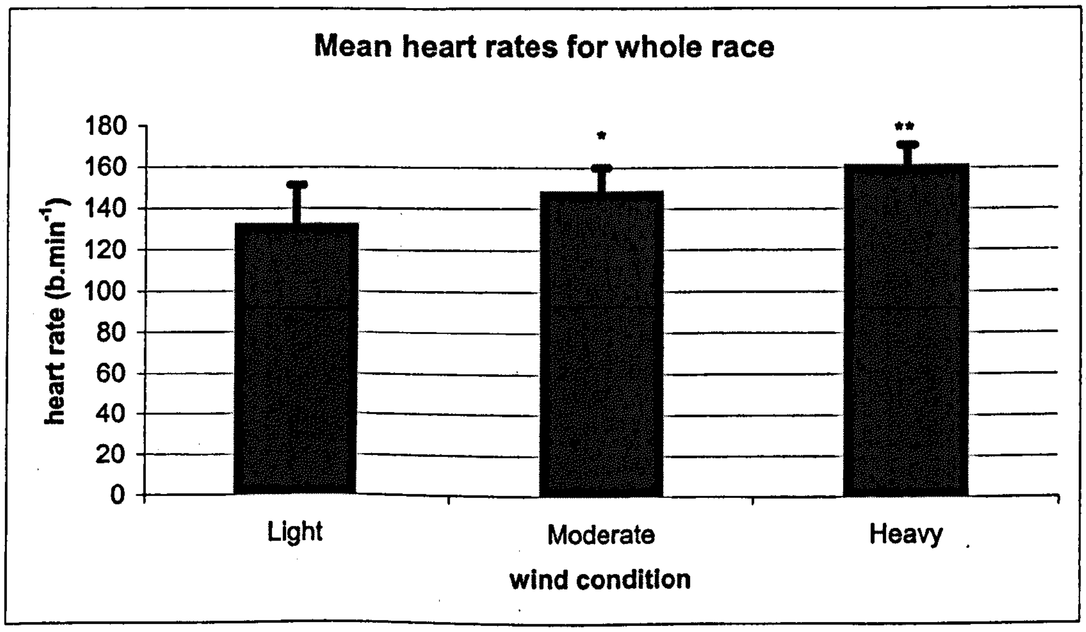
Table 4.2. Mean (± s.d.) heart rate data (beats.min^{-1}) for Laser sailing in light (2-4.5 m.s^{-1}), moderate (5-9 m.s^{-1}) and heavy (9-15 m.s^{-1}) winds.

	Upwind HR		**Downwind HR**		**Whole race HR**	
	Mean value	%max	mean value	% max	mean value	% max
Light winds (n=15, races=59)	138 ± 22	71 ±11	129 ± 21	67 ±11	132 ± 19	68 ±9
Moderate winds (n=15, races=48)	151 ± 13	78 ±7	139 ± 15	72 ±8	148 ± 12	76 ±7
Heavy winds (n=11, races=35)	163 ± 10	84 ±5	157 ± 12	81 ±6	161 ± 10	84 ±5

Upwind heart rates significantly greater than downwind heart rates in all wind conditions ($p<0.01$)

Mean heart rates for the whole race were significantly different ($p<0.01$) under each condition as reported in figure 4.1 below. Heart rates in heavy winds averaged 161 ± 10 beats.min^{-1} (84% of max HR) and were significantly greater ($p<0.01$) than those recorded in both moderate (148 ± 12 beats.min^{-1}) and light (132 ± 19 beats.min^{-1}) winds. Moderate wind heart rates were significantly greater ($p<0.01$) than those recorded in light winds.

Figure 4.1 Mean heart rates (± s.d.) in beats.min^{-1} for Laser sailing in light (2-4.5 m.s^{-1}), moderate (5-9 m.s^{-1}) and heavy (9-15 m.s^{-1}) winds.



* HR significantly greater than light wind conditions ($p<0.01$)
** HR significantly greater than light and moderate wind conditions ($p<0.01$)

Mean race durations for Laser sailing varied from 65.1 minutes in light winds, 55.4 minutes in moderate winds to 23.2 minutes in heavy winds. Race durations were significantly different ($p<0.01$) across the three wind conditions.

Table 4.3. Mean (± s.d.) leg times for upwind and downwind sailing and for whole races for Laser sailing in light (2-4.5 m.s^{-1}), moderate (5-9 m.s^{-1}) and heavy (9-15 m.s^{-1}) winds.

	Upwind leg (mins)	Downwind leg (mins)	Whole race (mins)
Light winds	15.8 ± 3.4	13.1 ± 9.4	65.1 ± 16.7
Moderate winds	14.5 ± 5.2	10.2 ± 3.1	55.4 ± 19.4
Heavy winds	8.8 ± 3.5	5.4 ± 2.4	23.2 ± 8.2

Mean post-race blood lactates increased significantly ($p<0.01$) as the wind speed increased. In light winds mean values were 1.70 ± 0.58 $mmol.l^{-1}$, in moderate winds they were 3.23 ± 1.25 $mmol.l^{-1}$ and in heavy winds they increased to 4.64 ± 1.08 $mmol.l^{-1}$.

Table 4.4. Mean (± s.d.) blood lactate values for Laser sailing in light (2-4.5 $m.s^{-1}$), moderate (5-9 $m.s^{-1}$) and heavy (9-15 $m.s^{-1}$) winds.

	Post-race blood lactate ($mmol.l^{-1}$)
Light winds (27 samples)	1.70 ± 0.58
Moderate winds (25 samples)	3.23 ± 1.25
Heavy winds (14 samples)	4.64 ± 1.08

Results significantly different in each wind condition ($p<0.01$)

4.3.2 Finn Sailing Results.

The physical characteristics for the Finn sailors are in table 4.5 below:

Table 4.5. Anthropometric data for Finn sailors (n=8).

Variable	Mean ± s.d.	Range
Age (years)	26.2 ± 4.3	21.1 – 32.8
Height (m)	1.85 ± 0.05	1.79 – 1.96
Mass (kg)	98.5 ± 3.7	94.6 – 103.1
Body fat %	18.4 ± 3.7	12.8 – 22.7
HR_{max} (beats.min^{-1})	195 ± 8.0	183 – 205

Mean heart rates for upwind and downwind sailing are shown below in table 4.6. The heart rates for upwind and downwind sailing were not significantly different ($p>0.05$) in both light wind and moderate wind conditions. In light winds mean upwind HR was 148 beats.min^{-1} as opposed to a mean value of 145 beats.min^{-1} for downwind sailing. In moderate winds mean upwind HR had increased to 152 beats.min^{-1} whilst downwind values had increased to 155 beats.min^{-1}.

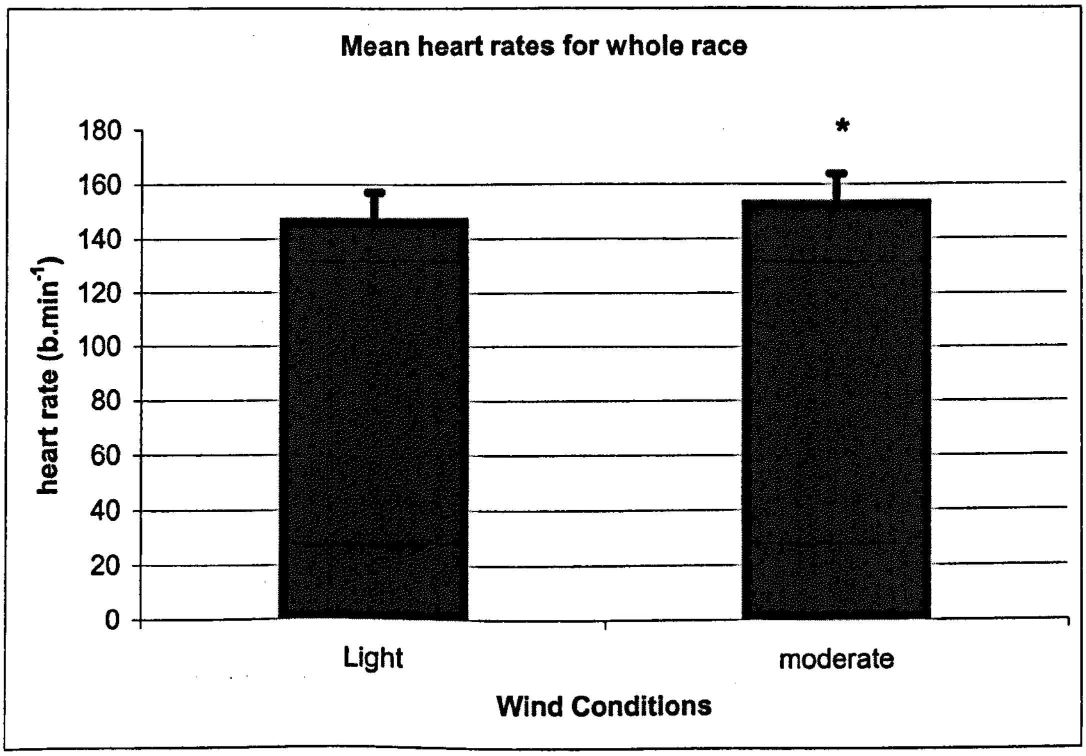
Table 4.6. Mean (± s.d.) heart rate data (beats.min^{-1}) for Finn sailing in light (2-4.5 m.s^{-1}) and moderate (5-9 m.s^{-1}) winds.

	Upwind HR		**Downwind HR**		**Whole race HR**	
	Mean value	%max	mean value	% max	mean value	% max
Light winds (n=8, races=44)	148 ± 15	76 ±8	145 ± 14	75 ±8	147 ± 10	75 ±5
Moderate winds (n=6, races=44)	152 ± 11	78 ±6	155 ± 10	79 ±6	154 ± 10	78 ±6

Upwind heart rates not significantly different than downwind heart rates in both wind conditions ($p>0.05$)

Mean heart rates averaged over the whole race were significantly greater for Finn sailing in moderate winds as opposed to light winds ($P<0.01$) where values were 154 ± 10 and 147 ± 10 beats.min^{-1}, respectively. Results can be seen graphically below. Mean heart rates for whole races for Finn sailing expressed relative to maximum heart rates varied from 74.7 ± 4.6% of maximum in light winds to 78.3 ±5.8 of maximum in moderate winds.

Figure 4.2. Mean heart rate (± s.d.) in beats.min^{-1} for Finn sailing in light (2-4.5 m.s^{-1}) and moderate (5-9 m.s^{-1}) wind conditions.



* Heart rates in moderate winds significantly greater than light wind conditions ($p<0.01$)

Mean race times can be seen in table 4.7 below. Race times in light winds (82.4 ± 31.7 minutes) were significantly greater than those in moderate winds (42.9 ± 40 minutes) ($p<0.01$). In both light wind conditions and moderate wind conditions there was no difference in times taken to complete the upwind and downwind legs of the course ($p>0.05$).

Table 4.7. Mean (± s.d.) leg times for upwind and downwind sailing and for whole races for Finn sailing in light (2-4.5 m.s^{-1}) and moderate (5-9 m.s^{-1}) winds.

	Upwind leg (mins)	Downwind leg (mins)	Whole race (mins)
Light winds (n=8, races=44)	19.3 ± 5.5	18.6 ± 6.3	82.4 ± 31.7
Moderate winds (n=6, races=44)	15.8 ± 6.9	14.2 ± 6.9	42.9 ± 40.0

Mean post-race blood lactates are shown below in table 4.8. Mean values recorded in moderate winds were 3.53 ± 1.53 $mmol.l^{-1}$ and these were significantly greater ($p<0.01$) than the light wind values which were 2.29 ± 0.86 $mmol.l^{-1}$.

Table 4.8. Mean (± s.d.) blood lactate values for Finn sailing in light (2-4.5 $m.s^{-1}$) and moderate (5-9 $m.s^{-1}$) winds.

	Post-race blood lactate ($mmol.l^{-1}$)
Light winds (21 samples)	2.29 ± 0.86
Moderate winds (25 samples)	3.53 ± 1.53

Results significantly different between wind conditions ($p<0.01$)

4.4 Discussion.

Anthropometric profiles of the Laser and Finn sailors in this study are similar to the profiles reported in the previous chapter. In brief the Laser sailors were younger, slightly smaller in height, considerably lighter and had less body fat than the Finn sailors. Probably the most important finding was the difference in body weights; Laser sailors tended to be around the 80 kg mark (actually 79.1 kg) and Finn sailors around 98 kg (actually 98.5 kg). These body weights are considered to be the goal weights for elite Laser and Finn sailors by the Royal Yachting Association and training programmes are built around these target weights (see chapter 7). Previous research has reported varying body weights for Finn sailors; 86 kg (Plyley et al., 1985), 80 kg (Gallozzi et al., 1993) 85.6 kg (Shephard, 1990) and 86.7 kg (Legg et al., 1997). These values were exceptionally light and are now out-dated. Prior to 1995 Finn sailors were permitted to wear weight jackets with an upper limit of 10kg whilst racing, in November 1995 the International Sailing Federation (ISAF) banned the use of weight jackets. This rule change has undoubtedly led to the increase in body weight required by a Finn sailor. The 80 kg mark for a Laser sailor is not disputed and most studies have reported values fairly close to this; 80 kg (Mackie & Legg, 1999), 74 kg (Vogiatzis et al., 1995a), and 75.6 kg (Blackburn, 1994). There are a few papers where the reported body weights for Laser sailors have been considerably less than this. Felici et al., (1999) and Vogiatzis et al., (1993) reported values of 69 and 69.5 kg for their subjects. The reason for these unusually light body weights were firstly because they were junior Laser sailors (Felici et al., 1999) and secondly they were not specifically Laser sailors (Vogiatzis et al., 1993) and in both cases not of an elite standard.

Heart rate data have been reported for some of the Olympic sailing classes, with Cudmore (1969) being one of the earliest. However, there are few comprehensive studies detailing heart rate data for different sailing classes in varying wind conditions whilst competing in regattas. Quite often previous research has been based on single case studies and the emphasis of the work has been on comparing data between the different classes (Bachemont et al., 1984; Gallozzi et al., 1993). Most of the data have also been collected during training sessions where the competitive element of the sport has been eliminated (Vogiatzis et al., 1995a).

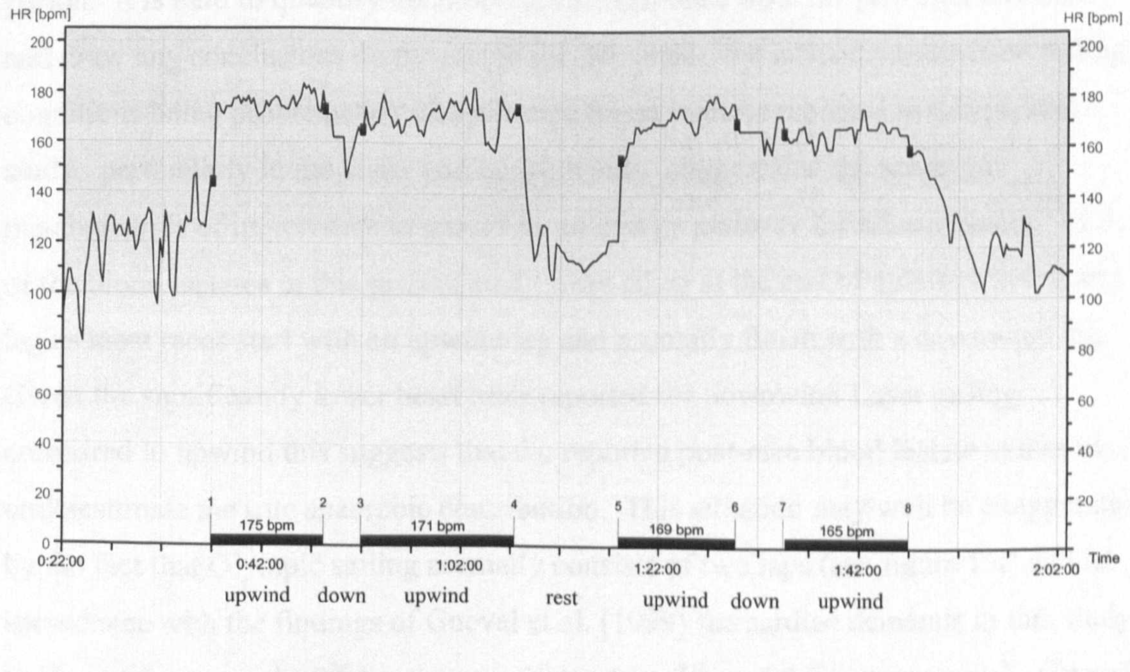
4.4.1 On-water measures for Laser sailing.

In common with previous studies, this present study found that upwind sailing in the Laser produces significantly elevated heart rates when compared to downwind sailing (Pudenz et al., 1981; Piehl-Aulin et al., 1977). This is irrespective of the wind speed. Pudenz et al., (1981) have suggested that the difference between upwind and downwind heart rates is as great as 30 beats.min^{-1} in strong wind conditions. They reported mean upwind and downwind heart rates of 168 and 138 beats.min^{-1}, respectively, in strong winds. In this present study the difference between upwind and downwind heart rates were less pronounced with a difference of only 9, 12 and 6 beats.min^{-1}, respectively in light, moderate and heavy winds. The smaller difference reported here is possibly because the downwind data included data from both running (going with the wind) and reaching (going across the wind). Reaching is still classified as going downwind but is more physically demanding than the running leg of the sailing course as near maximal hiking is still required when reaching. Previous research does not make it clear whether the downwind data included reaching legs.

In this study mean heart rates for Laser sailing increased as the wind speed increased. In light, moderate and heavy wind conditions the mean heart rates were 132 $\pm$ 19, 148 $\pm$ 12 and 161 $\pm$ 10 beats.min^{-1}, respectively. Higher heart rates with increasing wind speeds have been widely reported in previous literature (Harrison & Coleman, 1987; Piehl-Aulin et al., 1977; Vogiatzis et al., 1994; Vogiatzis et al., 1995a; Pudenz et al., 1981; Gallozzi et al., 1993). Vogiatzis et al., (1995b) reported mean heart rates of 135 $\pm$ 11 beats.min^{-1} and 155 $\pm$ 21 beats.min^{-1} in moderate and heavy winds; Marchetti et al., (1980) reported values of 148 beats.min^{-1} in moderate winds; and Vogiatzis et al., (1994) reported values of 145 $\pm$ 17 beats.min^{-1} and 153 $\pm$ 20 beats.min^{-1} in moderate and strong winds. As maximal heart rates can vary considerably between individuals (Harrison and Coleman, 1987) when comparing with previous research or between individuals a more suitable way to express heart rate data is to express it as a percentage to maximal heart rates. Problems commonly arise when previous research failed to establish maximum heart rates. In this present study heart rates expressed as percentages of maximum varied from 68 $\pm$ 9% in light winds, 76 $\pm$ 7% in moderate winds and 84 $\pm$ 5% in heavy winds. Previous studies have reported values of 69 $\pm$ 10% and 79 $\pm$ 10% in moderate and heavy winds (Vogiatzis et al., 1995b); 50.4%, 75.2% and 81% in light, moderate, and heavy winds respectively (Harrison & Coleman, 1987), 74 $\pm$ 11% in mixed wind conditions (Vogiatzis et al., 1995a) and values of between 65 and 78% for elite sailors in moderate winds (Castagna and Brisswalter, 2004). These are the only papers to have expressed sailing heart rates relative to maximal heart rates. As in this study, previous research has established maximal heart rates by performing cycle ergometry work to volitional exhaustion in a laboratory. The fact that the comparison is being made with a maximal heart rate from a cycling test in the laboratory reduces the ecological validity of making such a comparison.

A typical heart rate trace for a Laser sailor in moderate winds (5-9 $m.s^{-1}$) is shown below in figure 4.3. The trace depicts two races with a 10 minute rest between. Mean heart rates for both races were 171 and 166 $beats.min^{-1}$, respectively. The upwind and downwind heart rate splits were 172 and 165 $beats.min^{-1}$ for upwind sailing and 162 and 163 $beats.min^{-1}$ for downwind sailing. Post-race blood lactate samples were 4.81 and 5.01 $mmol.l^{-1}$ respectively, for races 1 and 2.

Figure 4.3. Typical heart rate trace for Laser Sailing in 15-18 knots (7-9 $m.s^{-1}$). Weymouth Bay, 20/11/94. Course: upwind, downwind, upwind – 2 races with 10 minute rest between.

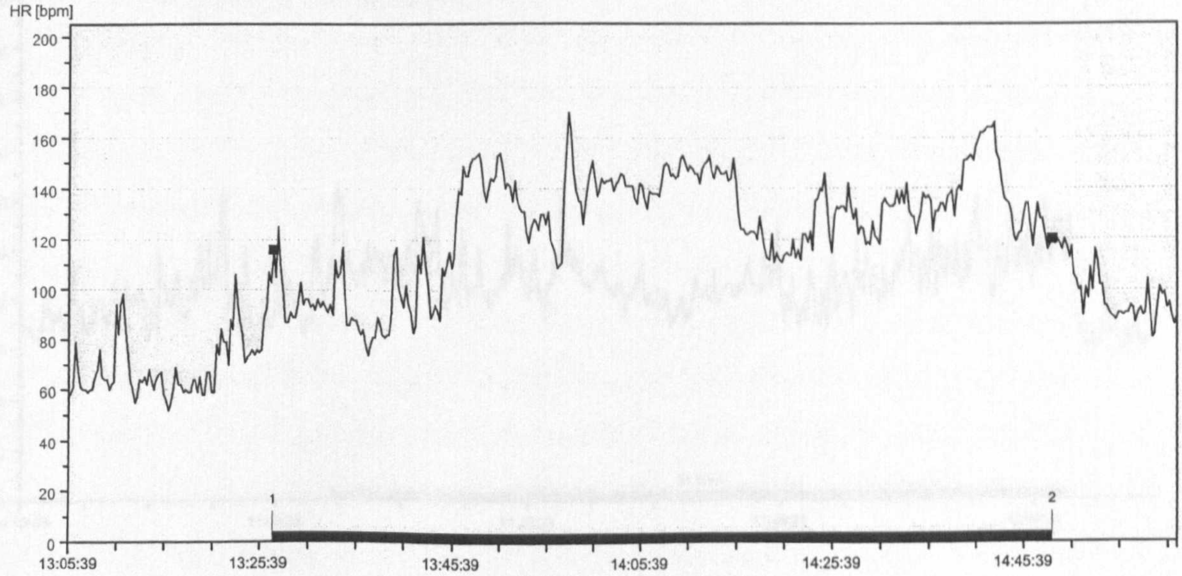


The mean heart rates for these two races amounted to 88.6 % and 86.0 % of the sailors' maximal heart rates. This elevated heart rate along with the high post-race blood lactate values of 4.81 and 5.01 $mmol.l^{-1}$ indicates that there are considerable physiological demands placed on the Laser sailor in such wind conditions. Blood lactate, despite its complex metabolism, is considered to be a relevant indicator of anaerobic glycolysis during exercise (Davis, 1985; Brooks, 1991). It is clear, given the mean race lengths of approx 55.4 ± 19.4 minutes in moderate winds, that both aerobic and anaerobic metabolisms play an important role as far as energy production is concerned. A combination of such a physiological demand and the fact that two or three races can be completed each day and that a typical regatta will be sailed over a six day period suggests that glycogen depletion may become an issue if appropriate nutritional strategies are not administered (McLoughlin et al., 1993).

Mean post-race blood lactates reported in this present study for Laser sailing increased significantly ($p<0.01$) as the wind speed increased and ranged from 1.70 ± 0.58 $mmol.l^{-1}$ in light winds, 3.23 ± 1.25 $mmol.l^{-1}$ in moderate winds and 4.64 ± 1.08 $mmol.l^{-1}$ in heavy winds. Piehl-Aulin et al., (1977) have reported higher values that ranged between 4 to 8 $mmol.l^{-1}$ after a demanding 40 minute sailing test. Vogiatzis et al., (1995a) reported mean values of 2.3 ± 0.8 $mmol.l^{-1}$ immediately after 10 minutes of upwind sailing in wind conditions of between 4 – 12 $m.s^{-1}$. Marchetti et al., (1980) have reported the lowest values of 1.8 ± 0.4 $mmol.l^{-1}$ following a 5 minute hiking period. It is hard to quantify the blood lactate response from the previous research and draw any conclusions on the metabolic demands; the lack of standardised sailing conditions being problematic. The elevated blood lactates reported in this present study, particularly in moderate and heavy winds, suggest that the anaerobic metabolism is of importance in providing an energy pathway for a Laser sailor. Most of the blood lactates in this present study were taken at the end of a downwind racing leg as most races start with an upwind leg and normally finish with a downwind leg. Given the significantly lower heart rates reported for downwind Laser sailing compared to upwind this suggests that the reported post-race blood lactate values may underestimate the true anaerobic contribution. This situation may well be exaggerated by the fact that Olympic sailing normally consists of two laps (see figure 1.4) and in accordance with the findings of Guevel et al. (1999) the cardiac demands in this study tend to be lower on the 2nd lap than the 1st lap (see figure 4.3 for an example). Guevel et al. (1999) suggests that the lap one is important for the sailors final classification, whereas in most cases lap two serves only to consolidate the final race position. A reduction in the physical exertion on the second leg could lead to some blood lactate being metabolised by active skeletal muscles which have a high oxidative capacity (Hermansen and Stensvold, 1972). As such the lactates which were taken 1 to 5 minutes after finishing the race (at the end of a downwind leg on the 2nd lap) may under-represent the true anaerobic metabolism. Values of 3.23 ± 1.25 mmol.l^{-1} in moderate winds and 4.64 ± 1.08 in heavy winds suggests considerable anaerobic mechanisms may be operating during competitive Laser racing.

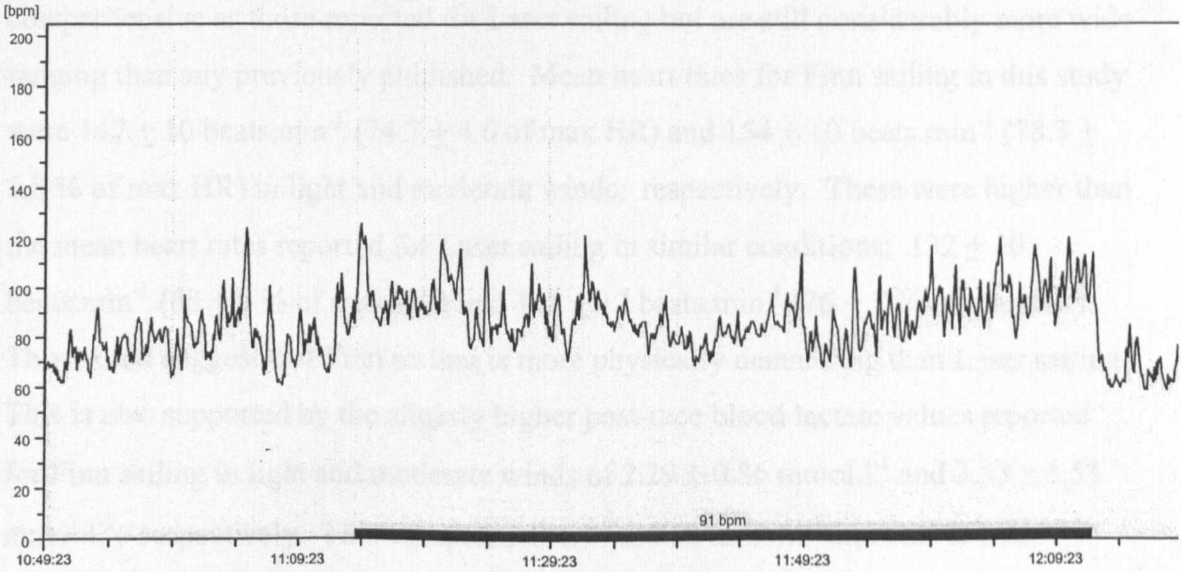
The elevated heart rates reported for Laser sailing have been heavily criticised as a misleading method for measuring the physical demands of the sport. Bachemont et al., (1984); Gallozzi et al., (1993) have indicated that the strong emotional aspect of the sport is responsible for the elevated heart rates and that this has distorted the true physiological picture. Indeed, dinghy racing has been likened to a game of chess for requiring similar demands of complex reasoning (Shephard, 1990) and sustained attention (Gouard, 1981). However, this does not explain why heart rates are so suppressed in the very lightest wind conditions and so elevated in heavy winds as the cognitive demands remain fairly steady throughout the race period. The heart rate trace shown below in figures 4.4 and 4.5 depicts typical heart rate traces for two Laser sailors. In figure 4.4 the race started in light conditions (2-3 m.s^{-1}) but increased to 5-6 m.s^{-1} (moderate) after about 20 minutes. The race length was approx 88 minutes and it is clear to see that the increased heart rate corresponds with the increased wind speed. If the emotional or cognitive aspect of Laser sailing was so prevalent then one would expect similar heart rate response throughout the whole race.

Figure 4.4. Laser Sailing in building winds (2-3 m.s^{-1} increasing 5-6 m.s^{-1} after first windward leg). Course: upwind, tight reach and run, upwind, run, upwind, run.



In figure 4.5 the wind conditions were light (2-3 m.s^{-1}) throughout the 58 minute race. Heart rate average was 91 beats.min^{-1}, with only occasional periods in excess of 100 beats.min^{-1}. This trace was recorded during a International Grade one Olympic class regatta (Le Hyeres, France, 2002) and the sailor came first in this race. The low heart rate would tend to suggest that the somatic anxiety or the excessive cognitive demands that have been suggested to exist were in fact having minimal effect. This subjects maximal heart rate in the laboratory has been recorded at 194 beats.min^{-1}.

Figure 4.5. Laser Sailing in light winds (2-3 m.s^{-1}) – mean heart rate 91 beats.min^{-1}. Race 5, Hyeres International Olympic regatta 2002, race position 1st.



Race lengths for Laser sailing are typically around 60 minutes (target race lengths at the 2000 Olympics were between 60-75 minutes for both Laser and Finn classes). At the 1996 Atlanta Olympics mean race lengths for Laser sailing were 55 minutes 59 seconds, with the upwind legs averaging 15.0 minutes over the 11 race series (**http://www.isaf.org/96olympics/general/default.asp**). In this present study light wind races averaged 65.1 $\pm$ 16.7 minutes, moderate wind races 55.4 $\pm$ 19.4 minutes and heavy wind races 23.2 $\pm$ 8.2 minutes. Both the light and moderate wind races are roughly around the 60 minute mark as expected. Race lengths in heavy winds are considerably less than this, primarily because these races largely came from the British racing series and not from International regattas. Correct racing courses are difficult to set in heavy winds and as such these races were normally held around a similar size course that would have been used for moderate wind racing but the extra boat speeds generated meant a much quicker race time. In this study mean race times for the upwind legs in light and moderate winds averaged 15.8 $\pm$ 3.4 and 14.5 $\pm$ 5.2 minutes, respectively. These are similar to the 15.0 minute averages reported for upwind legs for Laser sailing from the 1996 Atlanta Olympics. In heavy winds the upwind legs averaged only 8.8 $\pm$ 3.5 minutes, this is again due to the small race lengths in these conditions whilst racing in British national series regattas.

4.4.2 On-water measures for Finn sailing.

The heart rates and blood lactates reported in this study for Finn sailing are not as comprehensive as those reported for Laser sailing but are still considerably more wide ranging than any previously published. Mean heart rates for Finn sailing in this study were 147 $\pm$ 10 beats.min^{-1} (74.7 $\pm$ 4.6 of max HR) and 154 $\pm$ 10 beats.min^{-1} (78.3 $\pm$ 5.8 % of max HR) in light and moderate winds, respectively. These were higher than the mean heart rates reported for Laser sailing in similar conditions; 132 $\pm$ 10 beats.min^{-1} (68 $\pm$ 9 % of max HR) and 148 $\pm$ 12 beats.min^{-1} (76 $\pm$ 7 % of max HR). This would suggest that Finn sailing is more physically demanding than Laser sailing. This is also supported by the slightly higher post-race blood lactate values reported for Finn sailing in light and moderate winds of 2.29 ± 0.86 mmol.l^{-1} and 3.53 ± 1.53 mmol.l^{-1}, respectively. This compares to 1.70 ± 0.58 mmol.l^{-1} and 3.23 ± 1.25 mmol.l^{-1} for Laser sailing in similar light and moderate wind conditions. The values reported here are greater than those reported in other studies that investigated Finn sailing (Cudmore, 1969; Gallozzi et al., 1993).

The aim of this chapter was not to compare heart rates or blood lactates between different sailing classes but simply to describe what happens on the water for Laser and Finn sailing. However, the most notable difference between the two sets of data was that upwind and downwind heart rates for Finn sailing were not significantly different ($p>0.05$). In light winds, upwind and downwind heart rates for Finn sailing averaged 148 $\pm$ 15 and 145 $\pm$ 14 beats.min^{-1}, respectively; and in complete contrast Finn heart rates for downwind sailing (155 $\pm$ 10 beats.min^{-1}) were higher than upwind heart rates (145 $\pm$ 14 beats.min^{-1}) in moderate winds, but the differences were not statistically significant ($p=0.076$). Although the results were not statistically different, the important finding, particularly for the Finn sailor, is that they have a greater physiological demand when sailing downwind and, unlike the Laser sailor, have a more constant physiological requirement throughout the whole race. This is reflected in higher mean heart rates for Finn sailing when looking at the whole race. The Laser sailor has a comparative break physiologically speaking when sailing downwind. Although the work by Cudmore (1969) is out-dated and of little significance to the modern day Finn sailor he did report higher heart rates for downwind sailing than for upwind sailing. Gallozzi et al., (1993) did not break his Finn data down numerically into upwind/downwind values but from his graphical presentation (p852) there is no obvious difference in the heart rates between upwind and downwind sailing. The lack of any obvious upwind/downwind trends in the heart rates for Finn sailing, unlike that for Laser sailing, could be because downwind Finn sailing is more demanding than sailing a Laser downwind due to the extra power generated by the more sophisticated and powerful Finn rig.

The heart rates reported by Cudmore (1969) were low, with mean values of 68 beats.min^{-1} being suggested for light winds and 85 beats.min^{-1} and 95-100 beats.min^{-1} for upwind and downwind sailing in moderate wind. The substantial differences in heart rates reported by Cudmore and those from this present study are difficult to explain but are possibly a reflection on how Finn sailing has changed over the past 30 years. There have been major technological changes, particularly with the rig where high tech wing masts made from carbon fibre have replaced the old wooden masts that would have been used back in 1969. The Finn's highly tuned rig is very rigid and as such is very responsive to sailor movements. Thus, Finn sailing has gone from being fundamentally a static sport to being a much more dynamic sport where the sailor's bouncing in the boat is instrumental in fanning the super stiff rig and producing forward momentum. Cudmore (1969) summarised the low heart rates as a reflection on the isometric nature of 'sitting out' and that the only dynamic activity was pushing the boat around the dinghy park prior to launching when heart rates peaked at 120 beat.min^{-1}.

Gallozzi et al., (1993) reported a mean heart rate of 108 beats.min^{-1} for a single Finn sailor whilst competing in an International regatta in light winds. This is considerably lower than the mean values (147 $\pm$ 10 beats.min^{-1}) reported in this present study for light wind Finn sailing. The difference here can probably be explained by the "exceptionally undemanding conditions" in the Gallozzi study. Also case studies from a single race on one sailor could distort the true picture; the sailor concerned may have an exceptionally low maximum heart rate (not reported by Gallozzi et al.,) or they may just have had a bad race where they physically did not try hard for various motivational reasons.

Large individual differences in heart rate data between subjects in the same race is evident in the present data for Finn sailing. The reason for the large differences are difficult to explain but are possibly related to the skill level of the subjects. Figures 4.6 and 4.7 depict light wind heart rate traces for two different sailors whilst competing in the same race of the Finn class World Championships in Athens in August 1998.

Figure 4.6. Heart rate trace for Sub-elite Finn Sailor in light winds (3-5 m.s^{-1}) – mean heart rate 136 beats.min^{-1} (73.9% of max HR), race length 2 hours 01 minutes. Subject 'A'.

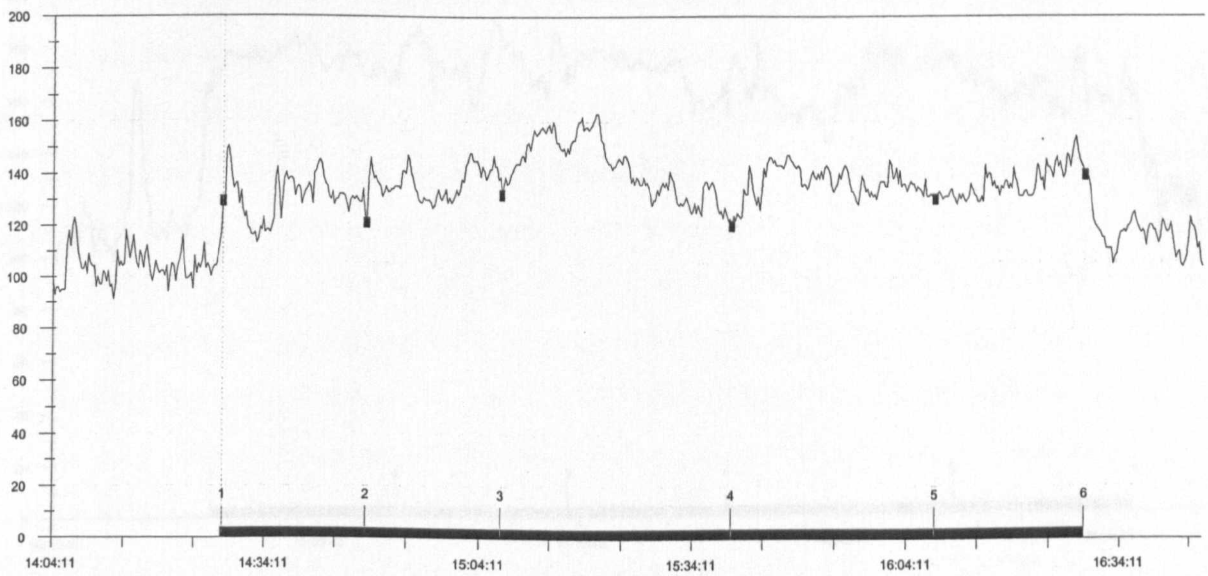
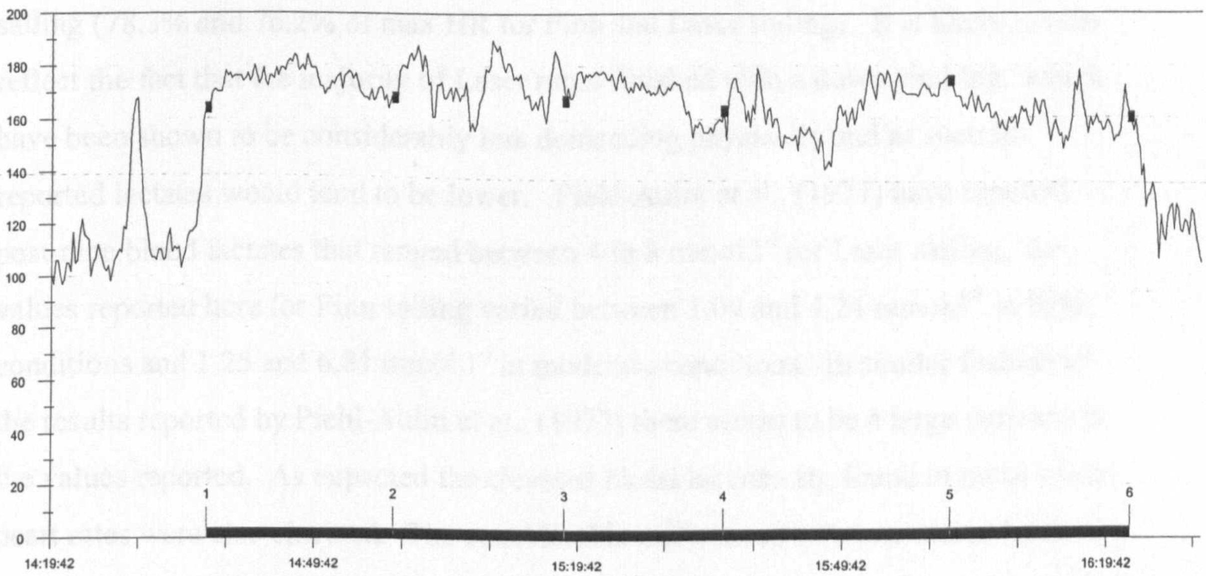


Figure 4.6 is the heart rate trace for an inexperienced Finn sailor (sailor 'A') who finished the regatta in approx 50th position whereas Figure 4.7 is that for an elite sailor (sailor 'B') who finished the regatta in 4th position and later went on to win an Olympic gold medal in the Finn class at the 2000 Games. Maximum heart rates for the two subjects from cycle ergometry tests in the laboratory are similar; the sub-elite sailor ('A') having a maximal heart rate of 186 beats.min^{-1} whilst the elite sailor ('B') one of 183 beats.min^{-1}. The sub-elite sailor had a mean heart rate of approx. 73.9% of maximum for the race duration whereas the elite sailor raced at approx. 91.8% of maximum. Fitness levels of the two subjects are slightly different with the elite sailor having a $\dot{V}O_{2max}$ of 56.7 ml.kg^{-1}.min^{-1} and the sub-elite sailor having one of 51.0 ml.kg^{-1}.min^{-1}. The difference in aerobic fitness does not explain the discrepancies reported in the heart rates, as one would normally

expect the fitter sailor to have a lower heart rate as they have a greater capacity for doing work as measured by $\dot{V}O_{2max}$. The sailing heart rate discrepancy is large and is probably related to the difference in skill levels between the two sailors and specifically the ability of the more skilled sailor to be able to work the boat in a dynamic fashion, particularly when sailing downwind.

Figure 4.7. Heart rate trace for Elite Finn Sailor in light winds (3-5 m.s^{-1}) – mean heart rate 168 beats.min^{-1} (91.8% of max HR), race length 1 hour 45 minutes. Subject 'B'.



The difference in heart rates reported here between different sailors in the same race, possibly relating to sailing ability or a measure of performance, makes it problematic when trying to compare mean values from a number of subjects to those reported in other research studies. The biggest problem is trying to quantify the sailing ability of the individual and to decide on the cut-off point to classify the athlete as elite or sub-elite. It is this difference in skill level that has been a missing factor in other on-water studies when the subjects have not necessarily been of an elite standard (Vogiatzis et al., 1993; Gallozzi et al., 1993; Vogiatzis et al., 1995a;), and subsequently heart rate and blood lactate values are lower than the values reported in this present study. It has already been stated in this chapter that case studies can be misleading but perhaps a case study from a truly elite sailor such as an Olympic Champion may aid research knowledge.

Post-race blood lactates for Finn sailing averaged 2.29 ± 0.86 $mmol.l^{-1}$ and 3.53 ± 1.53 $mmol.l^{-1}$ in light and moderate winds, respectively. These are higher than the values reported for the Laser sailors in this study. No other papers have reported blood lactate measures in Finn sailing. The elevated blood lactates, particularly in moderate winds, would suggest that there is some contribution from anaerobic metabolism. The difference in mean blood lactates between Finn and Laser sailing in moderate winds (3.53 ± 1.53 $mmol.l^{-1}$ for Finn and 3.23 ± 1.25 $mmol.l^{-1}$ for Laser) is probably not entirely a reflection on the higher mean heart rates reported for Finn sailing (78.3% and 76.2% of max HR for Finn and Laser sailing). It is likely to also reflect the fact that the majority of Laser races finished with a downwind leg, which have been shown to be considerably less demanding physically and as such the reported lactates would tend to be lower. Piehl-Aulin et al., (1977) have reported post-race blood lactates that ranged between 4 to 8 $mmol.l^{-1}$ for Laser sailing, the values reported here for Finn sailing varied between 1.09 and 4.24 $mmol.l^{-1}$ in light conditions and 1.25 and 6.81 $mmol.l^{-1}$ in moderate conditions. In similar fashion to the results reported by Piehl-Aulin et al., (1977) there seems to be a large variance in the values reported. As expected the elevated blood lactates are found in races when heart rates were also elevated. The considerable differences between values leads to two precautions; firstly the need to be careful when classifying data from a number of subjects as mean values may not accurately describe what is happening with the true elite sailor; and secondly care needs to be administered when grouping data into a specific wind range due to the ever changing wind conditions which are subsequently reflected in the physiological responses.

One omission from the results for Finn sailing is the lack of any data for heavy wind conditions. The main reason here is that for the purpose of this study heavy winds were classified as being winds in excess of 9 $m.s^{-1}$ (approx. 18 knots). This wind range is very close to the upper end of conditions in which Finn racing would take place. Due to the fragile nature of the Finn mast and the difficulty of controlling the boat in heavy winds very few races are completed in winds in excess of 10 $m.s^{-1}$. The Laser with its standard aluminium mast and one design sail is capable of racing in much stronger winds without the risk of equipment damage. Throughout the time course of this thesis there have been very few Finn races in heavy wind conditions and relatively few valid and reliable data are available.

Race durations for the Finn class at the Olympics have a target time of 60 minutes, which is similar to the Laser class racing. At the 1996 Atlanta Olympics mean race durations for Finn sailing were 74 minutes 38 seconds, with upwind legs averaging 17 minutes 28 seconds over 11 races (**http://www.isaf.org/96olympics/general/default.asp**). In this present study light wind races averaged 82.4 $\pm$ 31.7 minutes and moderate wind races 42.9 $\pm$ 40.0 minutes with upwind legs averagied 19.3 $\pm$ 5.5 minutes and 15.8 $\pm$ 6.9 minutes. The high standard deviations associated with the mean race times are due to the changes that have occurred in Finn racing to come in line with recommendations made by the International Sailing Federation (ISAF). Finn racing has traditionally been controlled by the International Finn class and their target race times for World Championship races is 120 to 150 minutes. ISAF has a target race time of 60-75 minutes for Finn racing. The results reported for Finn sailing come from a mix of ISAF controlled racing and also racing from Finn class world championships, which accounts for the large standard deviations.

4.5 Conclusions.

The on-water data reported in this chapter for both Laser and Finn sailing are similar to that reported by Piehl-Aulin et al., (1977) and Pudenz et al., (1981). There seems to be a lot of discrepancy with data reported from some on-water studies (Cudmore, 1969; Marchetti et al., 1980; Gallozzi et al., 1993; and Vogiatzis et al., 1995a). The reasons for these discrepancies may be due to the out-dated nature of some of the studies (Cudmore, 1969; Marchetti et al., 1980); the undemanding weather conditions (Gallozzi et al., 1993); poor skill level or non-elite nature of the sailors (Vogiatzis et al., 1995a); the case study nature of the research (Gallozzi et al., 1993); and the confusion of data arising from different types of sailing classes (Marchetti et al., 1980; Gallozzi et al., 1993). There are also few studies that have measured oxygen consumption on the water (Marchetti et al., 1980; Sandstrom et al., 1985; Vogiatzis et al., 1993; Gallozzi et al., 1993; Vogiatzis et al., 1995a; Devienne & Guezennec, 2000). Oxygen uptakes reported are also equivocal in nature with values ranging from 24 $ml.kg^{-1}.min^{-1}$ (Sandstrom et al., 1985), 31 $ml.kg^{-1}.min^{-1}$ (Marchetti et al., 1980); 80% of $\dot{V}O_{2max}$ (Devienne & Guezennec, 2000); 20.3 $ml.kg^{-1}.min^{-1}$ (Vogiatzis et al., 1994);

20.5 $ml.kg^{-1}.min^{-1}$ (Gallozzi et al., 1993); and 39% of $\dot{V}O_{2max}$ (Vogiatzis et al., 1995a). The large variances in oxygen responses are probably due to the factors already mentioned above.

It is clear that previous on-water studies have suggested that the physiological demands of dinghy sailing are equivocal in nature. This present study has highlighted that single-handed sailing in the Laser and Finn at the elite level produces moderately high physiological demands. Oxygen consumption has not been measured in the present study. The following chapters of this thesis are aimed at replicating single-handed dinghy sailing in the laboratory where firstly the physiological demands of static hiking are investigated and secondly the dynamic nature of dinghy sailing is simulated and comparisons made to the data reported in this present chapter.

CHAPTER 5

Chapter 5:

The physiological responses to 30 minutes of static simulated dinghy sailing.

5.1 Introduction.

A large amount of research supports the notion that dinghy sailing is primarily an isometric activity and that it is the physiological demands of static hiking that promote the elevated physiological requirements as reported from on-water studies (Pudenz 1981; Harrison and Coleman 1987; Vogiatzis et al., 1995a). This chapter is primarily aimed at clarifying whether the static hiking posture and the relatively large muscle mass associated with such an activity are responsible for the elevated physiological parameters measured on the water. A laboratory simulation concentrating solely on the hiking posture has the advantage that the experimental conditions can be tightly controlled and protocols standardised between subjects. Since previous researchers (Marchetti et al., 1980, Vogiatzis et al., 1995, Spurway 1997 and Blackburn 1994) have suggested that hiking is the major physical challenge in dinghy sailing, any simulation needs to replicate this posture. There are two main types of ergometers that can simulate dinghy sailing:

5.1.1 Ergometer 1: The hiking bench.

A simple and traditional method of simulating hiking performance is to use a static hiking bench. It is normally constructed out of wood, steel or fibreglass and fastened firmly to the ground. Sailors are required to support their body whilst leaning out from the hiking bench with their feet positioned under a toe-strap. If the sailor concentrates on the angles at the hip joint and the knee joint a realistic hiking posture compared to on-water sailing can be replicated (Piehl-Aulin et al., 1977; Niinimaa et al., 1977; Putman 1979; Marchetti et al., 1980; Spurway and Burns 1993). The static hiking bench is useful in that body joint angles and the forces exerted on the toe-strap can be tightly controlled allowing reproducible simulations where accessory movements, such as rapid hip extension/flexion and rotation that is common when bouncing the boat through waves, can be eliminated. The static hiking bench can also be developed so that the subjects can simulate body actions that would normally accompany sailing in large waves or gusty wind conditions. An elasticised rope can also be added to act as a mainsheet so that the constant trimming of the sail can be replicated (Kent 1983; Spurway and Burns 1993; Blackburn 1994). Such hiking benches do not move so it is difficult to simulate the bouncing movement associated with sailing small dinghies. However, hiking benches have been widely used, particularly by club level sailors during the winter months, as a means of developing or maintaining muscular endurance associated with the hiking specific muscles whilst time on the water is limited due to darkness and climatic conditions.

5.1.2. Ergometer 2: Dynamic hiking ergometers.

More recently sailing-specific dinghy ergometers have been used to simulate hiking performance and the subsequent physiological demands. Such ergometers are normally constructed out of the deck moulding of a dinghy and instead of being fixed to the ground are normally free to move on a fore and aft axis so that an angle of heel can be induced. Harrison et al., (1988) and McLoughlin et al., (1993) were the first to utilise such a dynamic simulator where they used water and weights, respectively, to simulate a heeling action. Blackburn (1994) and Vogiatzis et al., (1995) used springs to create the heeling moment. Subjects are required to counterbalance the heeling moment created by the simulator by hiking out as they would do on the water. The skill of keeping the dinghy on an even keel can be measured with an appropriate device; McLoughlin et al., (1993) used a computer to record potentiometer modulated voltages from which a hiking error could be established.

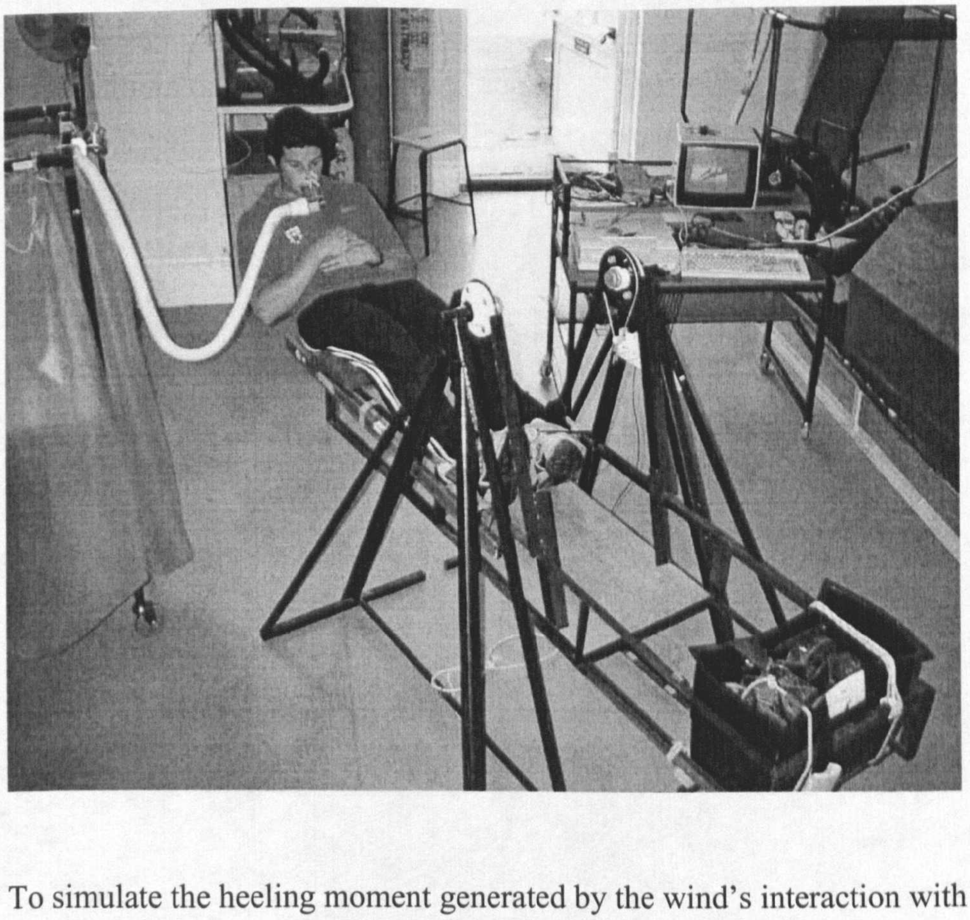
The purpose of the present experiment was to establish the physiological demands associated with a totally static simulation. From the physiological parameters measured it may be possible to make suggestions on the physiological role of hiking and make a direct comparison to the on-water data reported in chapter 4 of this thesis. Of particular interest will be the direct comparison of heart rates and blood lactates from this hiking simulation, utilising sport specific muscle groups, then relating them to measures recorded in the field setting. The operational hypothesis to be tested is that the isometric hiking action is not the major stimulus for increased cardiovascular, respiratory or blood lactate parameters.

5.2. Method.

5.2.1 Hiking bench construction.

A purpose built hiking bench was constructed for this experiment. Unlike the traditional hiking bench that is fixed to the ground this bench was made to pivot about a central point by using two 'A' support frames fitted with large diameter roller bearings. Thus, the bench was free to move about a fore and aft roll axis. The hiking bench construction was essentially similar to the ergometer described by McLoughlin et al., (1993). Also, in a similar fashion to McLoughlin et al., (1993), hiking performance was monitored via potentiometer modulated voltages recorded by a BBC micro computer. Although the units of measure were arbitrary units a performance score could be established.

Figure 5.1. Hiking bench used in this study.



To simulate the heeling moment generated by the wind's interaction with the sail calibrated weights were added at one end of the bench. The weights were proportional to body mass of the subject (this was established during pilot work). Subjects were required to counterbalance the weights by hiking in a similar fashion to the way they would have hiked on the water.

5.2.2 Simulation protocol.

Throughout the simulation the subjects were required to keep the hiking bench as level as possible. They were required to place their feet under the toe-strap (which was adjustable) and then support their body over the other side of the bench and thus balance the heeling moment. Subjects were verbally informed when the hiking bench was level. In addition to this verbal feedback the subjects could use computer generated graphics which showed a boat against a horizon to ascertain whether the hiking bench was level. When the bench was heeled the horizon appeared broken and when the bench was perfectly level the horizon appeared as a straight line. The hiking error was also displayed on the same computer screen; when the bench was perfectly level the hiking error was static. A spirit level was also placed on the hiking bench in clear view of the subject to act as another aid in determining whether the bench was perfectly horizontal. The subjects were encouraged to keep the simulator as flat as possible and were encouraged to avoid excessive body movements as this tended to rock the simulator either side of the horizontal position. It must be emphasised that the simulation was very static in nature, there was no upper-body movement as would be normal in trimming the sail and there were no accessory body movements that would commonly be found when sailing in conditions of varying wind strength/direction and/or fluctuations in wave or sea state.

5.2.3 Subjects.

Five male Laser sailors and three female Europe sailors, all of whom were members of the Royal Yachting Association's Olympic Development Squad, volunteered to participate in the study. Their physical characteristics were (mean ± s.d.), age 20.2 ± 2.1 yrs, height 1.766 m ± 0.06 m, and body mass 74.0 ± 4.4 kg. If the group were sub-divided into the five male and three female subjects the physical characteristics for age, height and body mass were 20.2 ± 1.6 years, 1.798 ± .005 m and 77.2 ± 1.2 kg for the male subjects and 20.2 ± 3.2 years, 1.726 ± .005 m and 69.0 ± 1.7 kg for female subjects, respectively. Prior to any testing all subjects were fully briefed about the experiment and informed consent forms completed (see appendix A). The study had ethical approval from University College Chichester's ethical committee.

5.2.4 Pilot and habituation trials.

Prior to conducting habituation sessions considerable effort was invested into establishing the correct loading for the 'leeward' side. The whole idea was to get the correct weight to create the capsizing moment in relationship to body mass of the sailor. This was considered to be essential so as to make the subjects adopt a hiking posture as similar as possible to the one they would normally hold on the water. The goal was to ensure that the subjects would be holding a posture that would maintain a knee joint angle of approx 140° (180° being full knee extension) and a hip joint angle of approx. 120° (180° being full hip extension) as it was felt that these angles best replicated the joint angles that were being maintained by Laser class sailors whilst sailing upwind (see figure 5.2 below). [Recent work by Mackie et al., (1999) have suggested a hip angle varying between 113° and 125° and a knee joint angle of between 147° and 149° for Laser sailing upwind in winds of 8 to 12 knots and 12 to 16 knots, respectively].

Figure 5.2. Typical joint angle for Laser sailor whilst sailing upwind.

During the pilot sessions it was established that the appropriate weight to offset on the leeward side would be 0.85 x body mass for males and 0.75 x body mass for females. Considering the small variances between body mass within the different genders (mean ± s.d. body mass was 77.2 ± 1.2 kg and 69.0 ± 1.7 kg for male and females, respectively) this rather crude scaling was considered to be appropriate. During the pilot sessions the most reliable physiological measure used to determine both the optimal load for the leeward side and the optimal duration of the experiment was the rate of perceived exertion (RPE)(Borg 1982).

Subjects underwent three habituation sessions prior to testing. Each habituation session lasted for 10 minutes; all sessions were conducted within seven days of the experimental trial. At least one full day's recovery was allowed before conducting the experimental trial. During the habituation sessions the subjects were also familiarised with the routine collection of physiological data that included, expired gas collection, finger prick capillary blood samples, blood pressure measures, wearing of a heart rate monitor, and familiarisation with the RPE scale. Apart from the three 10 minute habituation sessions the subjects did not practise.

5.2.5 Experimental protocol.

Each testing session consisted of the subjects undergoing a ten minute period of seated rest in the laboratory where physiological base line values were recorded. These were expired gas collection, blood pressure, heart rate, blood lactate and RPE. After this standardised rest period each subject underwent a 5 minute warm-up period on a Monark cycle ergometer (Monark 840 E) at a pedal cadence of approximately 60 rpm with a power output of approximately 75 watts and 60 watts for males and females, respectively.

Each trial consisted of a 30 minute continuous hiking bout. Subjects were allowed to get into position and get the hiking bench into a horizontal position prior to the trial starting. Each subject knew that hiking errors, relating to the time the bench was not horizontal, were being recorded by the computer. The hiking error was clearly visible at all times. Knee and joint angles were set at 140° and 120°, respectively, and subjects were encouraged to maintain that posture for the duration of the trial.

5.2.6 Measurement of physiological variables.

1) **Blood Pressure.** Blood pressure was measured via a standard clinical mercury sphygmomanometer cuff (Accoson mercury manometer), with the cuff placed around the upper arm and the stethoscope placed directly over the brachial artery at the elbow joint. After recording both systolic and diastolic pressures the cuff was completely deflated but left over the arm to prevent any accessory rocking of the hiking bench that could have occurred when re-positioning the cuff. Blood pressure readings were taken at the end of the 10 minute pre exercise resting period and then at 5 minute intervals throughout the experimental trial starting 5 minutes into the trial. The final blood pressure reading was taken 5 minutes after the trial when the subject had returned to a seated position.

2) **Expired gas Collection.** Expired gas was collected via Douglas bags. All Douglas bags were flushed with approx 40 litres of fresh air before being evacuated prior to use. Whilst wearing a nose clip, the subjects breathed through a mouthpiece connected via a low resistance respiratory valve (Salford valve box) to light weight respiratory tubing of approximately one metre in length connected to the Douglas bags. All expired samples during the experiment were of 60 seconds duration. A resting sample was taken during 5 minutes of seated rest prior to starting the trial. Expired gas samples during the experimental trial were collected at 5 minute intervals with the first collection being made between the 4th and 5th minutes.

Immediately after each trial the expired fraction of both oxygen (F_EO_2) and carbon-dioxide (F_ECO_2) were established using a calibrated Servomex gas analyser. A calibrated Harvard dry gas meter was used to measure expired gas volumes. Air temperature was measured by a temperature probe at the inlet of the volume meter. Barometric pressure was determined by a mercury barometer. Expired gas volumes were corrected to standard temperature and pressure, dry (STPD) by standard formulas established in an Excel spreadsheet. Values were established for minute volumes ($\dot{V}_E$), volumes of carbon dioxide produced ($\dot{V}CO_2$), volumes of oxygen used ($\dot{V}O_2$), respiratory exchange ratios (RER) and ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$).

3) **Blood sampling.** Finger tip capillary blood samples were taken immediately before starting the experimental trial and thereafter at 10 minute intervals with collection taking place immediately after completing the expired gas collection at the end of the 10th, 20th and 30th minutes. Fifty micro-litres of whole blood were drawn into a heparinised capillary tube and immediately analysed for blood lactate concentration on an automated blood lactate analyser (Yellow Springs International 2300 stat plus).

4) **Other measurements.** Heart rates were monitored continuously during the hiking trial via short range telemetry and stored in memory for later playback (Polar Electro Sports Tester PE 3000, Finland). The mean heart rates were recorded for the 4th-5th minute and then at 5 minute intervals throughout the trial up to and including the recovery phase. Rates of perceived exertion (Borg 1982) were recorded at 5 minute intervals throughout the experiment with the first value being recorded at the end of the 5th minute. Hiking performance was constantly monitored with a hiking error being calculated by the monitoring of potentiometer modulated voltages for periods when the hiking bench wasn't perfectly horizontal.

5.2.7 Statistical analysis.

Statistical analysis was conducted by the SPSS statistical package. A one way analysis of variance (ANOVA) for repeated measures was used to establish significant differences existed between the means. The Fisher HSD post-hoc test was used to identify significant differences where the results of the ANOVA were significant. Levels of significance was set at $p<0.05$. Results are presented as means ± standard deviation.

5.3 Results.

All raw data relevant to this chapter are shown in appendix D of the second volume of this thesis.

Mean results (± s.d.) for the major physiological variables measured are shown in Table 5.1. All variables increased from resting values during the 30 minute experimental trial.

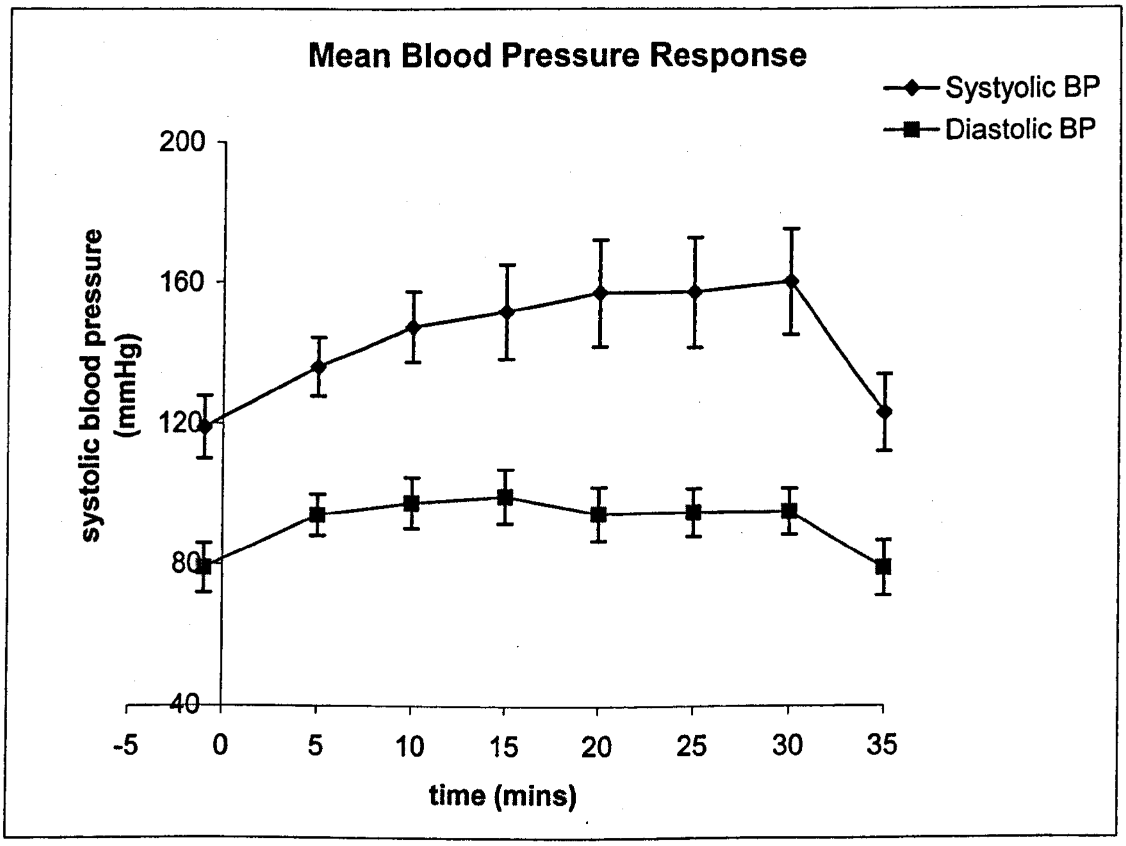
Table 5.1. Group means (± s.d.) for physiological responses to 30 min of static hiking (n=8).

Time	Systolic BP (mmHg)	Diastolic BP (mmHg)	Heart rate ($b.min^{-1}$)	$\dot{V}O_2$ ($l.min^{-1}$)	Lactate ($mmol.l^{-1}$)	RPE
Rest	119 ± 9	79 ± 7	75 ± 7	0.28 ± 0.1	1.26 ± 0.17	6.0
5 mins	136 ± 8	94 ± 6	95 ± 14	___	___	11.5
10 mins	148 ± 10	98 ± 7	99 ± 14	0.53 ± 0.17	1.42 ± 0.49	12.5
15 mins	152 ± 14	100 ± 8	98 ± 13	___	___	13.5
20 mins	157 ± 15	95 ± 8	98 ± 12	0.52 ± 0.15	1.46 ± 0.5	14.3
25 mins	157 ± 16	95 ± 7	100 ± 11	___	___	14.9
30 mins	160 ± 15	95 ± 7	101 ± 9	0.55 ± 0.14	1.47 ± 0.42	15.3
Post	123 ± 11	79 ± 8	80 ± 13	___	___	___

5.3.1 Blood pressure values.

One of the most striking results is the increase in both systolic and diastolic blood pressure during the hiking simulation. Both systolic and diastolic blood pressure were significantly greater ($p<0.01$) than resting values at every stage of the simulation. Systolic pressure continued to increase significantly throughout the first 10 minutes of the hiking trial ($p<0.01$) after which it remained fairly constant ($p>0.05$) with the exception of the measure taken during the final minute that was significantly greater than all other values ($p<0.05$). With the completion of the exercise there was a significant reduction ($p<0.01$) in systolic blood pressure to such an extent that pre and post exercise values were not statistically significant ($p>0.05$). The trend in both systolic and diastolic blood pressure is shown graphically in figure 5.3 below.

Figure 5.3. Group mean (± s.d.) values for systolic and diastolic blood pressure to 30 minutes of static hiking (n=8).

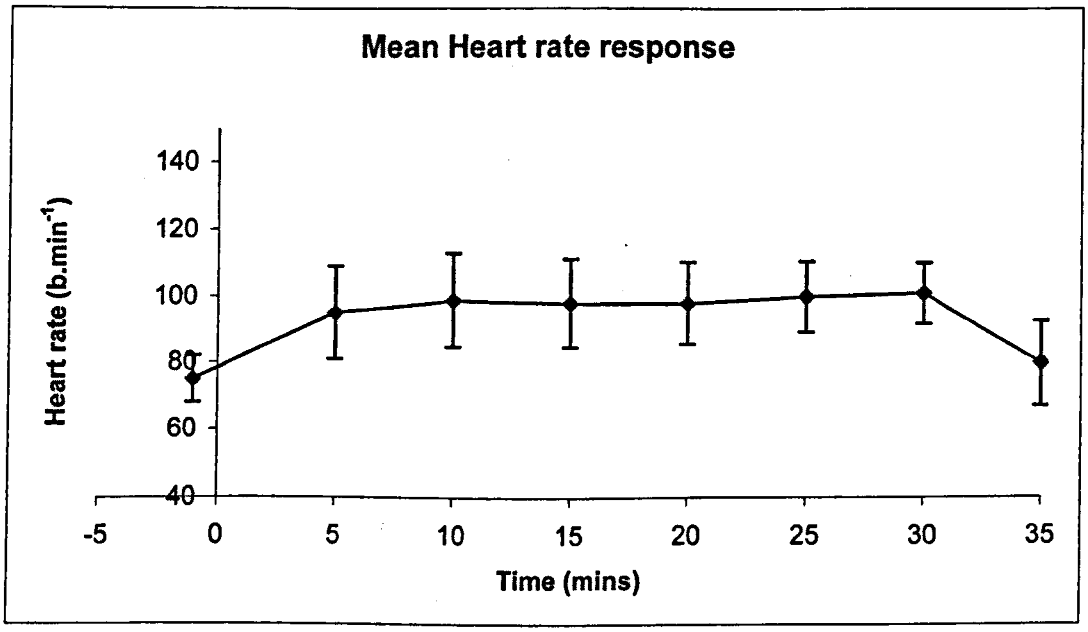


Diastolic pressure initially increased in a similar fashion to systolic pressure with significant ($p<0.01$) increases from resting values at every stage of the simulation. However, after the initial increase recorded 5 minutes into the simulation the diastolic pressure only gradually increased ($p>0.05$) until the 15th minute. Between the 15th and 20th minutes there was a significant decrease ($P<0.05$) after which it remained fairly steady till the end of the trail ($p>0.05$).

5.3.2 Heart rate values.

There was a significant increase ($p<0.01$) in heart rate at the onset of the simulation with was then maintained throughout the simulation. Graphical representation of mean heart rates can be seen in figure 5.4 below.

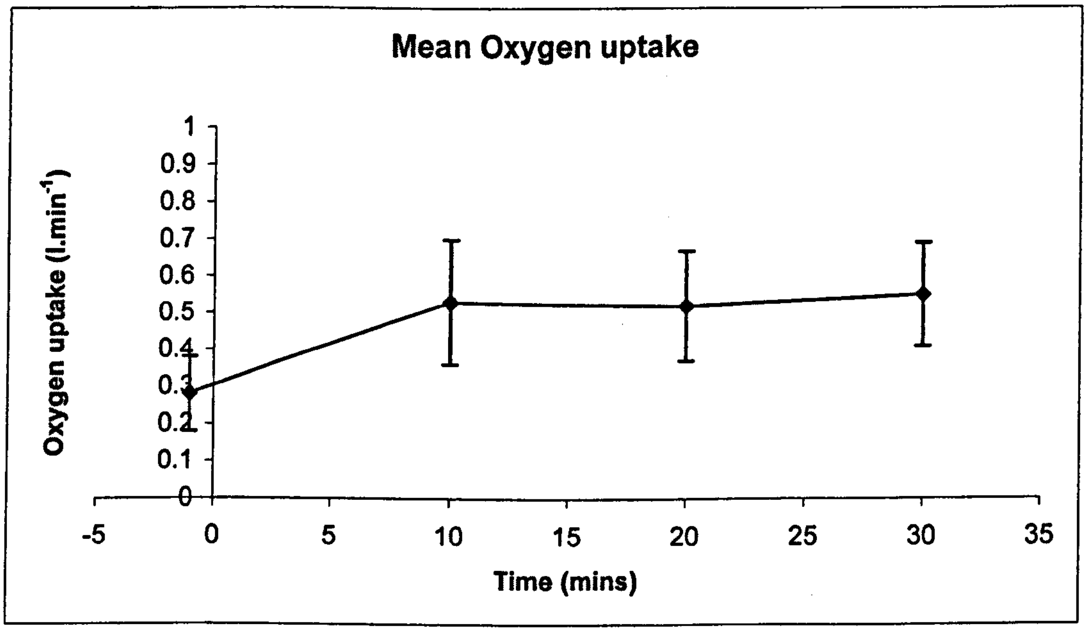
Figure 5.4. Group mean (± s.d.) values for heart rates recorded during the 30 minute static hiking trial (n=8).



After the initial increases in heart rates which were significant between rest and the 5th minute ($p<0.01$) and then between the 5th and 10th minutes ($p<0.05$), heart rates plateaued ($p>0.05$) throughout the rest of the simulation. Although there was a significant decrease in the heart rate recorded during the final minute of the simulation and that recorded during the 5th minute of the recovery period ($p<0.001$), post exercise heart rates were still significantly elevated compared to resting heart rates ($p<0.05$). Heart rates peaked at 101 beats.min^{-1} which was recorded in the final minute of the simulation.

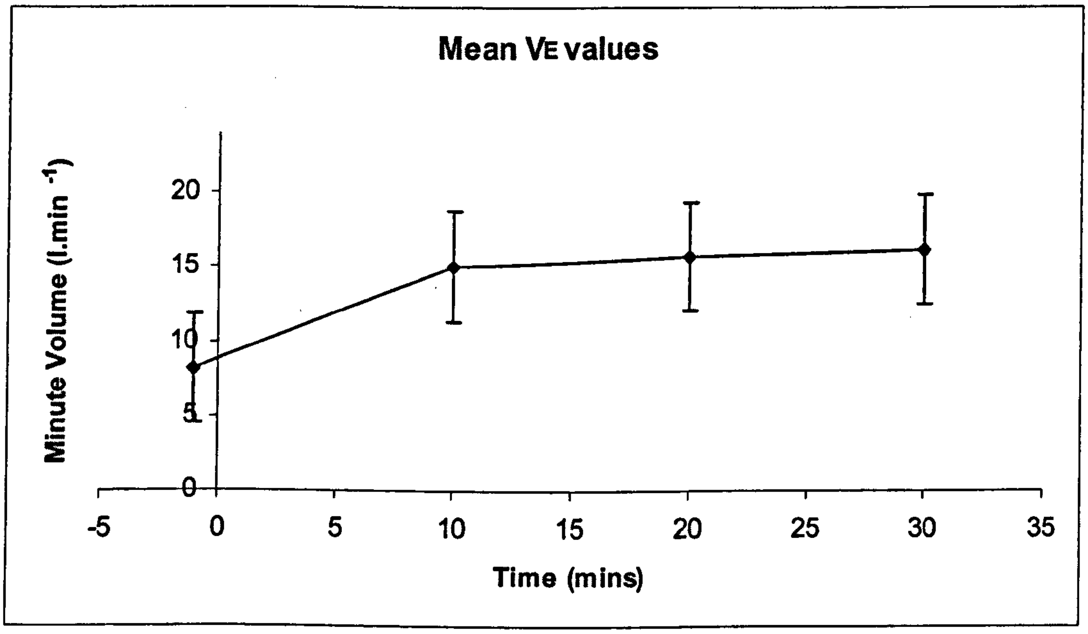
5.3.3 Respiratory variables. Values for oxygen consumption during the 30 minute trial are shown below in figure 5.5. Values recorded during the simulation were significantly greater than resting values ($p<0.01$). However, oxygen consumption during the hiking period did not significantly change ($P>.05$). To give some idea of relative oxygen consumptions the mean value for the group relative to body weight was 7.2 ± 2.1 ml.kg^{-1}.min^{-1}.

Figure 5.5. Group mean (± s.d.) values for oxygen consumption to 30 minutes of static hiking (n=8).



Minute volumes ($\dot{V}_E$) followed a similar pattern to oxygen consumptions with all exercise values being significantly greater ($p<0.01$) than resting values. The final minute volume recorded during the 30th minute of the simulation was significantly greater ($p<0.05$) than the value recorded during the 10th minute. Graphical representation of $\dot{V}_E$ can be seen in Figure 5.6 below.

Figure 5.6. Group mean (± s.d.) values for Minute Ventilation ($\dot{V}_E$) to 30 minutes of static hiking (n=8).

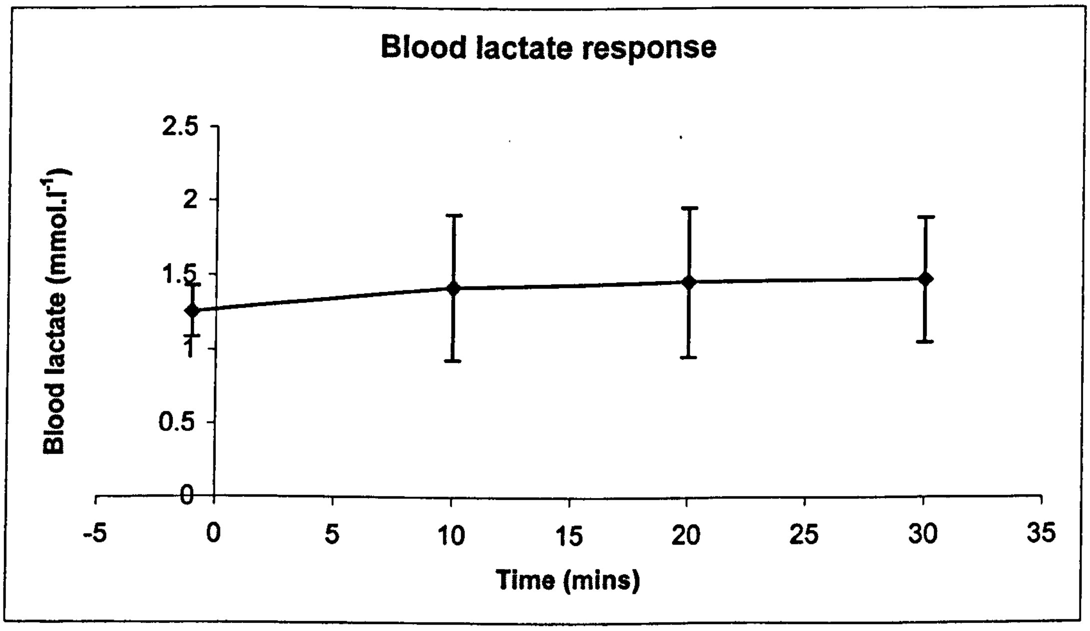


Despite the significant increase in $\dot{V}_E$ as the simulation progressed there was little change in the respiratory exchange ratio (RER) with mean values for the 10th, 20th and 30th minutes being 0.91 ± 0.08, 0.92 ± 0.09 and 0.89 ± 0.08, respectively.

5.3.4. Blood lactate values.

Looking at group mean values for blood lactate concentrations there were no significant changes ($p>0.05$) between either resting values and exercise values, or between the exercise values as the 30 minute hiking trial progressed. There is some evidence that the results show a large inter-subject variability with lactate values for some subjects increasing twofold whereas for other subjects values decreased during the simulation. Mean blood lactate responses are shown graphically in figure 5.7 below.

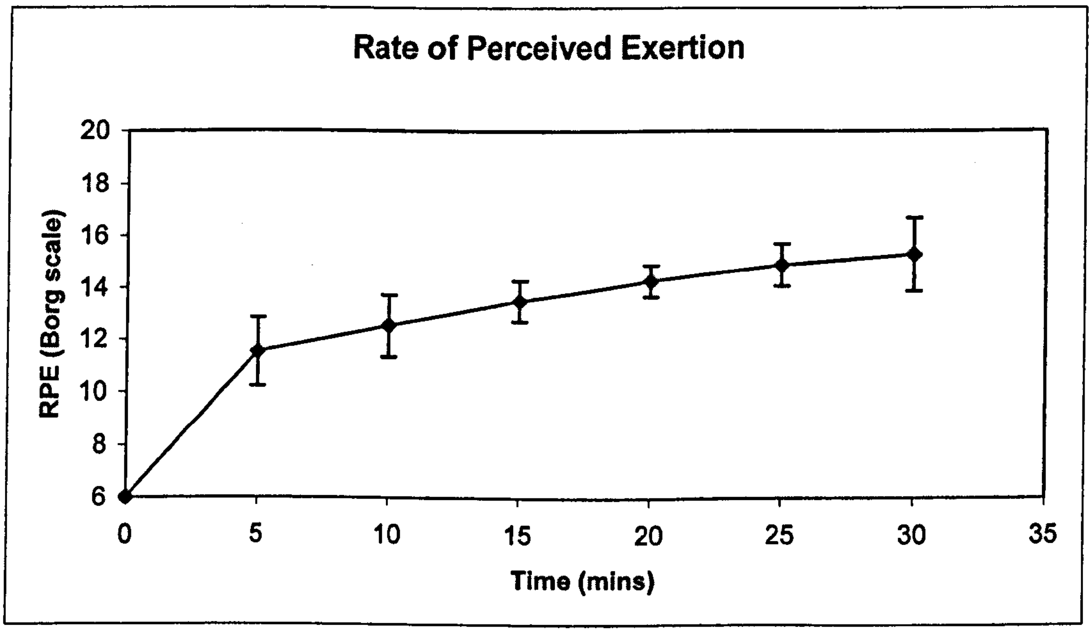
Figure 5.7. Group mean (± s.d.) values for blood lactate concentrations to 30 minutes of static hiking (n=8).



5.3.5. Rate of perceived exertion (RPE).

The rate of perceived exertion increased significantly ($p<0.05$) throughout the trial with the exception of the 25th and 30th minutes, where, although it increased, it did not reach statistical significance ($p>0.05$). RPE values increased from a mean value of 11.5 ± 1.3 in the 5th minute to 15.3 ± 1.4 in the 30th minute. Graphical representation of mean RPE values can be seen in figure 5.8 below.

Figure 5.8. Group mean (± s.d.) values for Rate of Perceived Exertion to 30 minutes of static hiking (n=8).



5.4 Discussion.

The main purpose of this study was to establish the physiological consequences of prolonged static hiking. Although all the increases in physiological variables reached statistical significance compared to resting values, the responses, with the exception of blood pressure, were modest. This suggests that the cardiorespiratory and cardiovascular systems were not taxed to any great extent, despite a relatively large amount of physical stress being reported. Mean RPE values for the simulation increased throughout from 11.5 ± 1.3 in the 5^{th} minute to 15.3 ± 1.4 in the 30^{th} minute. There was a large degree of muscular discomfort associated with such a static simulation; subjects reported numbness, and paraesthesia in the lower extremities, particularly in the toes and in the gastrocnemius and soleus muscles. Although EMG measures were not recorded, this suggests that blood flow was, to some extent, being restricted to the lower body. This is possibly caused by the prolonged contraction of the quadriceps group of muscles at a relatively high percentage of the muscle's maximum (Vogiatzis et al., 1996). Indeed Lind (1983) has suggested that any isometric contraction greater than 15% MVC induces a partial muscular ischemia with a reduced blood flow to the exercising muscle.

Research is almost universal in agreeing that the greatest physiological challenge to the dinghy sailor is the effort required to hike out in an attempt to keep the boat upright in stronger winds (Wright, 1976; Shephard, 1977; Felici et al., 1999). This simulation activated the muscles that are deemed to play a significant role in performing the hiking action, which are widely accepted as being the quadriceps and abdominals (Wright, 1976; Plyley et al., 1985; Shephard, 1990; Spurway, 1993 and Vogiatzis et al., 1996). Marchetti et al., (1980), have suggested that the rectus femoris exhibits the most pronounced activity when performing static hiking. Subjects throughout this simulation reported great muscular discomfort in the quadriceps, with burning in the muscle bed being reported by most subjects and some showing visible signs of muscular fatigue that included involuntary shaking of the legs. However, as reported by De Vito et al., (1993) a static simulation misrepresents the real picture as sailors, particularly in the single-handed classes, are required to perform fast flexo-extension movements at knee, hip and lumbar girdle. However, the rationale behind this experiment was to isolate the hiking posture to a prolonged static movement only to test the hypothesis that such a contraction could not be responsible for elevated heart rates and other physiological parameters reported from studies in the field (Pudenz et al., 1981; Vogiatzis et al., 1995; Spurway, 1997).

The measure of blood pressure in the laboratory has been conducted with simulations replicating both static hiking (Niinimaa et al., 1977; Marchetti et al., 1980; Felici et al., 1999) and also under dynamic hiking conditions (Blackburn 1994; Vogiatzis et al., 1996). Only one study has measured blood pressures in the field setting (Marchetti et al., 1980).

In the field, Marchetti et al., (1980), reported that systolic blood pressure increased whilst sailing in winds of 10-12 $m.s^{-1}$ from a resting value of 121 ± 10 mmHg to a value of 155 ± 5 mmHg at the end of a hiking bout that lasted for only 30 seconds (n=3). Marchetti et al., (1980) also conducted a static laboratory simulation of dinghy hiking on the same three experienced sailors that again focused on a 30 second hiking bout and found a mean systolic blood pressure of 149 ± 13 mmHg. The values reported by Marchetti are quite similar to the values found in this study for systolic blood pressure where over the 30 minute simulation it increased gradually from a resting value of 119 ± 9 mmHg to a peak value recorded in the 30th minute of 160 ± 15 mmHg. However, Marchetti recorded values at the end of a very short period of hiking (a single bout lasting only 30 seconds) whereas after 5 minutes of prolonged static hiking in this present study systolic blood pressure had only increased to 136 ± 8 mmHg. Marchetti failed to report any values for diastolic blood pressure.

Niinimaa et al., (1977) did record values for both systolic and diastolic blood pressures during a 5 minute static simulation. They increased sharply from resting values of 127 ± 13 and 80 ± 9 mmHg to a peak of 177 ± 18 and 109 ± 12 mmHg. The mean values were 164 ± 17 and 101 ± 6 mmHg. The peak figures are greater than those recorded in this study. But from these two early studies it is reasonable to say that the values measured reflect the severity of the hiking posture. The only other static simulation that reported blood pressure readings was conducted by Felici et al., (1999), where the severity of the hiking posture was set at either 60% or 85% of maximal hiking torque; systolic and diastolic values peaked at 183 ± 12 and 117 ± 12 mmHg and 195 ± 21 and 110 ± 21 mmHg, respectively, during hiking bouts to exhaustion.

It seems that the severity of the hiking posture has a direct relationship on the magnitude of the increase in systolic blood pressure. Lindhard (1920) was the first to report dramatic rises in both systolic and diastolic blood pressure with fatiguing isometric exercise (cited in Petrofsky & Phillips, 1986). However, with the sailing simulations conducted to date, the rise in diastolic blood pressure does not seem to be directly related to the severity of the exercise. Indeed, Felici et al., (1999) has reported lower diastolic values as the hiking severity was increased. However, the rise in diastolic blood pressure is one of the major differences between isometric and dynamic exercise, commonly with dynamic exercise there is a drop in diastolic blood pressure whilst exercising (Petrofsky & Phillips, 1986).

The values recorded for blood pressure in this present experiment are less than the values reported elsewhere in the literature, this is possibly a reflection on the ecological validity of the present simulation where much effort went into accurately simulating the correct hiking posture. Felici et al., (1999) had subjects fatiguing after only 188 ± 78 seconds in the 85% of maximal hiking torque trial and after 896 ± 313 seconds for the 60% of maximal hiking torque trial. Marchetti et al., (1980) only simulated a 30 second maximal hiking bout; Niinimaa et al., (1977) had subjects hike maximally for only 300 seconds. In this study subjects hiked for 1,800 seconds – hence the severity of the hiking action may have been more representative of the real on-water situation where a typical Laser race lasts approximately 40-45 minutes. It may be important that the only on-water measures reported in the literature (Marchetti et al., 1980) are similar to the values reported in this study.

Blackburn (1994) has reported mean values of 172 ± 18 and 100 ± 14 mmHg for systolic and diastolic blood pressure during a dynamic simulation of upwind Laser sailing and values of 150 ± 19 and 92 ± 12 mmHg for downwind sailing during the same simulation. Blackburn's protocol was dynamic in nature and formed a race simulation which lasted 84 minutes with three upwind legs with each leg lasting 20 minutes and included 13 tacks. In the dynamic simulation of Laser sailing conducted by Vogiatzis et al., (1996), they reported values for mean arterial blood pressure [diastolic plus 1/3 (systolic-diastolic)] and found that such values increased significantly from a mean pre-exercise value 90 mmHg to a final value of 120 mmHg at the end of the 4th hiking bout where each bout lasted 3 minutes separated by a 15 second rest interval (to simulate tacking). In comparison to this present study blood pressure expressed in the same method increased from a pre-exercise value of 118 ± 10 mmHg to peak values of 148 ± 12 mmHg.

Heart rates measured during this simulation, which ranged from 95 ± 14 beats.min^{-1} during the 5th minute to 101 ± 9 beats.min^{-1} during the 30th minute, are lower than values reported for other static simulations of dinghy hiking. Niinimaa et al., (1977) reported mean values of 131 ± 7 beats.min^{-1}, Marchetti et al., (1980) 146 ± 5 beats.min^{-1} and Felici et al., (1999) 138 ± 17 and 141 ± 13 beats.min^{-1} for hiking bouts at 60% and 85% of maximal hiking torque, respectively. Blackburn (1994), Vogiatzis et al., (1993) and Vogiatzis et al., (1996) reported mean heart rate values of 118 ± 25, and 112 ± 17 beats.min^{-1}, respectively from dynamic simulations of dinghy sailing.

This present simulation in a similar fashion to all other laboratory simulations of single-handed dinghy sailing, albeit static or dynamic in nature, have reported lower heart rates than those reported from on-water studies (Pudenz et al., 1981; Vogiatzis et al., 1994; Cunningham, 1995; and Vogiatzis, 1995a). Cunningham (1995), reported mean values for Laser sailors that varied from 132 ± 9 beats.min^{-1} in light winds (2-4 m.s^{-1}) up to 165 ± 13 beats.min^{-1} in strong winds (10-15 m.s^{-1}). Vogiatzis et al., (1994) reported mean values for Laser sailors that varied from 145 ± 17 beats.min^{-1} in moderate winds (6-7 m.s^{-1}) and increased up to 153 ± 20 beats.min^{-1} in strong winds (8-9 m.s^{-1}). Pudenz et al., (1981) reported mean upwind heart rates for Laser sailors of 168 ± 12 beats.min^{-1} in strong winds (8.1-13.8 m.s^{-1}) and values of 143 ± 9 beats.min^{-1} in moderate winds (3.4-8.0 m.s^{-1}). There are only two on-water studies where relatively low heart rates have been reported, these are either out-dated

(Cudmore, 1969) or were conducted in extremely light wind conditions where hiking was not required (Gallozzi et al., 1993).

It seems logical to conclude that there have been problems associated in replicating the accurate nature of dinghy sailing in the laboratory where the true physiological demands of the sport are commonly underestimated. The results of this study show that prolonged static contractions of the hiking specific muscles are not responsible for the elevated heart rates commonly cited from on-water studies. This is in agreement with classic isometric exercise studies that have been conducted in non-sailing situations, where it is well documented that both oxygen consumption and heart rate only increase modestly even during isometric exercise to exhaustion (Petrofsky & Phillips, 1986; Wiley & Lind, 1971; Myhre & Anderson, 1971). Petrofsky & Phillips went on to suggest that:

> *"the heart rate response during isometric exercise is very modest in nature and rarely exceeds 120 beats/min" (p27).*

Indeed Niinimaa et al., (1977) reported that during simulated dinghy hiking to exhaustion heart rates only peaked at 136 beats.min^{-1}, whereas maximal heart rates from a running $\dot{V}O_{2max}$ test on the same subjects averaged 196 beats.min^{-1}. Thus, given the exceptionally low heart rates from this simulation it seems likely that the elevated heart rates reported from on-water studies are not a reflection on the isometric nature of hiking but are the result of the dynamic nature involved with sailing small dinghies.

Blood lactate parameters only changed slightly ($p>0.05$) throughout this simulation and peaked at 1.47 mmol.l^{-1} during the final minute. These values are considerably lower than values reported from other simulations. Vogiatzis (1993) reported peak values of 4.0 ± 1.5 mmol.l^{-1} after three bouts of static hiking with each session separated by a 15 second rest period. The total duration of the three hiking sessions was approximately 30 minutes with the final hiking bout going to exhaustion. Blackburn (1994) reported values of 2.32 ± 0.81 mmol.l^{-1} immediately after a simulated 20 minute upwind leg. Vogiatzis et al., (1996) reported mean lactates that peaked at approx. 2.4 $mmol.l^{-1}$ after 4 successive bouts of hiking with each bout lasting 3 minutes and separated by a 15 second rest period. Felici et al., (1999) reported mean lactates of 3.1 ± 1.1 $mmol.l^{-1}$ and 3.9 ± 0.7 $mmol.l^{-1}$ for two hiking bouts to exhaustion at 60% and 85% of maximum hiking torque, respectively. It is clear that the blood lactate responses from laboratory simulations have varied considerably, possibly relating to the degree of physical exertion that the subjects were placed under. In this present study the static hiking posture replicated as accurately as possible the posture they normally hold on the water (both knee and hip angles were standardised). The only component missing from this simulation was the accessory movements that are normally associated with single-handed dinghy sailing; and it is possible that this lack of movement kept lactates suppressed. Indeed blood lactates reported from this simulation are considerably lower than values reported from on-water studies of single-handed sailing; 4 to 8 $mmol.l^{-1}$ (Piel-Alun, 1977), 2.3 ± 0.8 $mmol.l^{-1}$ (Vogiatzis et al., 1995a), and 1.8 ± 0.4 $mmol.l^{-1}$ (Marchetti et al., 1980). In general there is quite a large degree of dissimilarity with lactates measured both on the water and in laboratory conditions. On the water this is likely to be due to non standardised climatic conditions (predominantly wind speed, wave height and sea state) and in the lab setting probably caused by varying degrees of physical exertion between studies. For example, Vogiatzis et al., (1995b) reported blood lactates for moderate winds (4-8 $m.s^{-1}$) 1.6 ± 0.2 $mmol.l^{-1}$ and strong winds (9-12 $m.s^{-1}$) 3.0 ± 0.6 $mmol.l^{-1}$. Other studies have not separated differing wind conditions and have just reported mean values.

In this present study there was a fair degree of inter-subject variability in blood lactates; individual lactates at the completion of the hiking test varied between 2.15 and 0.82 $mmol.l^{-1}$. Vogiatzis et al., (1993) also showed considerable inter-subject variability between blood lactates, on completion of their hiking task they varied between 6.9 and 2.2 $mmol.l^{-1}$. It is not clear why there is such a large inter subject variability; possible reasons could be based around dietary status (Sjodin and Jacobs, 1981) or simply based on varying fitness levels of the subjects (not measured in this present study). Vogiatzis et al., (1993) reported peak lactates 5 minutes after finishing the hiking task. Unfortunately, in this present study post exercise blood samples were not taken. Peak lactates post exercise could possibly suggest that some blood pooling occurred in the working muscle and that the intramuscular pressure was too great for the waste products of metabolism to be returned in the normal way by the venous return.

In a similar fashion to heart rates and blood lactate response the oxygen consumption ($\dot{V}O_2$) during the 30 minute trial were low with mean values in this study varying between 0.52 $l.min^{-1}$ and 0.55 $l.min^{-1}$. With an average body mass of 74.0 kg, the mean $\dot{V}O_2$ relative to body weight equates to 7.0 and 7.4 $ml.kg^{-1}.min^{-1}$, respectively. Thus, minimal demands were placed on the cardio-respiratory system, which is in agreement with other static simulations. It can be established from the work of Marchetti et al., (1980) that a gross $\dot{V}O_2$ of 10.2 $ml.kg^{-1}.min^{-1}$ was recorded for the whole 5 minute period that expired gas was collected; however, hiking only took place for a 30 second period of the whole 5 minute period. Felici et al., (1999) suggested that there was a net oxygen consumption of 0.95 $l.min^{-1}$ (approx. 13.7 $ml.kg^{-1}.min^{-1}$) and 0.87 $l.min^{-1}$ (approx. 12.6 $ml.kg^{-1}.min^{-1}$) whilst hiking statically at 85% and 60% of maximal hiking torque, respectively; they suggested that this is comparable to a level walking at pace of approx. 1-1.5 $m.s^{-1}$.

Dynamic simulations have scarcely reported any additional increases in oxygen consumption. Blackburn (1994) and Vogiatzis et al., (1996) reported oxygen uptakes of 14.8 and 14.1 $ml.kg^{-1}.min^{-1}$, respectively, for an upwind simulation of Laser sailing under dynamic conditions. It is reasonable to be critical of all the laboratory simulations done to date, including the dynamic simulations, as they have been too static in nature. Any future laboratory simulations of dinghy sailing need to replicate the dynamic nature of the sport as previous studies seem to have failed in producing simulations that replicate the dynamic movements associated with single-handed sailing. This statement is further highlighted by some preliminary findings reported by Spurway et al., (2000), where they have suggested that a repeated leg movement of as little as 5 degrees (0.087 rad) on top of a sustained isometric contraction can significantly increase the physiological cost of the hiking activity as measured by cardiovascular, respiratory and blood lactate parameters.

This present study found a significant increase in $\dot{V}_E$ during the simulation along with no concurrent increase in $\dot{V}O_2$, this indicates that there was some evidence of hyperventilation as the hiking trial progressed. It has been shown that hyperventilation related to static exercise is evident when the muscle is activated at an intensity of greater than 20% of the muscles maximal voluntary contraction (MVC) (Myhre and Lange Andersen, 1971). The hyperventilation becomes more apparent with increased intensities. In contrast hyperventilation does not occur with dynamic exercise until a workload of approx 70-80 % of maximal aerobic power (Myhre and Lange Andersen, 1971). In this present study $\dot{V}_E$ increased significantly ($P<0.05$) between the 10th and 30th minutes with no concurrent increase in $\dot{V}O_2$. Such hyperventilation may be attributed to extra recruitment of Type II muscle fibers which would lead to increased EMG activity. EMG activity has been shown to increase with a constant isometric contraction due to increasing fatigue (Lloyd, 1971; Lind & Petrofsky, 1979). Goodwin et al., (1972) suggested that as isometric exercise continues there is a greater motor unit activity, associated with an increased voluntary effort, in-order to maintain the required given force. Increased EMG activity during simulated hiking has been reported by Vogiatzis et al., (1993) and Vogiatzis et al., (1996). In the present study, although EMG was not measured, it can be assumed that fatigue increased throughout the simulation as evident by the continual increase in rate of perceived exertion (RPE). It is not clear what is driving this hyperventilation but it is likely that the isometric contraction on the quadriceps muscles is restricting blood flow and results in elevated muscle lactate, increased extracellular potassium concentration and decreased pH. An increased concentration of extracellular potassium ions and a decreased pH could stimulate muscle chemoreflexes and their activation could reflexly increase $\dot{V}_E$ (McCloskey and Mitchell, 1972). An additional drive possibly responsible for an increased $\dot{V}_E$ may also come from an enhanced central command related to an increased EMG (Goodwin et al., 1972)

Despite the tendency for increased hyperventilation as the simulation progressed there was a slight decrease in the RER value from 0.905 ± 0.08 to 0.888 ± 0.08 in the 10th and 30th minutes, respectively. This is suggesting that towards the end of the simulation there was a shift towards greater fat utilisation. This is difficult to explain but could possibly by related to the depletion of muscle glycogen in the quadriceps group. However, it is hard to explain an increased fat utilization when oxygen consumption remained the same throughout the simulation.

Oxygen uptake measured on the water.

As outlined in the literature review the oxygen consumptions measured via portable gas analysers (Cosmed K2 and Cosmed K4) during on-water sailing are quite limited in number (Marchetti et al., 1980; Gallozzi et al., 1993; Vogiatzis et al., 1994; Vogiatzis et al., 1995a; and Devienne & Guezennec, 2000). Work by Devienne & Guezennec (2000) can be discarded as it relates to yacht racing as opposed to dinghy sailing. The other four papers have reported various oxygen consumptions from on-water sailing that have varied from 20.5 $ml.kg^{-1}.min^{-1}$ for one single-handed Finn sailor (Gallozzi et al., 1993); 10.4 $ml.kg^{-1}.min^{-1}$ for a Star crew (Gallozzi et al., 1993), 20.9 $ml.kg^{-1}.min^{-1}$ and 23.1 $ml.kg^{-1}.min^{-1}$ for Laser sailing in moderate and strong winds (Vogiatzis et al., 1994); to a mean value of 20.3 $ml.kg^{-1}.min^{-1}$ for Laser sailors in a wide wind range (4-12 $m.s^{-1}$) (Vogiatzis et al., 1995a). The $\dot{V}O_2$ data from the Marchetti et al., (1980) paper are difficult to interpret as they are poorly presented, but it seems that a mean oxygen consumption was recorded at 2.0 $l.min^{-1}$ for on-water sailing (presumably via the Douglas bag collection method). Given the mean body weight of the three subjects at 64.5 kg, this would give a $\dot{V}O_2$ of approximately 31 $ml.kg^{-1}.min^{-1}$. In comparison to the other on-water studies the values reported by Marchetti et al., (1980) seem to be significantly greater.

Thus, although the oxygen consumption from on-water studies is not consistently substantial it is significantly greater than the values reported from all the simulated studies of dinghy sailing, including this present static simulation (approx. 7.0 to 7.4 $ml.kg^{-1}.min^{-1}$), and both the dynamic simulations conducted to date (Blackburn, 1994; and Vogiatzis et al., 1996). As advocated earlier it would seem that all the simulations to date have failed to replicate the exact movements shown by the dinghy sailor. This is particularly the case considering that the on-water measures have been recorded either during training sessions as opposed to racing situations (Vogiatzis et al., 1994 and 1995a); or collected during regatta racing in extremely light wind conditions of 4-6 $m.s^{-1}$ where continuous hiking would not have been warranted (Gallozzi et al., 1993). Also, the validity and reliability of the results are undermined in the Marchetti et al., (1980) and Gallozzi et al., (1993) papers because of small group sizes.

5.4.1 Conclusion.

In summary, the present study suggests that the data collected from on-water investigations into the physiological demands of single-handed dinghy sailing are not compatible with the belief that static hiking is the principal driving force behind the elevations in cardiovascular, respiratory and blood lactate parameters.

CHAPTER 6

Chapter 6.

The physiological responses to 30 minutes of dynamic simulated dinghy sailing.

6.1 Introduction.

The findings of the previous chapter advocated that the physiological demands of static hiking were responsible for only minimal increases in both oxygen uptake and cardiovascular outputs. The exception to this was the substantial elevation in both systolic and diastolic blood pressure, and this is a well documented response to isometric exercise that was first reported by Lindhard (1920). Given the minimal increases in the majority of the physiological variables measured during the static simulation and the discrepancy between field data it is suggested that the static hiking action is not responsible for the elevated physiological measures that have been reported from 'on-water' studies (Pudenz 1981; Harrison and Coleman 1987; Vogiatzis et al., 1995a; and Cunningham, 1995). It seems that the elevation in physiological variables measured, and in particular heart rates, reported in these research papers are not a direct result of the isometric hiking action as has been suggested (Vogiatzis et al., 1995a; Spurway, 1997).

It is proposed that there is a dynamic movement super-imposed on top of the prolonged hiking action and thus the sport is dynamic in nature. Interestingly, some of the original researchers looking into the physiology of dinghy sailing, who once hailed dinghy sailing as being fundamentally static in nature, have recently started to advocate that dynamic activities might underpin the physiological demands of dinghy sailing. Spurway (1993) suggested that hiking involved:

> *"essentially a static (isometric) stress, at a considerable percentage of the muscle's maximum, is imposed on quadriceps and abdominal muscles" (p846).*

Whereas more recently, Spurway (1997), has suggested that the muscular activity of the sport may be "pseudo-isometric" in nature and that training recommendations should be based around isometric or "pseudo-isometric" activities. Spurway et al., (2000), has suggested that if a repeated counter movement of as little as 5 degrees

(0.087 radians) is conducted by the legs on top of a prolonged isometric contraction that this can significantly increase the physiological cost of the activity as measured by cardiovascular, respiratory and blood lactate parameters. Marchetti et al., (1980) were the first to blend on-water data collection with laboratory simulations of dinghy sailing. This early simulation was totally static in nature but more recent work has suggested that:

> *"the sailor's posture is never really static, him having to adapt to waves and wind variation. Thus on a background of isometric contraction jerks are superimposed which approximate the Maximal Voluntary Contraction (MVC)." (Marchetti, 1997, p40)*

Thus, there seems to be increasingly strong evidence for the belief that dinghy sailing is a dynamic sport and it is this dynamic nature that possibly places an enhanced physiological strain on the sailor. Rapid body movements are heavily utilised, particularly in small lightweight boats like the Laser, where the sailor uses as much body kinetics as possible to 'bounce' the boat through waves in an attempt to maximise boat speed. The use of such kinetics is tightly controlled under the sailing rules [rule 42 - propulsion rule] and is heavily policed on the water with umpires patrolling the race course. However, it is increasingly clear that the umpires are having a difficult job in carrying out their policing role (Cherrie 2002). This bouncing action requires the fast contraction of a large muscle mass, notably flexion/extension and rotation around the hip joint. Mackie and Legg (1999) have suggested that this dynamic movement is evident at least in stronger winds where they report:

> *"Instead of hiking at a constant rate as one tends to when the wind is slightly less, the sailor must constantly hike fully and then suddenly move inboard to counter effects of waves and sudden changes in wind speed. The result is a greater range of forces experienced in the hiking strap" (p 83) ....This indicated that environmental factors such as wave motion, wind fluctuations and body movements were responsible for a significant amount of the forces produced when sailing" (p84).*

In addition to the dynamic movements of the lower body, the elite dinghy sailor will almost constantly play the mainsheet in an attempt to keep the sail at the right angle of trim [trim refers to the angle of the sail in relation to the wind]. Indeed, most of the top level Laser sailors remove the deck cleats designed to hold the mainsheet, this is to prevent the mainsheet from accidentally cleating itself. Most novice or club sailors sail the majority of the race with the mainsheet cleated, as they don't have the skill to accurately trim the sail. This constant trimming of the sail at the elite end of the sport places an additional dynamic activity on the sailor that is virtually continuous throughout a race. It is well documented that at the onset of dynamic activity heart rate will immediately increase (Krogh and Lindhard, 1913).

Unlike the previous chapter simulating a static hiking posture as previous researchers had outlined hiking as being the major physical challenge to a dinghy sailor (Marchetti et al., 1980; Blackburn, 1994; Vogiatzis et al., 1995; and Spurway, 1997), this chapter outlines the physiological demands from a dynamic simulation of Laser sailing. The purpose of this experiment is two-fold:

Firstly, to create a laboratory simulator that can accurately replicate the dynamic nature of the sport. The design and construction of this dinghy ergometer will build on the knowledge outlined in previous dynamic simulations (Bursztyn et al., 1988; Blackburn, 1994; Vogiatzis et al., 1996; and Felici et al., 1999).

Secondly, to add to the existing knowledge in terms of the physiological demands underpinning elite single-handed dinghy sailing. The number of studies reporting valid physiological variables measured on the water is small. This is particularly the case when looking at the measurement of oxygen consumption, carbon dioxide production and minute ventilation. On-water measures have failed for various reasons; conducted in exceptionally light wind conditions and with very few subjects (Gallozzi et al., 1993); used 'club-standard' rather than elite sailors (Vogiatzis et al., 1995a); and data only collected during training rather than racing (Vogiatzis et al., 1995a). To date the dynamic simulations have been too static in nature and are thus not ecologically valid (Blackburn, 1994; Vogiatzis et al., 1996; and Felici et al., 1999). The only true dynamic simulation conducted is the unpublished work of Sandstrom et al., (1985) that is cited in the work of Blackburn (1994).

6.2 Method.

6.2.1 Subjects.

Six experienced male Laser sailors, all of whom were either members of the Royal Yachting Association's Olympic Development squad or the elite Olympic sailing squad, volunteered to participate in this study. Five of the six subjects were ranked in the top 10 Laser sailors in Britain (Laser Class Association Ladder) and the sixth sailor was a promising youth who had recently progressed from the radial rig to the full rigged Laser. Their physical characteristics can be seen in Table 1 in the results section. All six subjects were familiar with exercise testing and were regular visitors to the sports science laboratories at University College Chichester. Subjects gave their informed consent (see appendix A) to participate in this study and were informed that they could withdraw from the testing at will. This study had been approved by University College Chichester's ethics committee.

6.2.2 $\dot{V}O_{2max}$ protocol.

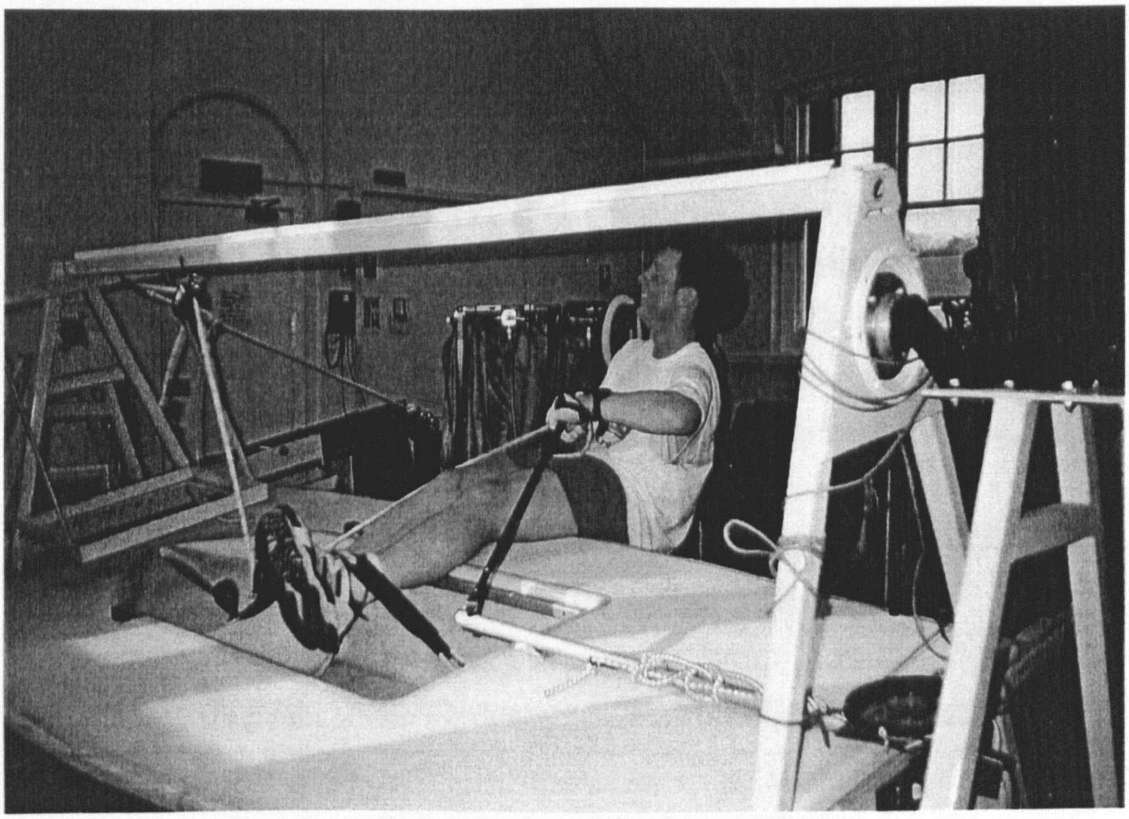
All subjects conducted a $\dot{V}O_{2max}$ test, which was conducted prior to any habituation trials on the sailing ergometer. $\dot{V}O_{2max}$ testing took place on a Monark 840E cycle ergometer. Gas was collected via Douglas bags and analysed via a Servomex gas analyser for CO_2 and O_2 percentage, gas volumes were measured via a Harvard gas meter. A standardised 5 minute warm up period on a Monark cycle ergometer at a pedal cadence of approximately 60 rpm with a power output of approximately 75 watts was conducted prior to testing. After this warm up period the subjects were given a 5 minute period to perform their own stretching routine before commencing the $\dot{V}O_{2max}$ test.

All $\dot{V}O_{2max}$ tests were conducted at 60 rpm and commenced with a power output of approximately 100 watts. This incremental test to volitional exhaustion was continuous with stages lasting 90 seconds with 60 second gas collections taking place during the final minute of each stage. The testing progressed with power increases of approximately 30 watts per stage until volitional exhaustion. Volitional exhaustion was deemed to exist when the subjects could no longer hold a pedal speed of 60 rpm. Throughout the testing session the subjects were verbally encouraged to perform to a maximal effort. The $\dot{V}O_{2max}$ test was conducted prior to the subjects first habituation session on the sailing ergometer. A minimum period of at least 7 days elapsed between the $\dot{V}O_{2max}$ test and the sailing simulation task.

6.2.3 Construction of Laser sailing ergometer.

The dinghy ergometer was developed from the simulators originally outlined by Bursztyn et al., (1988) and later by McLoughlin et al., (1993). The dinghy ergometer used a Laser deck moulding which was pivoted between two 'A' support frames fitted with large diameter roller bearings. Thus, this dinghy ergometer, in a similar fashion to the hiking bench described in the previous chapter, was free to move about a fore and aft roll axis ($\pm 30^0$). Unlike the work conducted by Bursztyn et al., (1988) and McLoughlin et al., (1993), hiking performance was not measured but the subjects were encouraged to keep the dinghy as flat as possible at all times. The heeling moment was created by placing a moveable weight stack on the leeward side of the boat with exercise intensity being proportional to load. Subjects were required to balance the heeling moment and thus keep the boat as horizontal as possible. The dynamic component of the simulation was provided by moving the weight stack along a tracking system that ran along the side-deck of the ergometer. Thus, by moving the weight stack further outboard the heeling moment could be increased and likewise sliding the weight stack inboard reduced the heeling moment. Initially it was intended to make the sideways movement of the weight stack controlled by a computer driven electric motor, in a similar fashion to the work conducted by Walls et al. (1998), but excessive costs prohibited this. Instead the weight stack was manually moved along the track at tightly controlled time periods. The calibrated weights placed on the leeward side were exactly equivalent to the mass of each subject – this loading was established during pilot work. The dinghy ergometer is shown in figure 6.1 below.

Figure 6.1 Laser sailing ergometer in use.



6.2.4 Pilot and habituation trials.

Prior to conducting any habituation sessions considerable effort was invested in establishing a protocol that accurately replicated the dynamic nature of dinghy sailing. During this phase the expertise and knowledge of the subjects were utilised in order to fine tweak the protocol.

Subjects underwent two habituation sessions prior to experimental testing. Each habituation session lasted for 30 minutes. In some cases there was a time period of up to 30 days between the first habituation period and the experimental simulation. This delay was unavoidable as the subjects were commonly out of the country competing and the experiment had to fit into their schedules. The subjects were requested to turn up at the laboratory in a rested state with at least one day's full recovery since their last training or sailing session. Despite the subjects' familiarity with exercise testing, including the collection of expired gas, the habituation sessions were still used to enhance this familiarisation and physiological measures were collected routinely during the habituation periods.

6.2.5 Simulation protocol

The dynamic nature of the simulation was established by analysing video footage of Laser racing from major championships. Video footage was provided by Royal Yachting Association's National racing coach and included the 1996 and 1997 Laser class World Championships held in South Africa and Chile, respectively. Both of these World Championships were windy events and thus this simulation replicates body movements associated with upwind sailing in winds of approx 7-10 $m.s^{-1}$. Video footage was analysed looking closely at body movements on three individuals. All three of these individuals were at that time ranked in the Worlds top 20, and all three of them took part in this simulation.

When analysing the video footage the following points were noted:

i) number and frequency of tacks
ii) amount of arm movement involved in trimming/pumping the mainsheet
iii) frequency of trimming/pumping the mainsheet
iv) number and frequency of movements involving rapid hip flexion and extension (gusts/lulls)
v) number and frequency of hip rotation movements in an attempt to get body weight forwards in the boat or towards the stern (bouncing the boat through waves)

6.2.6 Exercise protocol.

Based on these findings it was decided that a 30 minute upwind simulation would be constructed with the following protocol in an attempt to replicate body movements:

Gust of wind. every 30 seconds (starting 30 seconds into the simulation) the sliding weight was moved 20 cm further outboard. Duration of the gust was 10 seconds. Thus, the sailors were required to hike maximally (increased leg and hip extension in an attempt to increase righting moment) for 10 seconds.

Lull in the wind. every 30 seconds (starting 15 seconds into the simulation) the weight was moved 20 cm inboard from its normal position so as to represent a lull in the wind. Duration of the lull was 5 seconds. This required rapid hip and knee flexion as body weight was bought inboard in an attempt to prevent the dinghy from heeling to windward.

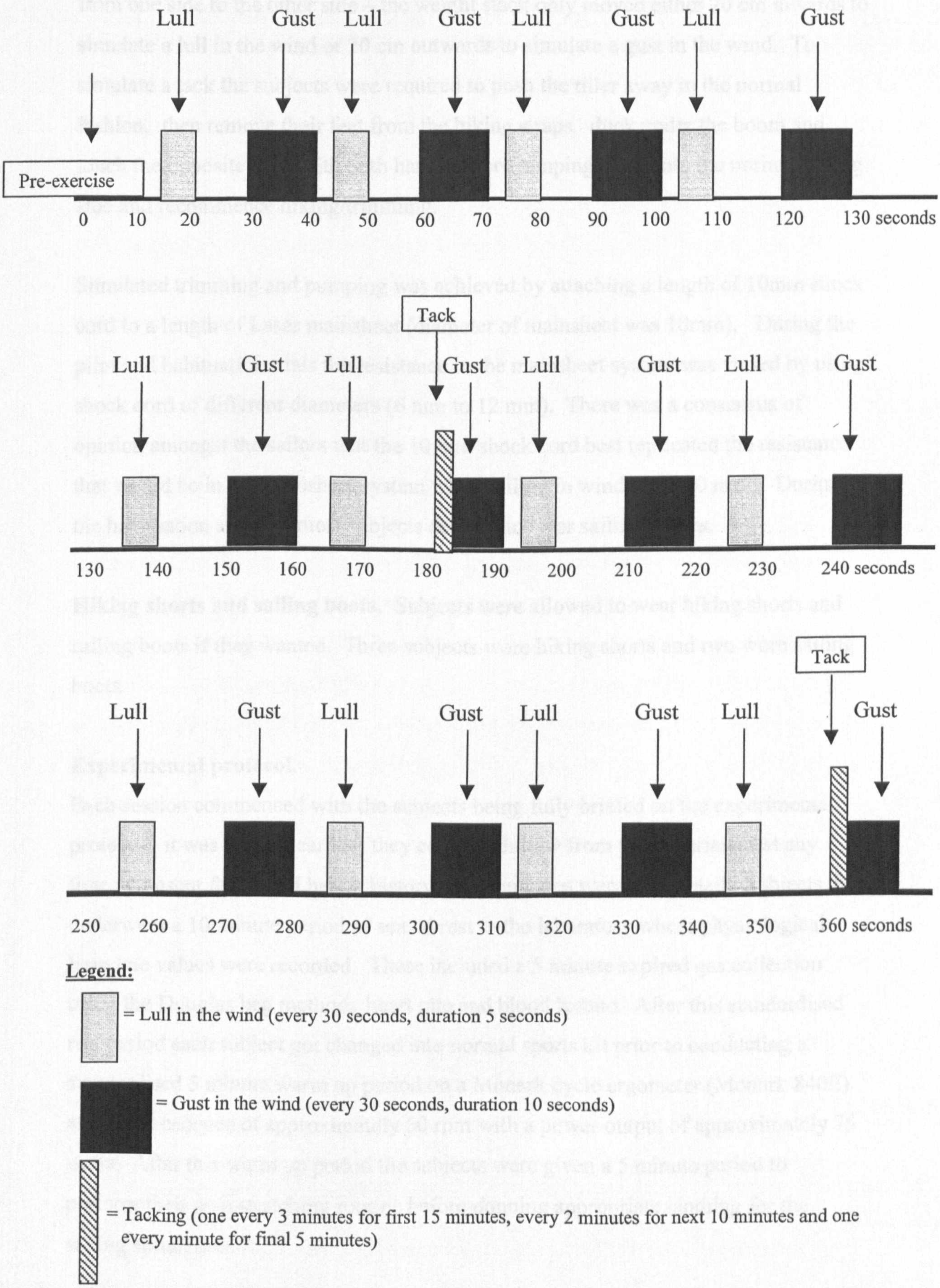
Tacking. A simulated tack was performed every 3 minutes for the first 15 minutes, every 2 minutes for the next 10 minutes and then every minute for the final 5 minutes of the simulation. The increased rate of tacking was used to simulate the increased need for tactics when approaching a windward buoy and the need to cover an opponent towards the finish.

Trimming. The sailors in the video analysed were virtually constantly playing the mainsheet in both trimming and pumping the sail – none of the three sailors studied in the video cleated the mainsheet. It was decided that for the simulation the sailors would be required to make a noticeable movement in the mainsheet (pumping or just trimming) every 10 seconds. This was controlled with a metronome beat.

Hip rotation – body weight movement forward or backwards. Immediately prior to each simulated gust or during the gust (every 30 seconds) the subjects were required to aggressively push body weight forwards or backwards (primarily hip rotation) in an attempt to either push the bow downwards through a wave or raise the bow over a wave, respectively. Such an action is commonly used in an attempt to bounce the boat through waves.

A schematic detailing the simulation protocol can be seen below in figure 6.2:

Figure 6.2: Schematic of simulation protocol.



The ergometer could not be tacked as the weight stack could not be safely transferred from one side to the other side – the weight stack only moved either 20 cm inwards to simulate a lull in the wind or 20 cm outwards to simulate a gust in the wind. To simulate a tack the subjects were required to push the tiller away in the normal fashion, then remove their feet from the hiking straps, duck under the boom and touch the opposite deck with both hands before jumping back onto the normal sailing side and recommence hiking/trimming.

Simulated trimming and pumping was achieved by attaching a length of 10mm shock cord to a length of Laser mainsheet (diameter of mainsheet was 10mm). During the pilot and habituation trials the resistance in the mainsheet system was varied by using shock cord of different diameters (6 mm to 12 mm). There was a consensus of opinion amongst the sailors that the 10 mm shock cord best replicated the resistance that would be in the mainsheet system when sailing in winds of 7-10 $m.s^{-1}$. During the habituation sessions most subjects decided to wear sailing gloves.

Hiking shorts and sailing boots. Subjects were allowed to wear hiking shorts and sailing boots if they wanted. Three subjects wore hiking shorts and two wore sailing boots.

Experimental protocol.
Each session commenced with the subjects being fully briefed on the experimental protocol; it was made clear that they could withdraw from the experiment at any time. Consent forms and health history questionnaires were completed. Subjects then underwent a 10 minute period of seated rest in the laboratory where physiological base line values were recorded. These included a 5 minute expired gas collection using the Douglas bag method, heart rate and blood lactate. After this standardised rest period each subject got changed into normal sports kit prior to conducting a standardised 5 minute warm up period on a Monark cycle ergometer (Monark 840E) at a pedal cadence of approximately 60 rpm with a power output of approximately 75 watts. After this warm up period the subjects were given a 5 minute period to perform their own stretching routine before donning appropriate clothing for the sailing simulation.

Each experimental trial consisted of a 30 minute continuous sailing bout. Subjects were not allowed to eat or drink during the simulation. A video which was edited from sailing clips of racing from the 1996 (South Africa) and the 1997 (Chile) Laser World championships was played continuously throughout the simulation. This video was only 2 minutes in length but edited so that it ran continuously for 30 minutes. The video highlighted the dynamic movement such as the rapid flexion/extension and rotation around the hip joint as well as the pumping/trimming of the mainsheet. The running of the video was synchronised with the start of the experiment so that the movements in the video related to what the subject was trying to do at any particular time during the simulation. Throughout the trial the subjects were encouraged to sail in a competitive fashion and keep the ergometer as flat as possible.

6.2.7 Measurement of physiological variables.

1) Expired gas Collection.

Expired gas was collected via Douglas bags. All Douglas bags were flushed with approx 40 litres of fresh air prior to being evacuated before use. Whilst wearing a nose clip, the subjects breathed through a mouthpiece connected via a low resistance respiratory valve (Salford valve box) to light weight respiratory tubing that was approximately 1 metre in length and connected to the Douglas bags. All expired gas samples were collected from the commencement of an inspiration of a breath to the inspiration of a following breath approximately 60 seconds later. The only exception to this was the initial resting collection of expired gas that was approximately 300 seconds in duration. Expired gas collections during the experimental trial were conducted at 5 minute intervals commencing during the 5th minute.

Immediately after each trial the expired fraction of oxygen (F_EO_2) and carbon-dioxide (F_ECO_2) were established using a calibrated Servomex Gas analyser. A calibrated Harvard dry gas meter was used to measure expired gas volumes. Air temperature was measured by a temperature probe at the inlet of the volume meter. Barometric pressure was determined by a mercury barometer. Expired gas volumes were corrected to standard temperature and pressure, dry (STPD) by standard formulas established in an Excel spreadsheet. Values were established for minute volumes ($\dot{V}_E$), volumes of carbon dioxide produced ($\dot{V}CO_2$), volumes of oxygen used

($\dot{V}O_2$), respiratory exchange ratios (RER) and ventilatory equivalent for oxygen ($\dot{V}_E / \dot{V}O_2$).

2) Blood sampling.

Finger tip capillary blood samples were taken immediately before starting the experimental trial and thereafter only during the final minute of the simulation and during the 5th minute of the recovery phase. Fifty micro-litres of whole blood were drawn into a heparinised capillary tube and immediately analysed for blood lactate concentration on an automated blood lactate analyser (Yellow Springs International 2300 stat plus).

3) Other measurements.

Heart rates were recorded during the 5th minute and then throughout the simulation at 5 minute intervals via short range telemetry (Polar Electro Sports Tester PE 3000, Finland).

6.2.8 Statistical Analysis.

Statistical analysis was conducted by the SPSS statistical package. A one-way analysis of variance (ANOVA) for repeated measures was used to establish where significant differences existed between the means. The Fisher HSD post-hoc test was used to identify significant differences where the results of the ANOVA were significant. Levels of significance was set at $p<0.05$. Results are presented as means ± standard deviation.

6.3. Results.

All raw data relevant to this chapter are shown in appendix E of the second volume of this thesis.

6.3.1 Physical characteristics.

The physical characteristics of the subjects can be seen in table 6.1 below. With the exception of one youth sailor (17.25 years and 71.0 kg) all subjects were rated in the top 10 Laser class sailors in Britain.

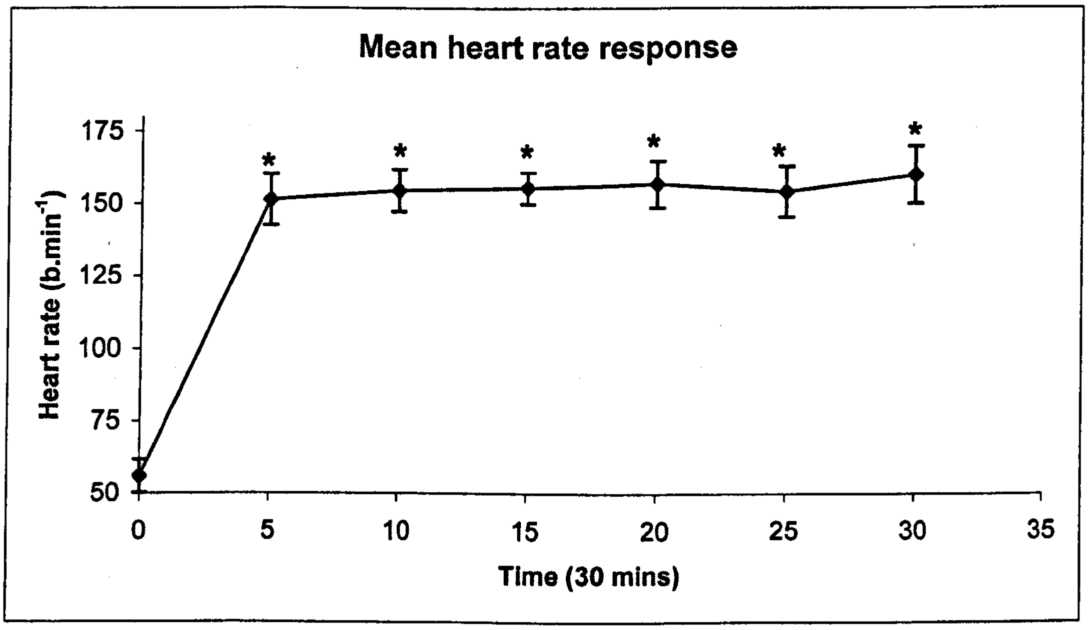
Table 6.1. Anthropometric and maximal exercise data for national level Laser sailors (n=6).

Variable	Mean ± s.d.	Range
Age (years)	19.65 ± 1.82	17.25 – 21.55
Height (m)	1.81 ± 0.03	1.775 – 1.84
Mass (kg)	78.02 ± 4.1	71 – 81.4
$\dot{V}O_{2max}$ (l.min^{-1})	4.32 ± 0.16	4.06 – 4.54
$\dot{V}O_{2max}$ (ml.kg^{-1}.min^{-1})	55.65 ± 4.0	50.1 – 60.3
HR_{max} (beats.min^{-1})	183 ± 8.0	173 – 194

6.3.2 Heart rate.

Mean heart rates (± s.d.) can be seen in Figure 6.3 below. Heart rates increased from a pre-exercise resting value of 56 ± 6 beats.min^{-1} to a peak value of 160 ± 10 beats.min^{-1}, recorded during the 30th minute. Mean heart rates at every stage during the 30 minute simulation were significantly ($p<0.01$) elevated compared to resting heart rates. However, mean heart rates did not increase significantly ($p>0.05$) during the simulation but rather settled out at a mean value of approx 155 beats.min^{-1}.

Figure 6.3. Group mean (± s.d.) values for heart rates recorded during the 30 minute dynamic simulation of dinghy sailing (n=6).



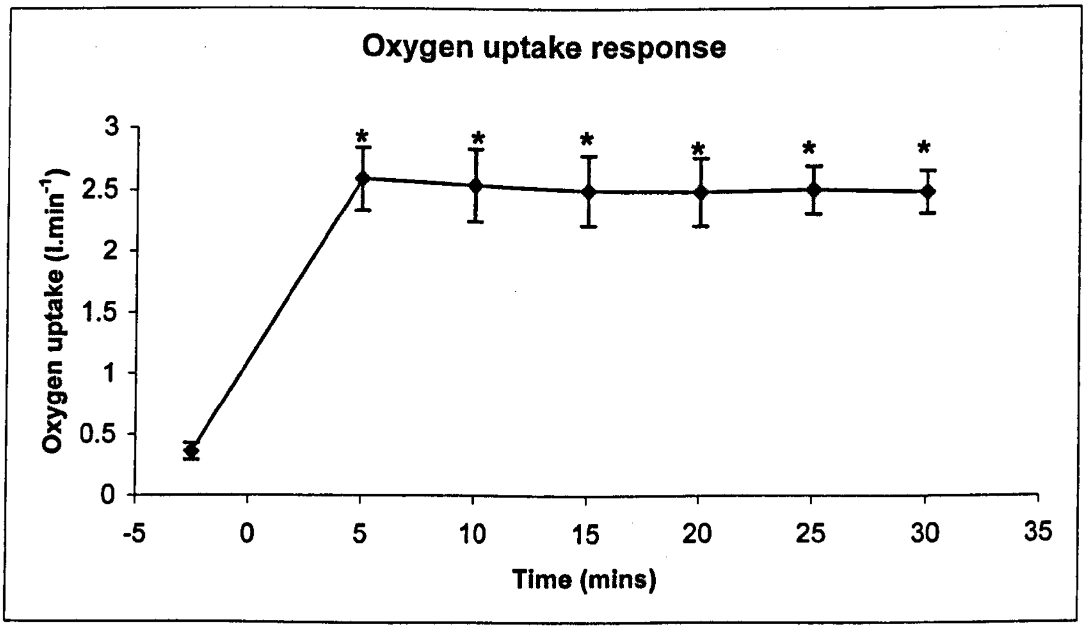
* Significantly greater than resting values ($p<0.01$)

6.3.3 Oxygen consumption.

Mean oxygen consumption for the 30 minute simulation was 2.51 ± 0.23 $l.min^{-1}$, which relative to body weight equated to 32.2 ± 2.95 $ml.kg^{-1}.min^{-1}$. The mean $\dot{V}O_2$ from the simulation expressed as a percentage of $\dot{V}O_{2max}$ was 58.1%.

The mean (± s.d.) oxygen uptake response for the 30 minute simulation can be seen in figure 6.4 below. Throughout the 30 minute exercise period all values of $\dot{V}O_2$ were significantly greater ($p<0.01$) than resting values. There were no significant ($p>0.05$) changes in $\dot{V}O_2$ during the simulation with the mean values only varying between 2.48 ± 0.25 to 2.58 ± 0.23 $l.min^{-1}$.

Figure 6.4. Group mean (± s.d.) values for oxygen consumption recorded during the 30 minute dynamic simulation of dinghy sailing (n=6).

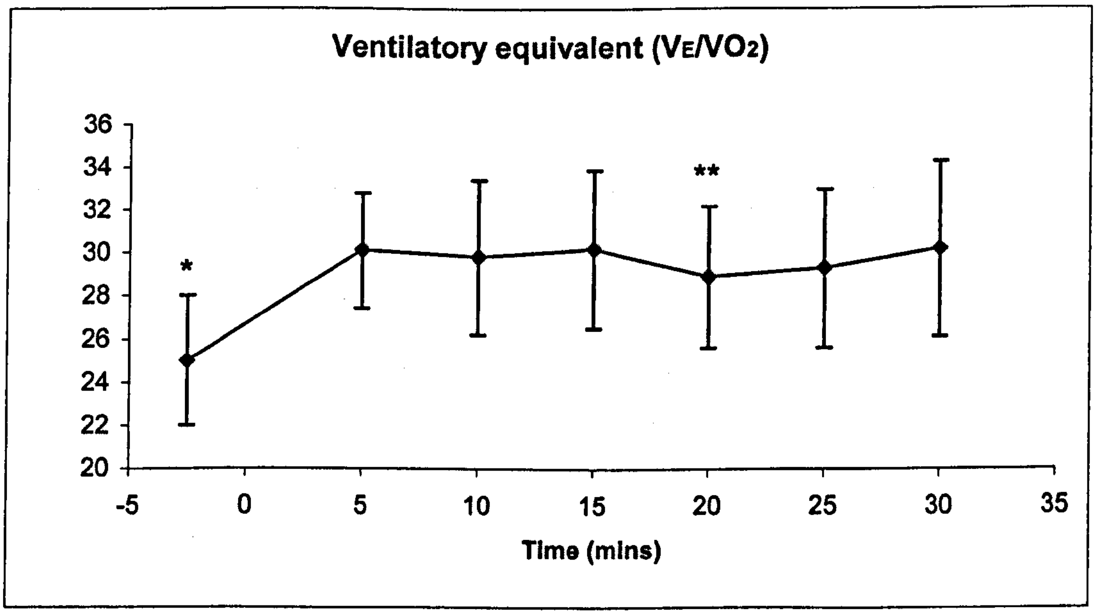


* Significantly greater than resting values ($p<0.01$)

6.3.4 Ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$).

Mean (± s.d.) values for the ventilatory equivalent for oxygen $\dot{V}_E/\dot{V}O_2$ were significantly elevated throughout the simulation when compared to resting values ($p<0.05$). Despite a slight, but significant ($P<0.05$), decrease in $\dot{V}_E/\dot{V}O_2$ recorded during the 20th minute, the mean values were consistently high and only varied from 28.9 ± 3.3 in the 20th minute to 30.2 ± 4.1 in 30th minute. The mean value for the simulation was 29.7 ± 3.5. Graphical representation of $\dot{V}_E/\dot{V}O_2$ can be seen in figure 6.5 below.

Figure 6.5. Group mean (± s.d.) values for ventilatory equivalent for oxygen during the 30 minute dynamic simulation of dinghy sailing (n=6).

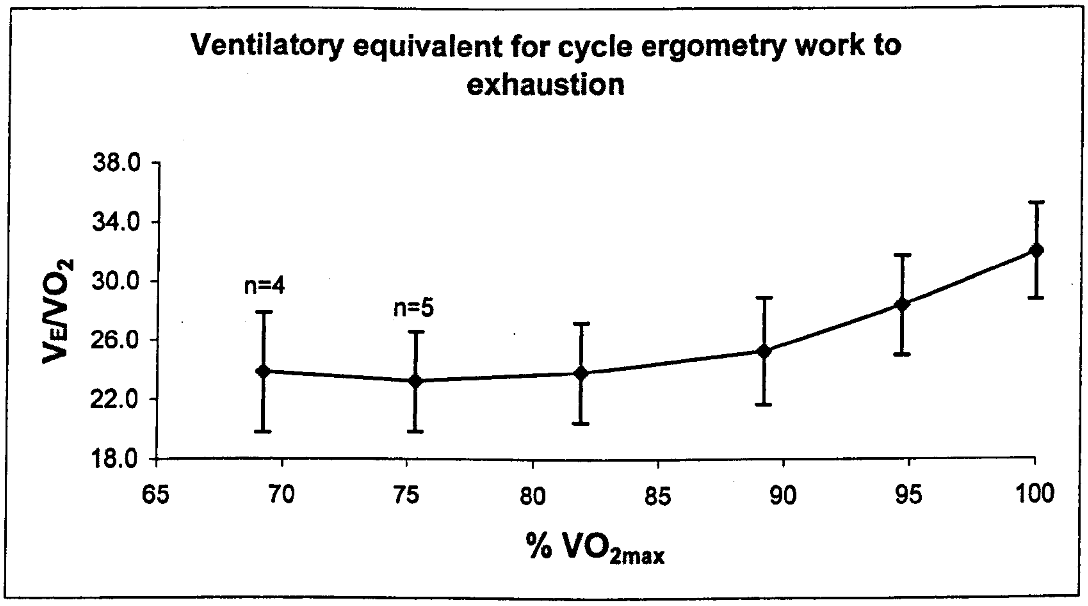


* Resting value significantly less than all exercising values ($p<0.05$)

** Significantly less than 15 min value ($p<0.05$)

The values for ventilatory equivalent during the sailing simulation are high given that they were only working at approx. 60% of $\dot{V}O_{2max}$. As a comparison the mean $\dot{V}_E/\dot{V}O_2$ recorded during the incremental cycle ergometry test to volitional fatigue are shown below in figure 6.6. During this cycle ergometry test a $\dot{V}_E/\dot{V}O_2$ of 29.7 was not reached till a $\dot{V}O_{2max}$ of 97.2 %

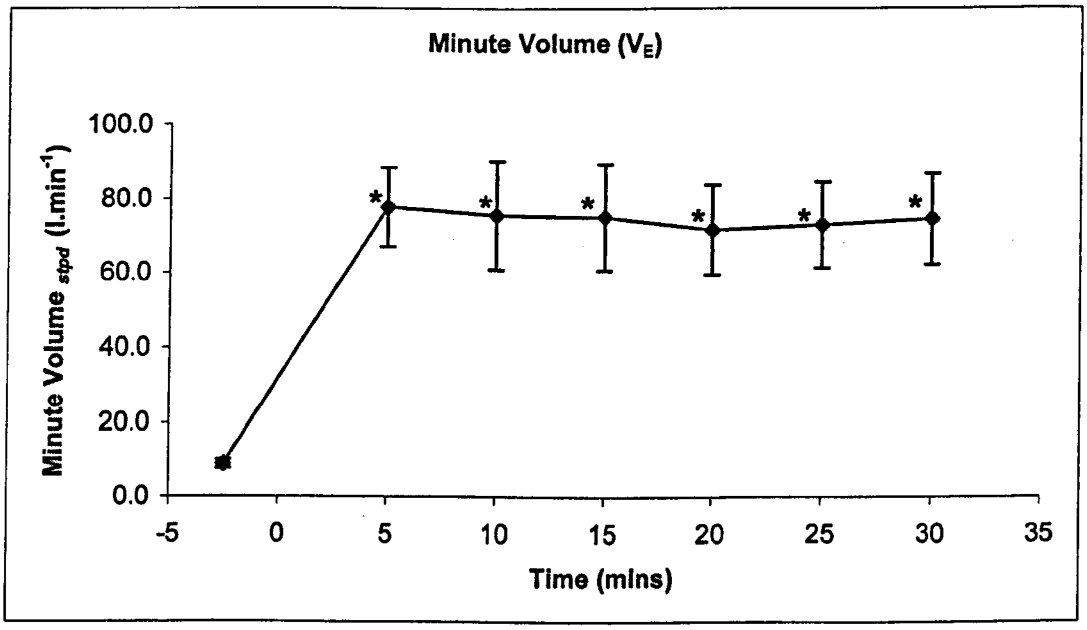
Figure 6.6. Group mean (± s.d.) values for ventilatory equivalent for oxygen during the $\dot{V}O_{2max}$ test to volitional fatigue (n=6, unless otherwise stated).



6.3.5 Minute Volume ($\dot{V}_E$).

There was a significant increase (p<0.01) in $\dot{V}_E$ from a mean resting value of 8.9 ± 1.2 l.min^{-1} when compared to all exercising values. There were no further significant changes (p>0.05) in $\dot{V}_E$ during the simulation. Mean $\dot{V}_E$ during the simulation levelled off and only varied by a maximum of 5.8 litres with 77.7 ± 10.7 and 71.9 ± 12.1 l.min^{-1} being recorded during the 5th and 20th minutes, respectively. Mean $\dot{V}_E$ for the sailing simulation can be seen graphically in figure 6.7 below.

Figure 6.7. Group mean (± s.d.) values for Minute Volumes ($\dot{V}_E$) during the 30 minute dynamic simulation of dinghy sailing (n=6).

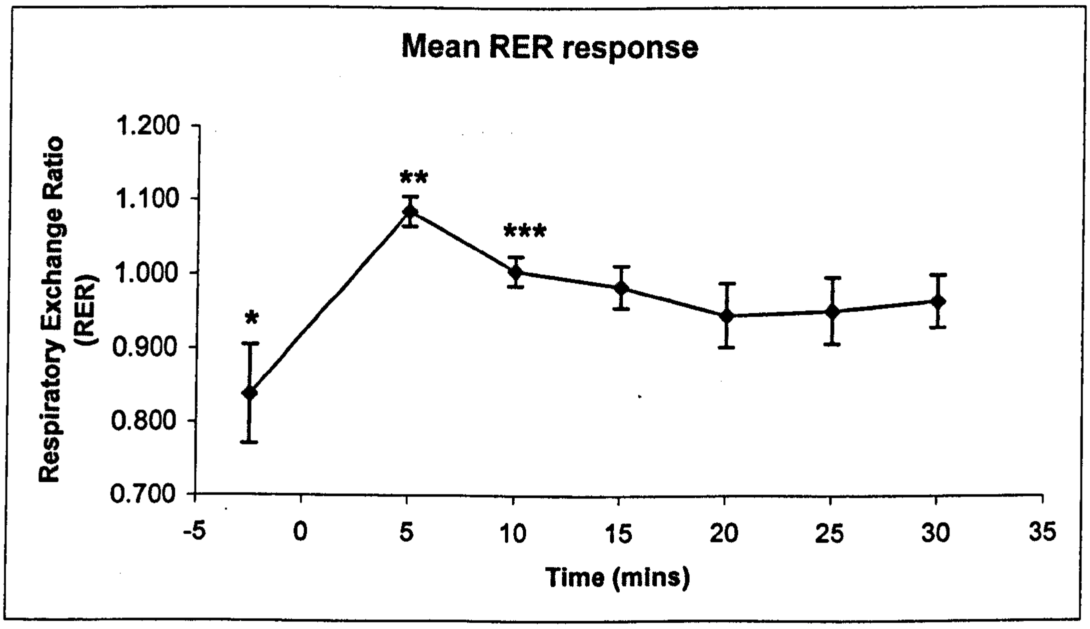


* Significantly greater than resting values (p<0.05)

6.3.6 Respiratory Exchange Ratio (RER).

All exercise values for RER were significantly greater ($p<0.01$) than resting values. After the initial large increase in the RER value that saw a mean resting value of 0.838 ± 0.067 increase to 1.084 ± 0.02 in the 4^{th}-5^{th} minute there was a gradual decline until it levelled off after 20 minutes. The RER value recorded during the 4^{th} – 5^{th} minute was significantly greater ($p<0.01$) than all other values. The value recorded during the 10^{th} minute was also significantly greater ($p<0.05$) than the values recorded during the 20^{th}, 25^{th} and 30^{th} minutes. Mean (± s.d.) for RER values can be seen graphically in figure 6.8 below.

Figure 6.8. Group mean (± s.d.) values for RER during the 30 minute dynamic simulation of dinghy sailing (n=6)



* Significantly less than all exercise values ($p<0.01$)

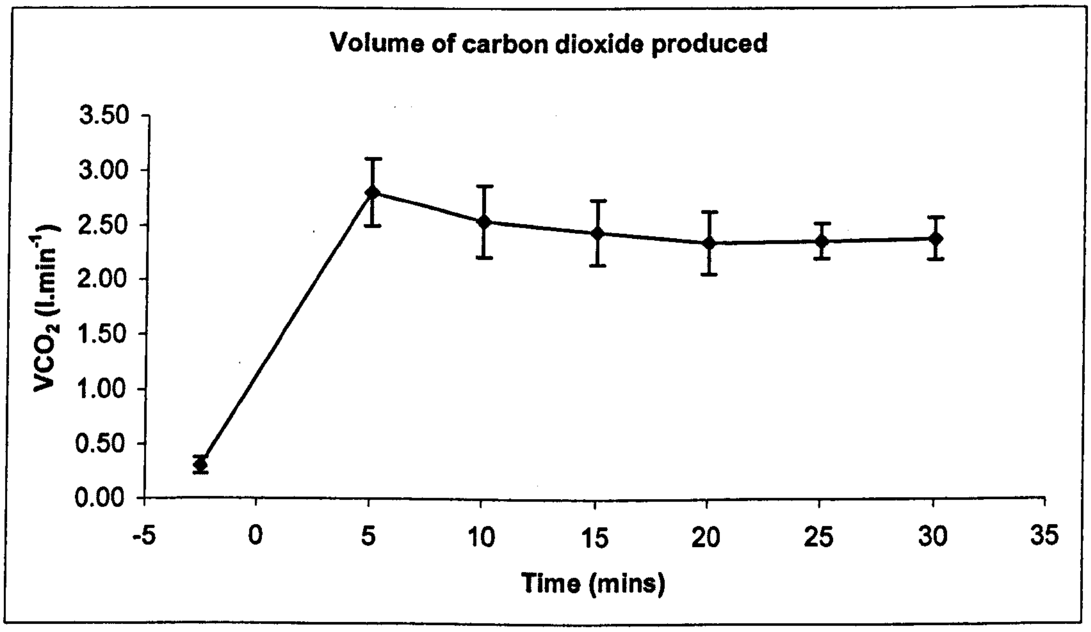
** Significantly greater than all other values ($p<0.01$)

*** Significantly greater than 20, 25 & 30 minute values ($p<0.05$)

6.3.7 Carbon-dioxide production ($\dot{V}CO_2$).

The trend for the $\dot{V}CO_2$ was similar to the responses listed above for the RER values. Exercise values were significantly greater ($p<0.05$) than resting values and the value recorded during 5th minute was significantly greater ($p<0.05$) than all other values. After the 5th minute there was a gradual, but non significant ($p>0.05$) decline in $\dot{V}CO_2$ before it levelled off after 15 minutes. Mean (± s.d.) values for $\dot{V}CO_2$ are reported graphically in figure 6.9 below.

Figure 6.9. Group mean (± s.d.) values for $\dot{V}CO_2$ during the 30 minute dynamic simulation of dinghy sailing (n=6).



6.3.8 Other Variables.

Blood lactate increased significantly ($p<0.01$) from a mean pre-exercise value of 1.08 ± 0.23 $mmol.l^{-1}$ to a mean value of 4.47 ± 0.23 $mmol.l^{-1}$ in the 30th minute. Throughout the simulation capillary blood samples, for blood lactate analysis, were only taken during the 30th minute. A post exercise sample was taken during 5th minute of the recovery period, this value being 3.54 ± 0.61 $mmol.l^{-1}$, which was significantly less ($p<0.01$) than the value recorded during the final minute of the simulation.

6.4 Discussion.

Aerobic fitness, according to most of the literature, is not of importance to the dinghy sailor (Niinimaa et al., 1977; Plyley et al., 1985; Shephard, 1990; Gallozzi et al., 1993; and Vogiatzis et al., 1994). It has been well documented in previous research that dinghy sailors have only modest maximal oxygen uptakes ($\dot{V}O_{2max}$); Niinimaa et al., (1977) 49.5 ± 6.7 ml.kg.$^{-1}$min^{-1}; Plyley et al., (1985) 45.3 ± 8.4 ml.kg^{-1}min^{-1}; Vogiatzis (1995a) 52.0 ± 6.0 ml.kg^{-1}min^{-1}. Mean $\dot{V}O_{2max}$ values for this present study were 55.4 ± 4.0 ml.kg^{-1}min^{-1} (4.71 ± 0.62 l.min^{-1}), with the highest and lowest individuals being 60.3 ml.kg^{-1}min^{-1} and 50.1 ml.kg^{-1}min^{-1}, respectively. These are slightly higher than the values listed above. However, higher maximal oxygen uptakes have been reported; Piehl-Aulin et al., (1977) 62.0 ± 8.0 ml.kg^{-1}min^{-1}; Blackburn (1994) 62.3 ± 8.2 ml.kg^{-1}min.$^{-1}$; Bojsen et al., (2003) 58.3 ± 4.2 ml.kg^{-1}min^{-1}; Larsson et al., (1996) 61.4 ± 2.0 ml.kg^{-1}min^{-1}. In the latter study, the authors reported that hiking sailors (n=8) had significantly greater $\dot{V}O_{2max}$ values of 63.8 ± 1.7 ml.kg^{-1}min^{-1} than non hikers (n=7) at 58.6 ± 3.8 ml.kg^{-1}min^{-1} ($P<0.05$). Larsson et al., (1996) reported the highest individual $\dot{V}O_{2max}$ figure of 71.0 ml.kg^{-1}min^{-1} for one of the male hikers. The sailors in this study were relatively well trained aerobically but considerably below the values reported by Larsson for elite Danish hiking sailors. There is no claim that single-handed dinghy sailors have to be exceptionally fit aerobically to perform at an elite level but they do need to be moderately trained aerobically. In comparison with endurance sports like cycling and running, sailors have a markedly lower (by approximately 25%) aerobic capacity (Åstrand, 1986; Rusko et al., 1978).

The mean heights and weights reported in this study, 1.81 ± 0.03 m and 78.02 ± 4.1 kg, are similar to values reported elsewhere in the literature and are similar to the values reported in chapter 3 of this thesis for elite Laser sailors. Blackburn (1994) reported values of 1.795 ± 0.048 m and 75.6 ± 4.1 kg for elite Australian Laser sailors, Vogiatzis et al., (1995a) 1.78 ± 0.08 m and 74 ± 14 kg for Scottish Laser sailors. Larsson et al., (1996) reported mean values of 1.83 ± 0.02 m and 80.3 ± 3.1 kg for elite Danish hiking sailors, however these values are not just for Laser sailors but all Olympic hiking sailors (including light weight 470 helms at 66 kg and heavy weight

Finn sailors at 93 kg). Felici et al., (1999) reported values of 1.79 ± 0.04 m and 69.0 ± 3.8 kg for junior Italian Laser sailors (mean age 17 ± 2.1 years). Care has to be taken when comparing anthropometric data of elite sailors reported in previous literature to make sure that one is comparing like with like. The anthropometric data from this study are not dissimilar from the values reported earlier (chapter 3 of this thesis) for British Laser sailors who have formed the bulk of the successful RYA's Olympic Laser squad over the past ten years; height 1.81 ± 0.04 m, mass 80.2 ± 3.8 kg, and age 22.9 ± 4.8 years (n=26).

Heart rates measured during this simulation, which ranged from 151 ± 9 beats.min^{-1} during the 5th minute to 160 ± 10 beats.min^{-1} during the 30th minute, are considerably higher than those reported from other attempted dynamic simulations. Blackburn (1994) reported mean values of 118 ± 25 beats.min^{-1}, Vogiatzis et al., (1993) 126 ± 15 beats.min^{-1}, Vogiatzis et al., (1996) 112 ± 6 beats.min^{-1}, and Felici et al., (1999) 138 ± 17 and 141 ± 13 beats.min^{-1} for hiking bouts at 60% and 85% of maximal hiking torque (MHT), respectively. It is interesting that this present simulation recorded higher heart rates despite the simulation being less fatiguing than some of the other dynamic simulations. Subjects reached volitional exhaustion after 188 seconds and 896 seconds (Felici et al., 1999) after hiking at 85% and 60% MHT. In the Vogiatzis et al., (1993) simulation the third hiking bout lasted approx 15 minutes before volitional fatigue and heart rates only peaked at 139 beats.min^{-1} with mean values of 126 ± 15 beats.min^{-1}. It seems that these simulations, aimed at replicating the dynamic nature of dinghy sailing, were too static in nature and hence, although the exercise was fatiguing, heart rates were still suppressed. The previous chapter detailed typical heart rate responses from a static simulation.

Blackburn (1994) used a protocol that was supposedly dynamic in nature where he simulated an 84 minute race with three upwind legs where each lasted 20 minutes and included 13 tacks. It seems that Blackburn did not overexert the hiking load as the subjects were able to perform the upwind hiking task for long time periods without excessive fatigue but it does seem that the dynamic element of the sport was not accurately replicated and that is why heart rates were suppressed. In this present simulation, which lasted for a 30 minute duration, it seems that heart rates were elevated due to the dynamic nature of the simulation.

In previous dynamic simulations [Vogiatzis et al., (1993), Vogiatzis et al., (1996) and Felici et al., (1999)] it seems probable that local muscular fatigue of the quadriceps was responsible for the early fatigue of the subjects. This is because the intensity of the hiking moment has been over emphasized and the subsequent contraction has been too static and probably at too high a percentage of MVC. Under such conditions a local ischaemia can result which causes rapid fatigue. Although no electromyograph (EMG) studies have been conducted on the water with dinghy sailing, the muscular contraction in the quadriceps may not be continuous and is probably less than 38.4 ± 3.5% MVC as suggested by Vogiatzis et al., (1993). With relatively long race lengths (average 60 to 75 minutes for the single-handed classes in the 2000 Olympics) the contraction of the quadriceps must either be at lower percentages of MVC or not continuous, to allow such prolonged hiking. It is plausible that the dynamic nature of dinghy sailing, although triggering elevated heart rates reported here, is responsible for reducing the local muscular fatigue of certain muscle groups such as the quadriceps. With such dynamic movements occurring in the boat it is normal practice for one leg to perform the majority of the hiking action whilst the other leg is working at a much lower percentage of MVC. This alternating of hiking legs is a common feature, particularly when driving body weight forwards or backwards in the boat to bounce through waves; when in the hiking position it is easier to rotate from the hips when pivoting off one leg rather than two legs. Such a strategy would make the muscular contraction involved in hiking less continuous and is perhaps sufficient to allow blood flow to perfuse the working muscles and remove waste products such as potassium ions and intra-muscular lactic acid and therefore restore the diminished muscle pH to normal values (Petrofsky & Phillips, 1986). Until a suitable on-water study looking at EMG activity is conducted the theory of alternating the muscular contraction between hiking legs will remain speculative. Laboratory simulations looking at EMG activity of the quadriceps muscle during hiking have failed to support such a theory; this is due to the static nature of past simulations. Personal communication with Ben Ainslie (Olympic silver medallist 1996 and gold medallist 2000 in the Laser class) has confirmed that such alternation of hiking legs is common practice during long upwind legs when staying on one tack for prolonged periods of time.

This present simulation, unlike other simulations of single-handed dinghy sailing, have reported similar heart rates to those commonly reported from on-water studies (Pudenz et al., 1981; Vogiatzis et al., 1994; Cunningham, 1995; Vogiatzis et al., 1995a; and Castagna & Brisswalter, 2004). Cunningham (1995) reported mean values for Laser sailors that varied from 132 ± 9 beats.min^{-1} in light winds (2-4 m.s^{-1}) up to 165 ± 13 beats.min^{-1} in strong winds (10-15 m.s^{-1}). It is worth noting that four of the six subjects taking part in this study were also involved in this earlier study. This study replicated sailing in winds of 7-10 m.s^{-1} and as such the heart rates are not dissimilar to those that were collected on the water in such conditions. Vogiatzis et al., (1994) reported mean values for Laser sailors that varied from 145 ± 17 beats.min^{-1} in moderate winds (6-7 m.s^{-1}) and increased up to 153 ± 20 beats.min^{-1} in strong winds (8-9 m.s^{-1}). Pudenz et al., (1981) reported mean upwind heart rates for Laser sailors of 168 ± 12 beats.min^{-1} in strong winds (8.1-13.8 m.s^{-1}) and values of 143 ± 9 beats.min^{-1} in moderate winds (3.4-8.0 m.s^{-1}). It is clear that the heart rates from this present study are similar to these values and as such it seems that this simulation was a fairly accurate simulation. There are only two on-water studies where relatively low heart rates have been reported, these are either out-dated (Cudmore, 1969) or were conducted in extremely light wind conditions where hiking was not required (Gallozzi et al., 1993).

The mean oxygen uptake from this simulation was 2.51 ± 0.23 l.min^{-1}, which relative to body weight equated to 32.2 ± 3.0 ml.kg^{-1}min^{-1}. Expressed as a percentage of $\dot{V}O_{2max}$ from cycle ergometry this equated to 58.1%. This is considerably higher than that reported for other dynamic simulations (Blackburn 1994; Vogiatzis et al., 1996; Felici et al., 1999) but similar to the values recently reported at the end of a prolonged hiking session on the water (Castagna and Brisswalter, 2004). Blackburn (1994) in his dynamic simulation of Laser sailing only reported $\dot{V}O_2$ values of 1.12 l.min^{-1} (approx. 14.8 ml.kg^{-1}.min^{-1}) for upwind sailing, which equated to approx 23.8% of $\dot{V}O_{2max}$ from cycle ergometry. Vogiatzis et al., (1996) suggested that mean $\dot{V}O_2$'s across the four bouts of dynamic Laser sailing only averaged 1.04 l.min^{-1} (approx. 14.1 ml.kg^{-1}.min^{-1}). Felici et al., (1999) detailed oxygen uptakes that were less than 1.0 $l.min^{-1}$ for the two hiking conditions studied. It is fair to be critical of these laboratory simulations as, although they were trying to replicate the dynamic nature of the sport, they seem to have failed.

The only research that has reported similar oxygen uptakes from a laboratory simulation to this present study is the unpublished work of Sandstrom et al., (1985) [cited in Blackburn, 1994]. They attempted to replicate the true dynamic nature of dinghy sailing. Blackburn refers to the results and summarises that the oxygen uptakes recorded by Sandstrom et al., were considerably higher with a mean value of 1.82 $l.min^{-1}$ (approx. 24 $ml.kg^{-1}.min^{-1}$) for a 10 minute hiking trial. Blackburn goes on to suggest that the simulation conducted by Sandstrom (1985) was more dynamic in nature and that it was:

> *"subjectively designed to mimic the demands of strong-wind dinghy sailing and involved a large dynamic component consisting of repeated movements of the body between sitting in and hiking out and a pumping action on a simulated mainsheet." (Blackburn 1994, p388).*

Apart from this comment about the work of Sandstrom et al., Blackburn (1994) makes very few other remarks about it, so it is hard to make any further conclusions. However, it does seem that if a simulation is correctly loaded to replicate the dynamic movements of single-handed sailing on top of the prolonged hiking action that is required to keep the dinghy upright, there does seem to be an increase in cardio-respiratory demand.

It is well documented that oxygen consumption during combined static and low level dynamic exercise may be as much as four times greater than that of static exercise alone (Kilbom and Brundin, 1976). It therefore seems that the elevated oxygen consumptions that reached 60% of $\dot{V}O_{2max}$ during the 10 minutes of simulated hiking in the Sandstrom et al., (1985) and reached 58.1% of $\dot{V}O_{2max}$ in this present study are probably due to extra dynamic activities, particularly flexion and extension around the hip joint and also the upper-body movements involved in pumping the sail. Indeed, preliminary findings reported by Spurway et al., (2000) have implied that a repeated leg movement of as little as 5 degrees (0.087 rad) on top of a sustained isometric contraction can significantly increase the physiological cost of the hiking activity as measured by cardiovascular, respiratory and blood lactate parameters.

One point that is hard to explain is the discrepancy between oxygen uptakes recorded in this study compared to those reported by Vogiatzis et al., (1995a) for their on-water study, given the fact that mean heart rates were quite similar. Indeed in this present study mean heart rates were 155 ± 8.0 beats.min^{-1} with mean oxygen uptakes of 2.51 ± 0.24 l.min^{-1} (32.2 ± 3.07 ml.kg^{-1}min^{-1}); whereas Vogiatzis (1995a) reported mean values from their on-water study of 145 ± 21 beats.min^{-1} and 1.50 ± 0.22 l.min^{-1} (20.3 ± 3.0 ml.kg^{-1}min^{-1}), respectively for heart rates and oxygen uptakes. Thus, although the mean heart rates are only 10 beats.min^{-1} higher in this present study the values for oxygen uptake are considerably higher. This might be explained by the fact that max heart rates were considerably different between the studies; in this study they were 183 ± 8 beats.min^{-1}, whereas Vogiatzis reported max heart rates of 196 ± 6 beats.min^{-1}. Thus, the relative work load expressed as a percentage of maximum heart rates are considerably different; 84.6% of max in this study whilst only 73.9% of max in the Vogiatzis study; and this may explain the differences in oxygen consumption. It must be emphasized that absolute values of heart rates should be treated with caution and if possible expressed in relation to each individuals' maximum.

Marchetti et al., (1980); Gallozzi et al., (1993); Vogiatzis et al., (1994); and Castagna & Brisswalter (2004), have also reported oxygen consumptions for on-water sailing. Values have varied from 20.5 ml.kg^{-1}.min^{-1} for a single-handed Finn sailor (Gallozzi et al., 1993); 10.4 ml.kg^{-1}.min^{-1} for a Star crew (Gallozzi et al., 1993), 20.9 ml.kg^{-1}.min^{-1} and 23.1 ml.kg^{-1}.min^{-1} for Laser sailing in moderate and strong winds (Vogiatzis et al., 1994) and 45.1 to 68.4 % $\dot{V}O_{2max}$ for prolonged Laser sailing (Castagna & Brisswalter, 2004). The $\dot{V}O_2$ data from the Marchetti et al., (1980), presumably measured via Douglas bags, is difficult to interpret but it seems that a mean oxygen consumption was recorded at 2.0 l.min^{-1} (31 ml.kg^{-1}.min^{-1}). These values are similar to the relative values (32.2 ± 3.07 ml.kg^{-1}min^{-1}) reported in this present study. It is clear that previous research is equivocal when reporting oxygen uptake values for dinghy sailing; probably the situation is confused by varying environmental conditions and the different classes of boat along with the varying roles of the sailors in these boats. It also seems that the majority of simulations to date have failed to replicate the exact movements to which the dinghy sailor is subjected. This is particularly the case considering that the on-water measures may well be underestimating the real scenario as they have either been recorded during training sessions as opposed to racing situations (Vogiatzis et al., 1994 and 1995a), and the only data collected during an on-water racing regatta (Gallozzi et al., 1993) were during extremely light wind conditions (4-6 $m.s^{-1}$) where continuous hiking would not have been warranted. Also, the very small subject size in both the Marchetti et al., (1980) and Gallozzi et al., (1993) papers are a concern.

Blood lactate responses can give an indication of the metabolic requirements of the task. In this present study blood lactates were significantly elevated ($p<0.01$) in the 30^{th} minute (4.47 ± 0.94 $mmol.l^{-1}$) when compared to pre-exercise values (1.08 ± 0.23 $mmol.l^{-1}$). Blood samples were not taken during the simulation, but given the almost stable response with heart rate and oxygen uptake during the simulation it is feasible to assume that the blood lactate response during the whole task would be similar to that recorded during the 30^{th} minute. A mean value of 4.47 ± 0.94 $mmol.l^{-1}$ is higher than reported values for other simulations of dinghy sailing which are 4.0 ± 1.5 $mmol.l^{-1}$ (Vogiatzis et al., 1993); 3.1 ± 1.1 $mmol.l^{-1}$ and 3.9 ± 0.7 $mmol.l^{-1}$ (Felici et al., 1999); 2.4 $mmol.l^{-1}$ (Vogiatzis et al., 1996); and 2.32 ± 0.81 $mmol.l^{-1}$ (Blackburn, 1994). The previous chapter detailed blood lactate response from a totally static simulation of hiking and values varied between 1.42 ± 0.49 to 1.47 ± 0.42 $mmol.l^{-1}$. Thus, it seems that the large variance in blood lactate responses between studies can be misleading when drawing conclusions about the metabolic requirements. Values as low as 1.42 ± 0.49 $mmol.l^{-1}$ (Cunningham et al., 1998) and 2.32 ± 0.81 $mmol.l^{-1}$ (Blackburn, 1994) would suggest that the anaerobic demands are minimal, whereas the values reported in this present study would suggest that anaerobic metabolism plays an important role. It seems that the blood lactate response varies according to both the intensity and the dynamic nature of the simulation and as such it is difficult to draw any conclusions from previous research.

Blood lactate responses from on-water studies have, in a similar fashion to laboratory studies, also varied considerably and are not directly comparable between papers. Values have varied from an individual peak of 8 $mmol.l^{-1}$ after a demanding 40 minute sailing test (Piel-Aulin et al., 1977); to mean values of 2.3 ± 0.8 $mmol.l^{-1}$ immediately after 10 minutes of upwind sailing in winds of 4 – 12 $m.s^{-1}$ (Vogiatzis et al., 1995a); and 1.8 ± 0.4 $mmol.l^{-1}$ following a 5 minute hiking period (Marchetti et al., 1980).

Blood lactates in this present study decreased significantly ($p<0.05$) after completing the 30 minute simulation where mean blood lactates decreased from 4.47 ± 0.94 $mmol.l^{-1}$ in the 30th minute to 3.54 ± 0.61 $mmol.l^{-1}$ in the 5th minute of the recovery period. This is in contrast to the work of Vogiatzis et al., (1993). They reported increases in mean blood lactates during a fatiguing hiking task from 4.0 ± 1.5 $mmol.l^{-1}$ during the final minute of the task to 5.7 ± 1.3 $mmol.l^{-1}$ during the 5th recovery minute. This work by Vogiatzis et al., (1993), as with other simulations, has been to static in nature and has over emphasized the continuous work load placed on the quadriceps. It seems that this has resulted in some blood pooling in the working muscle and that the intramuscular pressure was too great for the waste products of metabolism to be returned in the normal way by the venous return. At the cessation of the hiking task the intramuscular pressure was released and the waste products trapped in the working muscle allowed to perforate into the venous return in the normal way and this resulted in elevated post exercise blood lactates. The fact that this did not occur in this present study is complimentary to the dynamic nature of the simulation which has not been prevalent in other simulations.

Despite the fairly substantial values reported in this present study for oxygen uptake (58.1% of $\dot{V}O_{2max}$), there was still considerable evidence of an elevated respiratory drive in excess of that required for metabolism. The values for ventilatory equivalent ($\dot{V}_E / \dot{V}O_2$) from the simulation are considerably higher than would normally be expected for rhythmic dynamic exercise, such as cycling or running, at the same relative exercise intensity. The mean ventilatory equivalent for the 30 minute simulation was 29.7 ± 3.5 $l.min^{-1}$. As a comparison the ventilatory equivalent for the same subjects during their cycle ergomerty test to volitional exhaustion at 60% of feature associated with isometric exercise (Myhre and Andersen, 1971; Poole et al., 1988; Petrofsky and Phillips, 1986). Thus, it seems that although the simulation was dynamic in nature which resulted in increased oxygen uptakes and heart rates, particularly when compared to other simulations, there was still a large isometric component associated with the hiking task. Vogiatzis et al., (1996) similarly reported elevated respiratory drive when compared to metabolism and Vogiatzis et al., (1995a) claims that this is a feature that occurs on the water. Correspondingly, hyperventilation is a common feature associated with dinghy sailing and in this present study the respiratory exchange ratios (RER) were considerably higher than one normally associates with dynamic exercise at the same relative exercise intensity. Various factors may be driving this increased respiratory drive. Increased muscle chemoreflexes activity due to elevated potassium ions and a diminished inter-muscular pH (McCloskey and Mitchell, 1972; Tibes, 1977;) ; enhanced central command as fatigue sets in (Goodwin et al., 1972); the increased sensation of pain and fatigue in the working muscles leading to activation of the respiratory neurons via the cortex (Duncan et al., 1981); or increased outflow of catecholamines associated with increased pain and fatigue are also capable of inducing hyperventilation (Whelan and Young, 1953).

The elevated RER's and ventilatory equivalent for oxygen reported in this present study suggests that this simulation has succeeded in establishing a dynamic protocol that is underpinned with an isometric contraction of a large muscle mass and as such is in accurate simulation of dinghy sailing. Marchetti et al., (1997) summed up the activity of a dinghy sailor as 'never being static' but having to adapt to waves and wind variation and on the background of isometric contraction jerks are superimposed which approximate the Maximal Voluntary Contraction (MVC). It seems that this is exactly what this simulation has replicated.

6.5 Conclusion.

Most laboratory simulations of Laser sailing have suggested that the physiological demands are considerably less than reported here. Vogiatzis et al., (1996) reported mean heart rates and oxygen uptakes of 112 beats.min^{-1} and 1.04 l.min^{-1} (14.1 ml.kg^{-1}.min.$^{-1}$) and Blackburn (1994) reported mean values of 118 ± 25 beats.min^{-1} and 1.12 l.min^{-1} (14.8 ml.kg^{-1}.min. $^{-1}$). It is doubtful whether these simulations accurately replicated the true dynamic nature of the sport particularly the activities of rapid flexion, extension and rotation around the hip joint and the near continuous upper-body movements involved in pumping and trimming the sail. This present study reported a mean heart rate for the 30 minute simulation of 155 b.min^{-1} (84.7% of HR max) with an accompanying mean oxygen uptake of 2.51 ± 0.23 l.min^{-1} (58.1% $\dot{V}O_{2max}$). These results are similar to the most recent on-water research conducted into Laser sailing by Castagna & Brisswalter (2004) where heart rates and oxygen uptakes for elite sailors reached 78.5% of HR max and 68.4% of $\dot{V}O_{2max}$, respectively. This would suggest that this simulation accurately replicated the true dynamic nature of elite Laser sailing.

CHAPTER 7

Chapter 7.

Physiological profiles, testing protocols and training recommendations for elite single-handed dinghy sailors.

7.1 Introduction.

Previous literature detailing the physiological profiles of dinghy sailors has been covered in depth in chapter 2 of this thesis. It would seem from previous research that muscular strength, muscular endurance and aerobic fitness are areas that need to be considered when establishing such profiles. Most of the literature emphasises the importance of leg and abdominal strength for hiking sailors. The methods of testing leg strength have varied. Both extension and flexion around the knee joint have been investigated and the form of muscular contractions have varied from eccentric and concentric isokinetic contractions to isometric ones. Probably the most relevant research detailing the strength requirements for single-handed hiking sailors is that conducted by Aagaard et al., (1998). They concluded that sailors have exceptionally high values for eccentric quadriceps strength and that it would seem that both this dynamic strength (i.e. maximal eccentric) and isometric muscle strength are important for optimal hiking performance. Aagaard et al., (1998) also mentions the importance of trunk extensor muscles in stabilising the lower back and spine during hiking. As single-handed sailing races typically last between 60-75 minutes it is reasonable to assume that endurance of these muscles is also important for success.

Strength and muscular endurance of the upper-body are also important in trimming the position of the sails (Niinimaa et al., 1977; Plyley et al., 1985; and Blackburn, 1994). The dynamic loadings in a Laser class mainsheet has been recorded at approximately 550 N when sailing upwind in 12 knots (Blackburn, 1994).

The importance of aerobic fitness for a single-handed dinghy sailor is a debatable point amongst sailing researchers where it has traditionally been seen to be of only minor importance (Niinimaa et al., 1977; Plyley et al., 1985; Shephard, 1990; Gallozzi et al., 1993; Vogiatzis et al., 1994 and 1995a). More recently the importance of aerobic fitness has been highlighted (Blackburn, 1994; Larsson et al., 1996; and Bojsen et al., 2003) with aerobic fitness levels of elite sailors being comparable to those observed in elite athletes in aerobically demanding team sports (Larsson et al., 1996; Bojsen et al., 2003).

Physiological testing protocols have been outlined in some of the previous literature along with the subsequent physiological profiles of elite sailors [Larsson et al., (1996); and Bojsen et al., (2003) for Danish Olympic sailors and Blackburn, (2000) for Australian Olympic sailors]. The Danish data covers two periods; data for the squad pre 1992 Olympics (Larsson et al., 1966) and data for the present 2000-2004 Danish Olympic squads (Bojsen et al., 2003). They all include anthropometric measurements as well as measures of aerobic fitness and some form of functional test measuring leg strength and endurance, and abdominal endurance. Bojsen et al., (2003) also reported functional hamstring-quadriceps ratios (eccentric hamstring to concentric quadriceps moments) as they feel that the over-development of quadriceps muscles of hiking sailors in relation to hamstring development leaves them prone to potential knee joint instability and possible knee joint overload and injury.

The British Association of Sports and Exercise Sciences (BASES) offers physiological testing guidelines with a specific section outlining the considerations for the assessments of sailors (BASES, 1997). This advice was written by Professor Neil Spurway and covers generic fitness assessment including conducting $\dot{V}O_{2max}$ testing, preferably on a cycle ergometer, and sit and reach tests measuring flexibility. It also includes specific tests for hiking sailors including crude guidelines for measuring strength and endurance of the quadriceps muscles by using a mix of squats and static squats, abdominals by performing slow trunk curls, and measures of back and arm strength-endurance. This advice is dated and is based on Spurway's underlying philosophy that hiking is static in nature:

> *"Hiking itself. This places near-isometric endurance demand on tibialis anterior, quadriceps and abdominals; the ratios between the three vary, but in most people, sailing most shapes of boat, quadriceps are activated to the highest percentage of their maxima and tibialis least" (BASES, 1997, p123).*

An understanding of the physiological demands of single-handed dinghy sailing coupled with an appropriate battery of fitness tests allows the applied sports scientist to address both the requirements of the sport and the relative strengths and weaknesses of individual sailors. The prescription and optimisation of a training program must be based on the physiological demands that the athlete undergoes during competition and training. Based on this premise an appropriate training programme can be administered. Having a battery of fitness tests which are relevant to the physiological demands of the sport is fundamental for optimising appropriate training prescription. Bojsen et al. (2003) have suggested that given the amount of time that Olympic sailors devote to the competitive and technical aspects of the sports such as boat handling, gear development, speed tuning, technical and tactical understanding, then time is scarce to conduct any physical training. Thus, it is important that the time spent in training to improve various physical abilities is effective, and that the training is directed to improve factors that are limiting sailing performance. In an attempt to prescribe effective and relevant training programmes the Danish Sailing Federation have embarked on a system of identifying an optimal method of monitoring and improving the physical performance of Olympic class sailors with an endpoint of minimising training time but still improving the physical capacities that are important to each individual sailing class (Bojsen et al., 2003).

Cudmore (1969), was one of the first to offer specific training advice for single-handed dinghy sailors. He advised that in winds above $7 m.s^{-1}$ the most physical challenge to the Finn sailor was overcoming local muscular fatigue in the upper limbs, stomach, back and the quadriceps group of muscles and recommended that these areas should be the focus of the sailors' off-water training programme. The first dry land winter training programme outlined in the scientific literature specifically for dinghy sailors was that by Wright et al., (1976). They had proposed that dry land training was only necessary during winter periods when not sailing. It was their notion that during the sailing season the sailors developed the necessary physiological components simply by sailing long hours. The training prescription recommended by Wright et al., (1976) included weekly circuit sessions, weight-training, muscular endurance and running sessions. The different sessions were blended in during a 14 week training period where they trained on average four times per week. The sailors were enthusiastic about the benefits of the training sessions concluding that they had greater tolerance of the hiking position with subsequent improvements in racing results. The weight training programme implicated by Wright et al., (1976) was largely dynamic in nature and included exercises specifically aimed at hiking improvements and included sit-ups on a downward sloping board, weighted sit-ups from the hiking position, leg press, leg extension, clean and press and upper-body pulley work.

Spurway and Burns (1993) have been critical of the work conducted by Wright et al., (1976) claiming that the training prescription was not static enough in nature particularly with reference to the hiking specific muscles. They implemented a common aerobic base between two groups of sailors but split the hiking specific training into static and dynamic regimens. They concluded that static training, specific to the hiking muscles, was more beneficial than dynamic training and as such:

> *"fitness training for dinghy sailors should include as much static exercise of the hiking muscles as the participants can tolerate" (p866)*

They highlight the 'boring' nature of performing static exercise and note that they had a large drop out with 50% of subjects performing the static training not completing the training period of 10 weeks.

BASES (1997) and Blackburn (2000) only offer physiological testing advice but do not suggest any training recommendations. The main training implication suggested by Vogiatzis et al., (1995a) centres on the low aerobic capacities measured during their on-water study of Laser sailing and they emphasise that:

> *"the training regimes for dinghy sailors should involve a limited number of aerobic activities ...." (Vogiatzis et al., 1995a, p 107).*

Blackburn (1994) suggests that the muscular discomfort felt by the subjects during the simulation would indicate that the muscular contraction during hiking is inhibited before a peak in energy supply, by either aerobic and anaerobic metabolism, is reached. From this statement he concludes that although dynamic aerobic training is warranted in the training schedule of a dinghy sailor, primarily to facilitate recovery, that static training is essential for task specific adaptation of the circulation.

The main aims of this chapter are threefold:

Firstly, to highlight the present physiological testing protocols approved by the National Governing Body for sailing in the U.K. (RYA), and used on the present British Olympic sailing squads.

Secondly, to highlight the physiological profiles of the elite British sailors forming the Olympic single-handed sailing classes based on the described testing protocols.

Thirdly, to discuss training recommendations presently being prescribed for elite British Olympic single-handed dinghy sailors.

7.2 Physiological testing protocols.

7.2.1 Aerobic fitness.

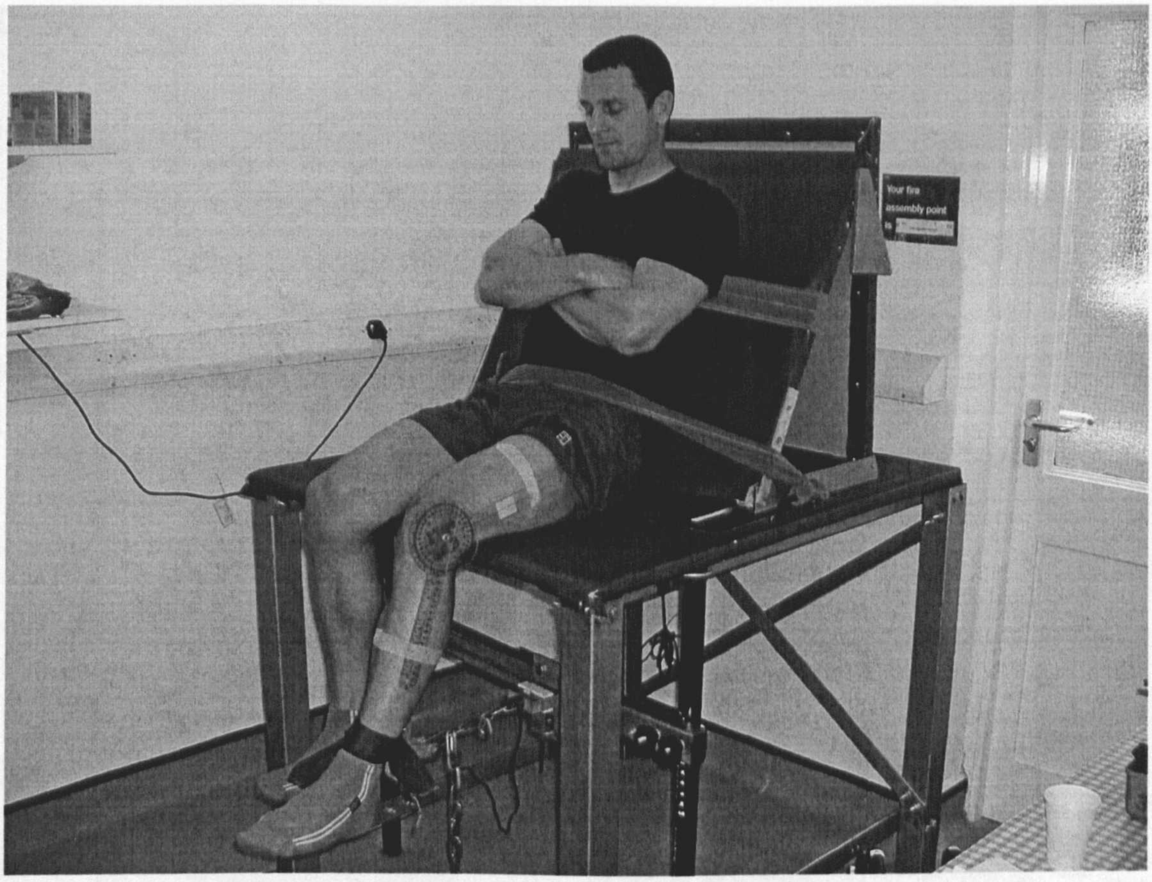
All subjects completed consent forms (see appendix A) prior to taking part in this testing. Aerobic fitness testing is conducted by means of an incremental exercise test on either a Concept 2 rowing ergometer, an SRM cycle ergometer or a Woodway treadmill (sailors choice). Aerobic testing consists of a sub-maximal test which goes straight into a $\dot{V}O_{2max}$ test. The sub-maximal test has exercise stages that vary in length between 4 and 6 minutes (6 minutes for the first stage followed by 3 further stages each of 4 minutes duration) to allow physiological steady state to be established (BASES, 1997). Expired gas and heart rates are collected during the final minute of each stage with a blood lactate being taken at the completion of each stage. Expired gas is collected via Douglas bags and later analysed on a Servomex 1410 gas analyser. During the sub-maximal test, power increments on the rower and the SRM cycle ergometer vary between 20 and 50 watts depending on the size and fitness of the sailor concerned. The treadmill is kept at a gradient of 1% throughout the sub-maximal test with speed increments of 1 $km.h^{-1}$ on each stage. On completion of the 4th stage the testing goes straight into a max test and is continued until volitional exhaustion is reached.

For the max testing, power on the SRM cycle ergometer is increased at a rate of 6 watts every 15 seconds, and power increments on the rowing ergometer vary between 15 and 25 watts every 40 seconds, again depending on fitness and size of the sailor. During the $\dot{V}O_{2max}$ test the treadmill is kept at a constant speed with the gradient increased at a rate of 0.7% every 15 seconds. All subjects are verbally encouraged to push themselves to volitional exhaustion. Expired gas is collected continuously throughout the max test via interconnected Douglas bags. Blood samples are not obtained during the max test except for a post-test sample taken 3 to 4 minutes after completion. The treadmill and cycle ergometer protocols are continuous in nature throughout both the sub-max and max tests. The protocol for the rowing ergometer test is discontinuous in nature during the sub-maximal test with a 30 second rest between stages to permit blood sampling; and continuous during the max test. The damper of the rowing ergometer is set to produce a drag factor of 145. Maximal power outputs on both the cycling and rowing ergometer tests are calculated as maximal power averaged during the final 60 seconds (max minute power). From the sub-maximal test oxygen uptakes and power outputs (or running speeds) are calculated at a point equivalent to 4.0 mmol of blood lactate. The majority of the tests are conducted on the SRM cycle ergometer, exact breakdowns are given in table 7.1 within the results section 7.3 of this chapter.

7.2.2 Isometric leg strength testing.

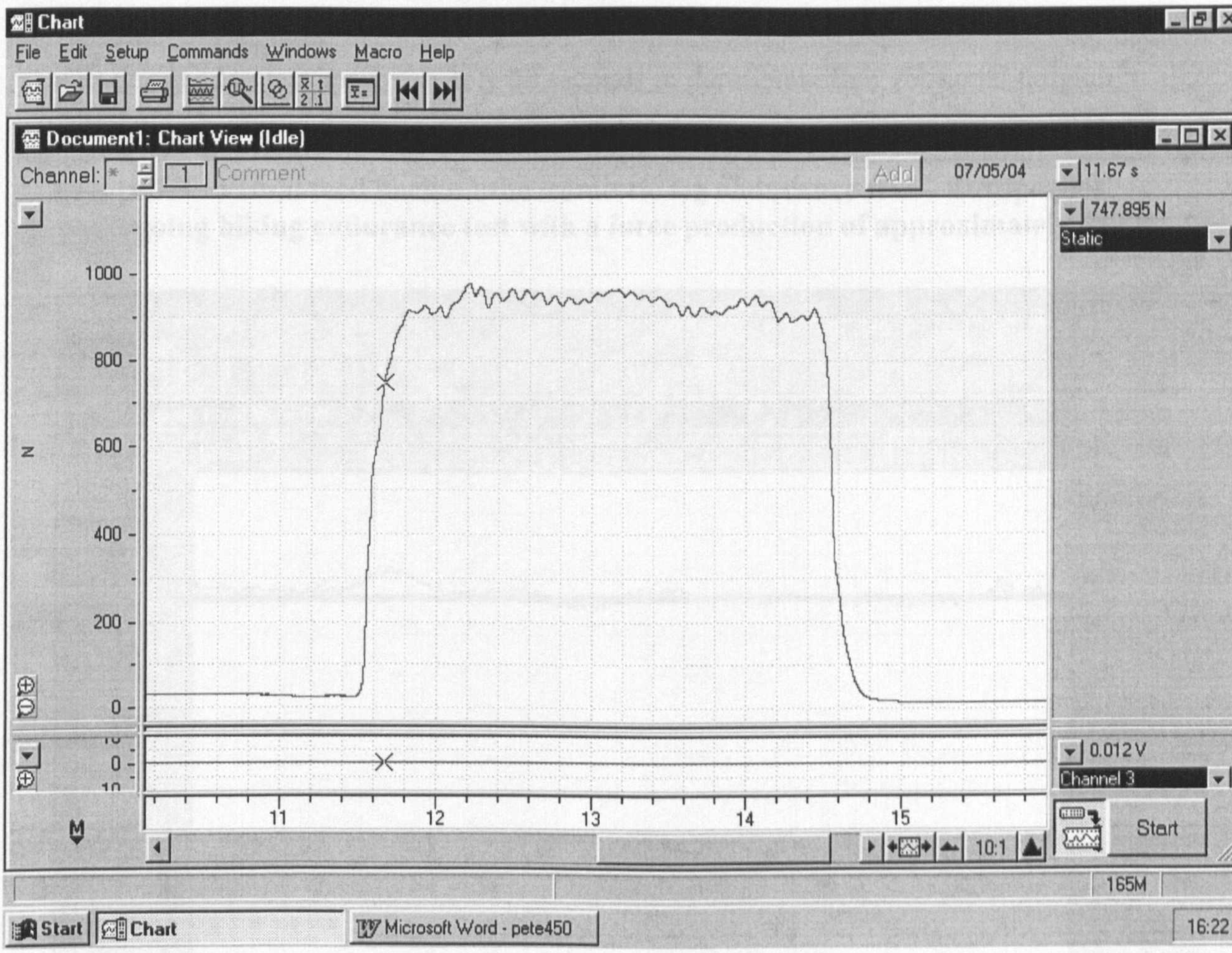
This test involves the sailors sitting on a specifically constructed chair as shown in figure 7.1 below. The knee angle is fixed at 125° and the hip angle fixed at 115°. The sailor is seated with arms folded with one restraining belt around the hips and one around the upper chest to prevent any ancillary movement. A webbing strap is secured on the leg immediately above the ankle and connected to a calibrated strain gauge via stud-link chain. The length of the chain is adjusted to ensure that the angle at the knee remains fixed at 125°. The back of the knee is set on the edge of the bench with the back-rest adjusted so that it is tight against the lumbar part of the back. The height of the strain gauge is adjusted according to limb length so as to ensure a horizontal pull from the ankle.

Figure 7.1 Isometric leg testing apparatus.



The sailors are required to apply a maximal force for a period of 3-4 seconds through the leg in an attempt to extend it to full extension. The isometric force applied to the strain gauge is recorded via a PowerLab 400 dual channel receiver (McLab, ADI Instruments Ltd.) connected to a desk top computer. The sailors perform 3 maximal contractions on each leg with the peak force in Newtons being recorded. Figure 7.2 below shows a typical force production curve for a maximal isometric contraction of the quadriceps muscle.

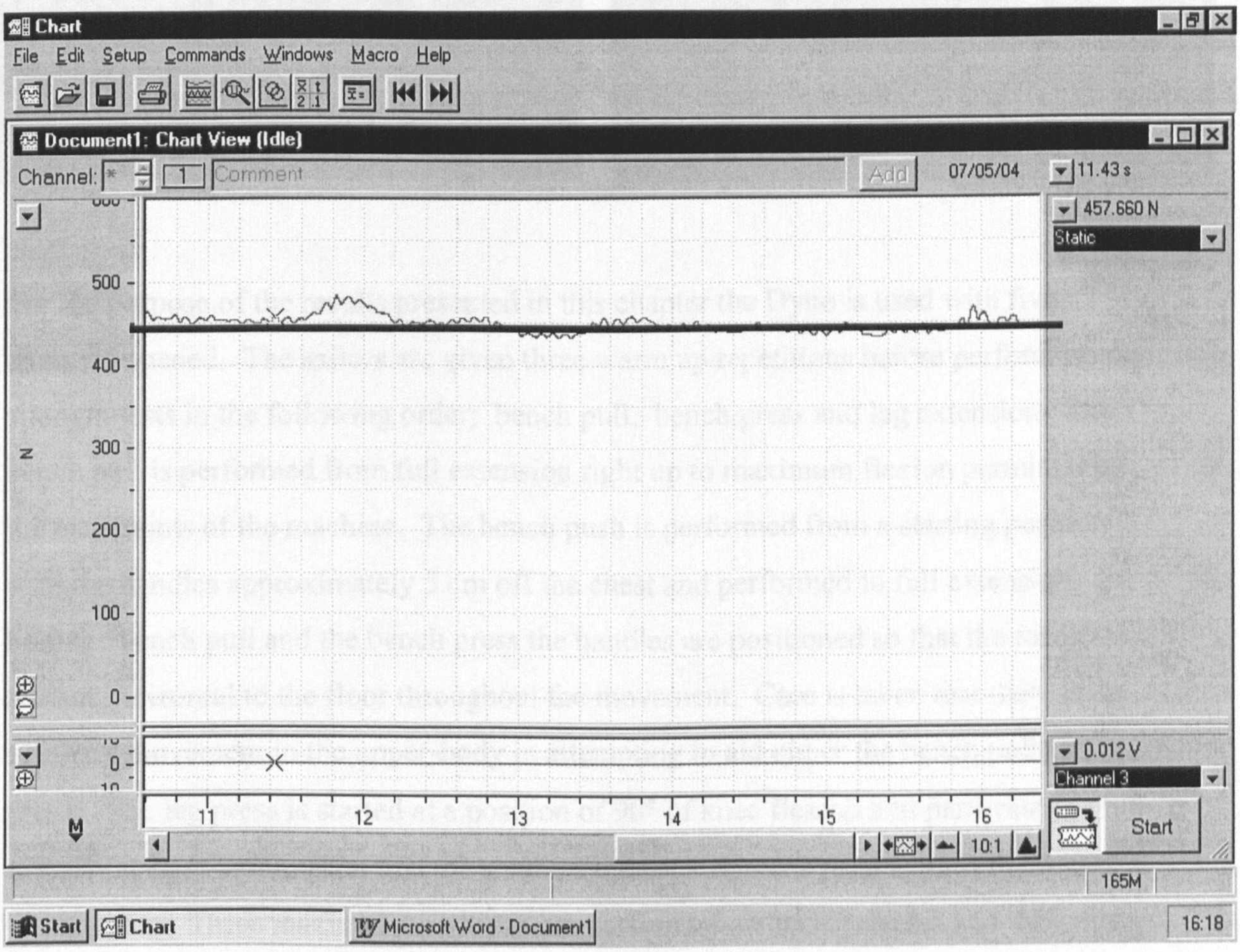
Figure 7.2 Force production curve for maximal isometric leg contraction on hiking chair (peak force approximately 985 Newtons).



7.2.3. Isometric leg endurance.

Following the maximal isometric leg extensions the sailors are given an appropriate rest and allowed to stretch before performing the isometric leg endurance test. This test examines the sailors' stronger leg only as established from the results of the maximal isometric strength test. A muscular contraction of the leg extensor muscles is required to hold a set force output for as long as possible. The force is held till volitional exhaustion. Both verbal and visual feedback is given to ensure the correct force output is maintained throughout this test. The visual feedback is the most important and is supplied by placing a line through the correct position on the force axes on the computer screen depicting the force production curve (see figure 7.3 below). The sailors are required to produce the appropriate muscular contraction to keep the force production curve on this horizontal line for as long as possible. The mean static forces that are required to be held vary between classes with the Finn sailors holding 666 N, Laser sailors 600 N and the Europe sailors 450 N. These forces were established from pilot work during the early part of 2000 with the aim of getting an approximate force that represented 65% of the subjects maximal voluntary contraction (MVC). The test was designed to last approximately 60 seconds in duration before volitional fatigue.

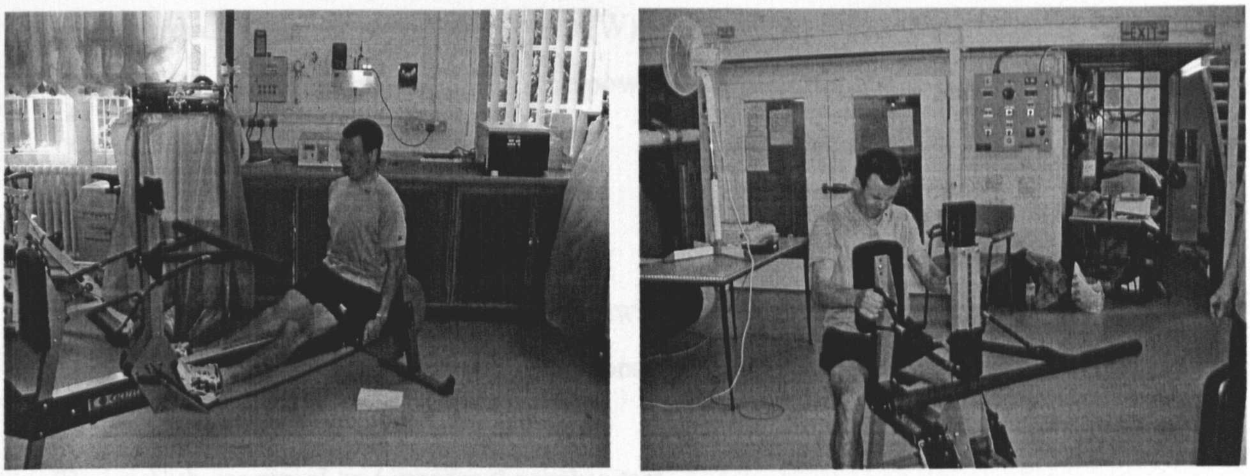
Figure 7.3. Visual feed back on the isometric leg endurance test – Europeailor undergoing hiking endurance test with a force production of approximately 450 N.



7.2.4 Dyno strength testing.

The Dyno machine (Concept 2) is used for both upper-body and lower-body strength testing and works on the same principle as the Concept 2 rowing ergometer. The apparatus is commercially available from Concept 2 (http://www.concept2.co.uk/dyno/) and is shown in figure 7.4.

Figure 7.4 Dyno machine being used for the seated leg extension and the seated bench pull.



For the purpose of the results presented in this chapter the Dyno is used with five dampers opened. The sailors are given three warm up repetitions before performing the strength tests in the following order: bench pull, bench press and leg extension. The bench pull is performed from full extension right up to maximum flexion permitted by the constraints of the machine. The bench push is performed from a starting position with the handles approximately 5 cm off the chest and performed to full extension. For both the bench pull and the bench press the handles are positioned so that the forearms remain horizontal to the floor throughout the movement. Care is taken that there is no ancillary movement in the upper-body in attempting to aid either the bench pull or press. The leg press is started at a position of 90° of knee flexion and performed to full extension, care being taken that the small of the back remains tight against the seat of the machine. Three maximal repetitions are performed on each exercise and their mean is reported in the data of this thesis. Data are reported in kilograms and are also scaled against body weight to give a performance index. The performance index is the mean result in kg divided by body weight, with body weight being raised to the power of two-thirds (Nevill et al., 1992).

7.2.5 Anaerobic power test.

This test consists of a flat-out 40 second sprint and is performed on the Concept 2 rowing ergometer. The drag-factor is set at 145 and the readout set on a 40 second count down with a stationary start. The sailors are instructed to perform maximally and not to pace themselves. Peak power, the time to reach peak power (normally between 8.5 and 12 seconds), and the average power maintained throughout the 40 second sprint are recorded. Data are reported in watts (W) and again a performance index is calculated by raising body weight to the power of two-thirds and dividing it by the power outputs recorded.

7.2.6 The sequence of testing.

The sequence of exercise testing is as follows:

1) Health history questionnaire and consent forms
2) Anthropometric data
3) Sub-maximal and maximal aerobic test

   15 minute break
4) Dyno strength tests
5) 40 second maximal sprint on Concept 2 rowing ergometer

   15 minute break
6) Maximal isometric strength testing

   5 minute break and leg stretching
7) Hiking endurance test

7.2.7 Statistical Analysis.

Means and standard deviations are reported for each physiological assessment. Student t-tests have been used to compare the means between the Laser, Finn and Europe classes. Levels of significance were set at $p<0.05$.

7.3. Results.

All raw data relevant to this chapter are shown in appendix B of the second volume of this thesis.

The mode of exercise testing for the aerobic tests was chosen by the sailors, with their being encouraged to use the mode of exercise that formed the largest part of their off-water training programme. In this way the heart rate prescriptions outlined in their training programmes were more specific and relevant for training purposes. The details of the mode of exercise chosen for the three Olympic single-handed classes are shown below in table 7.1.

Table 7.1. Mode of exercise testing for aerobic fitness tests listed by class.

	Laser sailors (n=12)	Finn sailors (n=8)	Europe sailors (n=10)
SRM cycle ergo	**11**	**6**	**4**
Rowing ergo	**0**	**2**	**3**
Treadmill	**1**	**0**	**3**

Only one out of twenty sailors chose to run during the aerobic fitness assessment. This is possibly due to the high impact nature of running and the fact that the knees are a potential vulnerable area for any dinghy sailor (Bojsen et al., 2003). Indeed, running is not a recommended way to perform aerobic training (BASES, 1997), and does not feature in many training programmes.

Table 7.2 details the physiological profiles for both Laser (n=12) and Finn sailors (n=8). Laser sailors had significantly greater ($p<0.05$) oxygen uptakes at both OBLA and at $\dot{V}O_{2max}$ when expressed relative to body weight ($ml.kg^{-1}.min^{-1}$) but not at absolute values ($l.min^{-1}$). There is a similar trend for power outputs with Laser sailors having significantly greater ($p<0.05$) power outputs at both OBLA and exhaustion when expressed relative to body weight ($watts.kg^{-1}$) but not significantly different in absolute values. Finn sailors had significantly higher ($p<0.05$) values for maximal isometric leg strength, isometric leg endurance, Dyno seated pull and push, max anaerobic power and average 40 second anaerobic power. These values were not expressed relative to body weight.

Table 7.2 Mean (± s.d.) physiological data for male Laser and male Finn class sailors who were members of the elite British Olympic sailing squad 2003-2004.

Variable	Laser sailors (N=12)	Finn sailors (N=8)
$\dot{V}O_2$ @ OBLA ($l.min^{-1}$)	3.79 ± 0.32	3.87 ± 0.51
$\dot{V}O_2$ @ OBLA ($ml.kg^{-1}.min^{-1}$)	47.4 ± 3.9	*40.3 ± 5.3
Power @ OBLA (watts)	290.0 ± 29.6	261.8 ± 47.0
Power @ OBLA ($watts.kg^{-1}$)	3.63 ± 0.37	*2.73 ± 0.49
$\dot{V}O_{2max}$ ($l.min^{-1}$)	4.71 ± 0.48	4.90 ± 0.59
$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)	59.0 ± 5.7	*51.1 ± 5.2
Heart rate max ($b.min^{-1}$)	191.1 ± 4.9	199.0 ± 6.3
Max aerobic power (watts)	405.9 ± 55.4	396.0 ± 46.9
Max aerobic power ($watts.kg^{-1}$)	5.08 ± 0.67	*4.12 ± 0.38
Max isometric leg strength (Newton)	857.3 ± 110.5	*1046.8 ± 140.3
+Isometric leg endurance time (s)	46.7 ± 16.3 @ 600 N	*65.3 ± 27.0 @ 666 N
Leg endurance force / mean max isometric strength	70.0%	63.6%
Dyno seated pull (kg)	88.2 ± 7.8	*103.1 ± 8.6
Dyno seated bench push (kg)	80.2 ± 9.8	*94.8 ± 12.2
Dyno leg extension (kg)	196.1 ± 33.2	220.4 ± 32.8
Max anaerobic power (watts)	625.3 ± 106.3	*776.6 ± 93.3
Mean anaerobic power (watts)	535.5 ± 62.8	*640.0 ± 58.8

+Leg endurance conducted at 666 Newtons for Finn and 600 Newtons for Laser sailors

* Significantly different between Laser and Finn classes ($p<0.05$)

Table 7.3 depicts the physiological profiles for Europe sailors (n=10). In comparison to Laser sailors the Europe sailors had significantly lower ($p<0.05$) values for all variables measured, including those expressed relative to body weight. In comparison to Finn sailors, the Europe sailors also recorded significantly lower ($p<0.05$) values for all variables except oxygen uptake and power output at OBLA when expressed relative to body weight and for isometric leg endurance time.

Table 7.3 Mean (± s.d.) physiological data for female Europe class sailors who were members of the elite British Olympic sailing squad 2003-2004.

Variable	Europe sailors (N=10)
$\dot{V}O_2$ @ OBLA ($l.min^{-1}$)	#* 2.54 ± 0.21
$\dot{V}O_2$ @ OBLA ($ml.kg^{-1}.min^{-1}$)	*38.2 ± 3.1
Power @ OBLA (watts)	#*178.2 ± 15.3
Power @ OBLA ($watts.kg^{-1}$)	*2.68 ± 0.23
$\dot{V}O_{2max}$ ($l.min^{-1}$)	#*3.00 ± 0.19
$\dot{V}O_{2max}$ ($ml.kg^{-1}.min^{-1}$)	*45.1 ± 2.9
Heart rate max ($b.min^{-1}$)	197.5 ± 11.8
Max aerobic power (watts)	#*256.2 ± 27.0
Max isometric leg strength (Newton)	#*679.3 ± 88.4
+Isometric leg endurance time (s)	#49.3 ± 11.9 @ 450
Leg endurance force / mean max isometric strength	66.2%
Dyno seated pull (kg)	#*57.5 ± 7.7
Dyno seated bench push (kg)	#*55.2 ± 9.0
Dyno leg extension (kg)	#*151.0 ± 32.4
Max anaerobic power (watts)	#*409.5 ± 60.3
Mean anaerobic power (watts)	#*348.1 ± 46.1

+Leg endurance conducted at 450 Newtons for Europe sailors

*significantly different between Europe and Laser classes ($p<0.05$)

#significantly different between Europe and Finn classes ($p<0.05$)

7.4 Discussion.

The physiological testing protocols conducted on the British single-handed sailing squads are similar to other recommended protocols (Blackburn et al., 2000; Bojsen et al., 2003) in that they included anthropometric measures (reported in chapter 3 of this thesis), measures of aerobic fitness, muscular strength and muscular endurance; with the latter specifically looking at the major muscles involved in hiking, namely the quadriceps. In agreement with the BASES physiological testing guidelines (BASES, 1997) – specific considerations for the assessment of sailors – the majority of the aerobic testing sessions (86%) were conducted on cycle or rowing ergometers with only 14% of assessments conducted on a treadmill. This is in contrast to the work of Bojsen et al. (2003), where all the Danish sailors performed a maximal oxygen uptake test on the treadmill; but is in agreement with Blackburn (2000) who advocates aerobic testing on a cycle ergometer.

7.4.1 Aerobic protocols and profiles.

Blackburn (2000) outlines an aerobic test which establishes power output on a cycle ergometer at a point equivalent to 75% of maximal heart rate and uses this as an aerobic performance measure. This power output is corrected against temperature and atmospheric pressure and is divided by body weight to give an aerobic power measurement in watts.kg^{-1}. Blackburn presents mean figures and expected ranges for each Olympic sailing class. Possibly the biggest flaw with this aerobic testing is that the maximal heart rate is estimated from the sailors age (max heart rates in beats.min^{-1} = 220 – age in years). Bojsen et al., (2003) conducted treadmill based $\dot{V}O_{2max}$ tests on elite Danish sailors. The testing protocol was similar to that recommended by the BASES (1997), for the assessment of maximal aerobic power. They utilised a treadmill at a set speed and increased the gradient at a rate of 2% every 90 seconds until volitional exhaustion. The treadmill speed was varied according to the fitness levels so that all tests lasted between 4-6 minutes, running speed being approximately 14-16 km.h^{-1}. Gas collection was continuous throughout with the maximal oxygen consumptions being reported in both absolute and relative terms and also being scaled to two-thirds body weight. Aerobic testing of New Zealand sailors consisted of a 12 minute self paced time trial on a Concept 2 rowing ergometer where total distance covered and the time to reach 2,500 m were the aerobic performance measures (Legg et al., 1997). They do not report any oxygen uptake data. Blackburn (1994) conducted maximal aerobic testing on 10 Australian Laser sailors on a cycle ergometer with 25 watt increments every 60 seconds until volitional exhaustion (approximately 10-14 minute test duration). Blackburn reported mean absolute maximal oxygen uptake values.

The maximal oxygen uptakes reported in this chapter for elite Laser sailors from the 2003-2004 British Olympic sailing squad were 59.0 ± 5.7 ml.kg^{-1}.min^{-1} (n=12). These values are slightly higher than those reported in Chapter 6 for Laser sailors (55.7 ± 4.0 ml.kg^{-1}.min^{-1}). Other maximal oxygen uptake values for Laser sailors have been reported: 62.3 ± 8.2 ml.kg^{-1}min.$^{-1}$ (Blackburn, 1994); 52.0 ± 6.0 ml.kg^{-1}min^{-1} (Vogiatzis et al., 1995a); 58.3 ± 4.2 ml.kg^{-1}min^{-1} (Bojsen et al., 2003); 58.2 ± 4.7 ml.kg^{-1}min^{-1} (Castagna and Brisswalter, 2004). All values are quite similar with the exception of those reported by Vogiatzis et al., (1995a) which are considerably lower. The values reported by Bojsen et al., (2003) and Castagna and Brisswalter., (2004) are for elite Danish and French Laser sailors and are the most relevant to modern-day Olympic Laser sailors. These values are very similar to those reported here for elite British Laser sailors. It would seem that elite Laser sailors require a moderate aerobic base where maximal oxygen uptakes are comparable to those typically reported for athletes from most team sports (Rusko et al., 1978; Bergeron et al., 1991; Resina et al., 1991; and Bangsbo et al., 1993), but are approximately 20% less than those reported for elite endurance athletes from sports such as cycling and running (Åstrand and Rodahl, 1986). The moderate levels of aerobic fitness measured for elite Laser sailors would suggest that aerobic training was warranted in order to facilitate muscular recovery, to boost cardiac endurance and to aid the dynamic activities involved in elite dinghy sailing.

There is little in the literature reporting aerobic fitness levels for Finn sailors. This chapter has reported similar absolute values for all aerobic fitness measures (oxygen uptakes and power outputs at max and OBLA) between the Laser and Finn sailors. However, absolute values are misleading due to the large differences in body weights with Finn sailors being approximately 16 kg heavier at 95.9 ± 4.1 kg compared to Laser sailors at 79.9 ± 4.2 kg. Relative to body weight the aerobic fitness levels of Finn sailors were significantly lower ($p<0.05$) than those reported for Laser sailors with oxygen uptakes of 51.1 ± 5.2 $ml.kg^{-1}min.^{-1}$ and 40.3 ± 5.3 $ml.kg^{-1}min.^{-1}$ at $\dot{V}O_{2max}$ and OBLA, respectively. This compares to 59.0 ± 5.7 $ml.kg^{-1}min.^{-1}$ and 47.4 ± 3.9 $ml.kg^{-1}min.^{-1}$ for Laser sailors. Bojsen et al., (2003) reported $\dot{V}O_{2max}$ values for Finn sailors (n=4) of 63.3 ± 2.4 $ml.kg^{-1}min.^{-1}$ for sailors tested during 1991-1995. They also report values for heavy hikers (Star and Finn sailors combined, n=5) for fitness tests conducted during 2002 at 47.6 ± 3.5 $ml.kg^{-1}min.^{-1}$. It is difficult to know why there is such a difference in the two sets of values reported by Bojsen et al., (2003). It could either be due to the declining levels of aerobic fitness with Danish Finn sailors between the two reported periods 1991-1995 and 2002. Alternatively, it could be due to the 2002 data including a mix of Star and Finn sailors and the less fit Star crews lowering the overall means. Interestingly, during the two time periods weight jackets have been banned from Finn sailing, so Finn sailors have generally increased body weight and this could have had some negative effect on relative oxygen uptakes, especially if this weight gain has primarily been achieved by increasing body fat.

What is clear from the data reported in this thesis is that Finn sailors are considerably less aerobically fit than Laser sailors. This difference is also evident in the work conducted by Legg et al., (1997) and agrees with the suggestions made by Blackburn (2000). Blackburn (2000) detailed mean values for aerobic cycling power relative to body weight at 75% max heart rate; Finn sailors (n=2) being 2.52 $watts.kg^{-1}$ and Laser sailors (n=34) being 3.11 $watts.kg^{-1}$. One performance measure of aerobic fitness used in the Legg et al., (1997) study was the time to row 2,500 m on a self paced time trial on a rowing ergometer. Times between Finn (n=3) and Laser (n=6) sailors were similar at 545 ± 10 seconds and 561 ± 19 seconds, respectively. Given that Finn sailors were approximately 9.5 kg heavier it is likely that if the data could be corrected to eliminate body weight effect then the Laser sailors would be shown to be considerably fitter. Unfortunately, Legg et al., (1997) did not collect expired gas so no oxygen uptake data are available. Considering the findings of Chapter 4 of this thesis where on-water measures for both heart rates (% max) and blood lactates were higher for Finn sailing compared to those recorded in similar conditions for Laser sailing, it is surprising that there is the difference in aerobic fitness levels between the two groups. It may be that the Finn sailors highlight weight gain as being crucial to sailing performance and as a consequence aerobic fitness decreases. This is particularly the case with the sailors progressing from Laser to Finn and the extra weight gain of approximately 16 kg that is required. Interestingly body fats reported in chapter 3 are much higher for Finn sailors (18.4 ± 3.7 %) than for Laser sailors (13.0 ± 2.3 %) suggesting that more importance is put on weight gain in the Finn possibly at the expense of aerobic fitness. Also Laser sailors commonly conduct considerable aerobic training in order to keep body weight down to the 80 kg mark which is reflected in the low body fat percentages.

The case study below depicts the longitudinal physiological profile of an elite Laser sailor transferring to the Finn class after the 1996-2000 Olympic cycle. The sailor concerned has reached top world rankings in both classes. Probably the most marked changes are the increases in body weight and body fat percentage and the decreases in oxygen uptakes relative to body weight. The decrease in oxygen uptake probably suggests that aerobic fitness is not such an important factor for the Finn sailor where strength and body weight are possibly more influential in determining performance.

Table 7.4 Case study: Elite Laser sailor transferring to Finn Class:

	Test 18 (Finn):	Test 15 (Finn)	Test 14 (Laser)
Cycling OBLA test:	**March 04**	**April 02**	**July 00**
Power at OBLA:	250.8 watts	238.3 watts	280.0 watts
Power/weight ratio:	2.64 watts/kg	2.55 watts/kg	3.46 watts/kg
VO_2 at OBLA:	40.2 $ml.kg^{-1}min.^{-1}$	38.4 $ml.kg^{-1}min.^{-1}$	48.3 $ml.kg^{-1}min.^{-1}$
OBLA heart rate:	163 b/min	158 b/min	164 b/min
RER value:	0.97 – 1.15	0.86 – 1.06	0.82 – 1.01
Body Weight:	95.0 kg	93.6 kg	80.4 kg
Cycling VO_{2max} test:	**March 04**	**April 02**	**July 00**
VO_2 max:	43.9 $ml.kg^{-1}min.^{-1}$	45.7 $ml.kg^{-1}min.^{-1}$	58.7 $ml.kg^{-1}min.^{-1}$
Max Power:	329.7 watts	345.1 watts	421.2 watts
Max power/weight:	3.47 w/kg	3.69 w/kg	5.24 watts/kg
Max heart rate:	186 b/min	184 b/min	194 b/min
Max blood lactate:	8.78 mmol	9.74 mmol	7.90 mmol
VO_2 OBLA/VO_2 max:	91.6 %	82.3 %	82.3%
Dyno Strength testing:	**March 04**	**April 02**	**July 00**
Bench pull:	110 kg	82 kg	******
Bench push:	106 kg	76 kg	******
Leg push:	249 kg	181 kg	******
Isometric leg strength (quadriceps):			
	March 04	**April 02**	**July 00**
Left leg (125°):	1102 Newtons	858 Newtons	884 Newtons
Right leg (125°):	1059 Newtons	815 Newtons	822 Newtons
Average:	**1081 Newtons**	**826 Newtons**	**853 Newtons**
Test 5: Leg Endurance at 666 Newtons (*Finn) or 600 Newtons (⁺Laser):			
	***March 04**	***April 02**	**⁺July 00**
Time to fatigue:	85.3 seconds	47.7 seconds	51.1 seconds
Mean force:	655 Newtons	645 Newtons	588 Newtons
Body Composition	**March 04**	**April 02**	**July 00**
Body fat:	15.6 %	17.5 %	10.0 %
Body Mass Index:	27.8	27.9	24.0

Height: 1.83 m. Fitness tested 18 times between November 1993 (17.5 years of age) and March 2004 (27.1 years of age). Commenced Laser sailing 1992, started Finn sailing March 2002.

In a similar fashion to Finn sailors, measures of aerobic fitness for elite Europe sailors are scarce in the literature. Bojsen et al., (2003) is the only paper to report $\dot{V}O_{2max}$ values for Europe sailors. In two periods covering 1991-1995 and 2002 they have reported values of 51.7 ± 5.3 $ml.kg^{-1}min.^{-1}$ (n=4) and 47.3 ± 4.9 $ml.kg^{-1}min.^{-1}$ (n=6) for maximal oxygen uptakes for elite Danish Europe sailors. This compares to values of 45.1 ± 2.9 $ml.kg^{-1}min.^{-1}$ (n=10) reported in this chapter for elite British Europe sailors during 2003-2004. No other papers have reported maximal oxygen uptakes for Europe sailors but Larsson et al., (1996) have reported mean values for elite female Danish sailors for three Olympic classes of Europe, 470 and windsurfer. A mean $\dot{V}O_{2max}$ of

50.1 ± 1.4 $ml.kg^{-1}min^{-1}$ was reported with a range of 46-55 $ml.kg^{-1}min^{-1}$. They do not split the data into separate classes, presumably because the sample size is small with only six subjects in total. What is clear is that the values presented in this chapter for Europe sailors forming the 2003-2004 British Olympic squad are slightly lower than other values reported.

7.4.2 Isometric leg strength, protocols and profiles.

It is difficult to compare the results for the maximal isometric knee extensor strength or the isometric leg endurance reported in this chapter to those from previous studies due to the unique nature of these tests as described in section 7.2.2 and 7.2.3. What is clear is that previous researchers have in their own ways tried to quantify the strength of the quadriceps in, or near to, the correct hiking position (Wright et al., 1976; Blackburn, 1994; Larsson et al., 1996; Aagaard et al., 1998; Blackburn, 2000; and Bojsen et al., 2003). All the previous research is in agreement that the strength of the quadriceps is an important element in determining the ability to hike for prolonged periods (Wright et al., 1976; Plyley et al., 1985; Shephard, 1990; Spurway, 1993 and Vogiatzis et al., 1996). Additionally, it is important for the applied sports scientist involved in exercise prescription to have a reliable measure of both the strength and endurance of the quadriceps to ascertain the effectiveness of the training programme in increasing hiking duration. Some of the tests of hiking endurance have been relatively crude. Blackburn (2000) used a bucket looped over the sailors feet and added weights at regular intervals until fatigue, with time being the performance measure. Some have favoured isokinetic tests at various angular velocities using apparatus such as the Kin-Com and Cybex dynamoters (Blackburn, 1994; Aagaard et al., 1997; Aagaard et al., 1998; and Bojsen et al;, 2003). In a similar format to this study Larsson et al., (1996) used strain gauge force transducers to record loads exerted by the quadriceps.

There are probably two major factors to consider when performing strength and endurance tests on the quadriceps. Firstly, should the muscular contractions be isometric or isokinetic in nature? If isokinetic, at what angular velocities should the testing be conducted? Secondly, at what joint angles should the knee and hips (and possibly ankles) be positioned and how accurately should these angles be maintained during the test? The angle at the knee joint is important for any isometric contraction as this will invariably have an effect on the values obtained. Hip angle is also important, particularly as the rectus-femoris muscle attaches on the anterior inferior iliac spine and is involved in hip extension as well as knee extension. Being able to replicate the same protocol in a test/retest situation also suggests that knee and hip angles should be standardised.

Mackie et al., (1999) have measured ankle, knee and hip angles for the three Olympic single-handed dinghy classes in varying wind conditions, although their data are very limited in subject numbers. Knee angles in light (4 to 6 $m.s^{-1}$) and moderate winds (6 to 8 $m.s^{-1}$) were 155 ± 6° and 138 ± 8° for Europes (n=3), 149 ± 3° and 147 ± 5° for Lasers (n=3) and 120 ± 13° and 125 ± 11° for Finns (n=2) [for clarification purposes 180° is full extension]. With the exception of the Europe sailors where the legs became more flexed, by approximately 17° with increasing winds, there was little change in knee angle with either Laser or Finn sailors with increasing wind speeds. The increase in flexion around the knee joint in Europe sailors with increasing winds is difficult to explain but may be due to fatigue due to prolonged hiking that would be taking place. There seems to be more variance in the hip angle between different wind conditions. Mackie et al., (1999) have reported hip angles in light (4 to 6 $m.s^{-1}$) and moderate winds (6 to 8 $m.s^{-1}$) of 114 ± 11° and 104 ± 8° for Europes (n=3), 113 ± 12° and 125 ± 10° for Lasers (n=3) and 101 ± 13° and 112 ± 9° for Finns (n=2). Again it is difficult to explain the additional flexion around the hip joint with Europe sailors in the stronger wind condition, as the increased flexion at both knee and hip joints would reduce righting moment. Calculating the mean knee and hip angles across the three classes gives values of 139° at the knee and 112° at the hip and as such any strength or muscular endurance work in the laboratory should be based close to these angles. However, given the large differences in the knee joint angles between the three classes there is a good case for dealing with each class separately and having differing joint angles depending on the class of sailor being evaluated.

The present testing protocols for leg strength and endurance used on the single handed sailors forming the British Olympic squads are isometric in nature and have a knee angle fixed at 125° with the hip being fixed at 115° of flexion. Restraining straps are used to maintain these angles during testing (see figure 7.1). However, evaluating knee extensor strength the angle of the hip joint is important primarily due to the origin of the Rectus Femoris muscle as stated earlier. Unlike the Vastus Medialis, Vastus Lateralis and the Vastus Intermedius which are only involved in movement around the knee joint the Rectus Femoris is also involved in hip flexion. The protocols described have been in use since March 2000. It is felt that isometric testing where the knee angle is fixed, more accurately reflects the movement around that joint during sailing. Mackie et al., (1999) concurs with earlier work by De Vito et al., (1993) highlighting that the angle around the knee joint does not change very much during hiking. This can also be reflected in the low standard deviations reported by Mackie et al., (1999) for the three single-handed classes [these may also be partially expected due to the small numbers of subjects].

De Vito et al., (1993) established that the knee joint varies by less than ±5° during hiking from a starting point of approximately 155°; and the hip joint varies slightly more by approximately ±15° from a starting position of 113°. Both the knee and hip angles decrease over time reflecting increased flexion as fatigue set in. The data reported by De Vito et al., (1993) need to taken with caution as it comes from a laboratory simulation and is not detailing what happens on the water. An isokinetic contraction around the knee joint performed over the whole range of movement from full flexion to full extension, at varying speeds, does not reflect what happens in the boat (De Vito et al., 1993; Mackie et al., 1999). Other researchers have used varying knee angles for isometric contractions: 129° (Blackburn, 1994); 135° (Larsson et al., 1996); 115° (Aagaard et al., 1998); and 110° (Bojsen et al., 2003). The knee flexion of 129° [and hip angle of 104°] used by Blackburn (1994) was based on mean body position during hiking, observed from filming with subsequent biomechanical analysis. The difference in knee and hip angles reported by Blackburn (1994) compared to that established by Mackie et al., (1999) for elite Laser sailors possibly reflects the change in hiking posture in the intervening 5 years. A major change that took place between 1994 and 1999 was the banning of weighted jackets from dinghy racing [originally a 4 kg weight jacket would have been worn in the Laser class] and possibly as a consequence the sailor now has to hike in a more extended position to exert a similar righting moment. Blackburn's (1994) data are at odds with that reported by De Vito et al., (1993) where the latter reports much straighter legs with a starting knee angle of approximately 155°. This more extended position has also been reported by Cockerill (2000) and is considered less prone to injury, especially on the knees. The present knee angle of 125° used for testing British sailors is possibly too flexed and an angle approaching 150° would now be more realistic for testing Laser and Europe sailors whereas as 125° looks accurate for Finn sailors. There is a strong case for changing the testing protocols to suit individual classes and enhance the accuracy of the now straighter legged hiking positions being reported. Hip angle set at 115° seems to accurately replicate hip angles measured on the water (Mackie et al., 1999) with the exception of Laser sailors who approach 125° in moderate winds and possibly more in stronger winds, although the latter has not been reported in the literature. The mean hip angle of 104° observed by Blackburn (1994) for elite Laser sailors in moderate winds now seems dated.

The mean values for maximal isometric leg strength for the three single-handed classes were; Europe 679.3 ± 88.4 Newtons, Laser 857.3 ± 110.5 Newtons and Finn 1046.8 ± 140.3 Newtons. The differences between the three classes were statistically significant ($p<0.05$). Maximal isometric leg strength for Europe, Laser and Finn sailors have only been reported once previously in the literature. Mackie et al., (1999) have reported MVC's measured isometrically on a hiking bench at joint angles similar to those recorded during sailing; Europe 544 ± 66 Newtons (n=3); Laser 766 ± 136 Newtons (n=2); and Finn 871 ± 31 Newtons (n=2). These values follow a similar trend to the data reported in this chapter with Finn sailors having greater leg strength followed by Laser and then Europe sailors. However, the values reported by Mackie et al., (1999) are considerably less than the values reported in this chapter; Europe 20% less; Laser 12% less; and Finn 17% less. Caution is needed when making conclusions from the work of Mackie et al., (1999); firstly, the subject size was very small; and secondly, their method was questionable as they mention. Niinimaa et al., (1977) reported mean values of 1044 ± 242 Newtons for male members of Ontario sailing squad, unfortunately the data were not split between the different sailing classes. These values were considerably higher than their counterparts from rowing (741 ± 208 Nm) and swimming (720 ± 168 Nm), and supported evidence for superior knee extensor strength for sailors.

The variance in leg strength reported in this chapter between the sailing classes is not surprising considering the difference in body weights; Europe 66.5 ± 3.8 kg, Laser 79.9 ± 4.2 kg and Finn 95.9 ± 4.1 kg. If maximal leg strengths are scaled against body weight raised to the power of $^2/_3$ (Nevill et al., 1992), the values are: Europe 40.8 Newtons.kg^{-67}, Laser 45.6 Newtons.kg^{-67} and Finn 49.2 Newtons.kg^{-67}. This suggests that the results, even when corrected for body weight, follow a similar trend with Finn sailors having the greater knee extensor strength followed by Laser and then Europe sailors. The differences in knee extensor strength between male and female sailors are well documented in the literature (Aagaard et al., 1997; Aagaard et al., 1998; Larsson et a;., 1996; Mackie et al., 1999), but there is only limited literature detailing the differences between Laser and Finn (Mackie et al., 1999). Mackie and Legg (1999) have suggested that such differences are accountable by the differences in body weight when they reported on-water data for two Laser sailors of differing body weights. The findings of this present study do not concur with that, even when strength values have been scaled against body weight the Finn sailors still have significantly higher values for knee extensor strength.

From table 7.4 above, it is interesting to note that when this highly successful Laser sailor transferred from Laser to Finn sailing, despite body weight increasing by approximately 13 kg, maximal isometric leg strength decreased. Again, this would possibly suggest that leg strength is not simply related to body weight but may instead be linked to specific adaptations induced by sailing itself (Aagaard et al., 1998). In this case study the specific adaptation induced by Finn sailing had not yet been achieved since the sailor had been Finn sailing for less than one month. Almost two years later (March 2004) the leg strength had increased by approximately 30%, this increase may be due to specific weight training on the lower body, adaptation to sailing a Finn or probably a combination of both.

Mackie and Legg (1999) have estimated that during hiking, Laser sailors developed sustained forces of up to 647 Newtons, with occasional jerks to levels as high as 843 Newtons. The highest values were established whilst sailing upwind as opposed to downwind but not necessarily in the strongest wind conditions. Their data report bilateral values with both legs acting on the toe strap in a normal hiking set up, whereas the values reported in this chapter are for unilateral measures where only one leg is acting. Thus, if their values are halved that will give some idea of the force being exerted by each leg

(~323.5 Newtons). Dividing this by the mean MVC values reported in this chapter for Laser sailors (323.5/857.3) gives an estimation of the percentage of MVC required to hike and equates to 37.7% MVC. This should be taken as a crude indicator for numerous reasons: different subjects are being used between two independent studies; one study is measuring bilateral values on the water and the other is recording unilateral values from laboratory based work; the work of Mackie and Legg (1999) is limited in subject numbers and includes data from only one elite Laser sailor weighing 80 kg and one club standard Laser sailor weighing 94 kg; their study did not include any measures from the elite sailor in strong winds and also they did not include any MVC values for the elite sailor, so it is impossible to evaluate the percent of MVC that was being achieved. Mackie and Legg (1999) suggest that the club sailor averaged 39%, 59% and 44% of MVC in light, moderate and strong winds. These values seem elevated and are higher than our estimate (37.4%) and are also greater than estimates advocated by Vogiatzis et al., (1993), which were 38.4 ± 3.5% MVC. In a separate study Mackie et al., (1999) have suggested that peak forces recorded in the toe strap exceeded 100% MVC at times (109% MVC being the highest, recorded for Europe sailors). They explained this as a result of the additional loading when the boat reached the top of the waves in choppy conditions, which occurred approximately every 2-3 seconds. However, there seem to be some questions raised about the method of ascertaining the MVC's where:

> *"the sailors were concerned that they may be injured if they were required to exert maximal efforts due to the apparent lack of robustness of the bench. Thus, in order to obtain a 'best estimate' of hiking and mainsheeting MVC's, it was necessary to establish the relationship between MVC's on the portable hiking bench and the MVC obtained using a Biodex dynamometer seat and the original load cells in a separate group of subjects in a lab setting....." (Mackie and Legg, 1999, p385).*

Thus, the MVC's were not achieved by the sailors but have been adjusted by 47% based on a 'correction factor'. The values for %MVC reported by Mackie and Legg (1999) must be treated with some scepticism, as indeed they suggest themselves, the accuracy of these estimates are not known and should only be used as indicators.

Aagaard et al., (1998) have also reported higher peak isometric quadriceps strength in elite dinghy sailors compared to matched controls but they have also suggested that the difference is less pronounced than the corresponding difference in peak eccentric quadriceps strength. They went on to suggest that this may well be an adaptation induced by sailing itself and that hiking performance was related to maximal eccentric knee extensor strength. Aagaard et al., (1998) conclude by suggesting that, in contrast to Shephard (1990), both isometric and dynamic (maximal eccentric) knee extensor strength are important for optimal hiking performance. Eccentric knee extensor strength is important as the sailor frequently incorporates small amplitude dynamic movements into hiking because there is a need to constantly compensate for motions caused by the waves and wind and a totally static posture would quickly lead to fatigue due to the occlusion of blood flow associated with such contractions (Petrofsky and Phillips, 1986). Based on the findings of Aagaard et al., (1998) there seems a logical case for measuring eccentric knee extensor strength in elite hiking sailors as well the isometric strength, with the former possibly being more related to hiking performance.

7.4.3 Isometric leg endurance, protocols and profiles.

In comparison to the number of studies that report maximal knee extensor strength for dinghy sailors there are less detailing muscular endurance data for the same muscles. It is felt that, because hiking is a prolonged activity, an endurance measure of the knee extensor strength would be appropriate. Additionally, it is crucial that a strength and conditioning programme aimed primarily at increasing muscular strength of the quadriceps should also have some effect on the muscular endurance of that muscle and thus increase hiking duration. Without an endurance test it would not be known whether increased strength leads to an increase in hiking duration. It is logical that a high MVC for the knee extensor strength would be beneficial as this would allow the quadriceps to work at a lower percentage of that MVC and still exert the same external loading and thus permit the sailor to hike for longer before fatigue sets in. The protocol described for leg endurance (see 7.2.3) uses the same apparatus as used for measuring maximal isometric knee extensor strength, the endurance test is performed only on the stronger leg with the knee and hip angles being maintained at 125° and 115°, respectively. The protocol is different to others in that the sailors are required to hold a set force, and not a set % of MVC, until exhaustion. Most other studies have required the subjects to work at a fixed percent of MVC till exhaustion (Niinimaa et al., 1977; Spurway and Burns, 1993; and Larsson et al., 1996;). The leg endurance protocols are based on the following principles: Firstly, sailors in any specific class tend to have fairly homogenous body weights as seen by the low standard deviations [Europe 66.5 ± 3.8 kg (n=10), Laser 79.9 ± 4.2 kg (n=12) and Finn 95.9 ± 4.1 kg (n=8)]. Secondly, given the similar body weights between sailors in the same class it is fairly safe to assume that the external loading whilst hiking would be similar for each sailor within a class. Thirdly, based on these principles it seems inappropriate to conduct an endurance test at a fixed % of MVC as this would not offer any advantage to the sailor who has increased their maximal knee extensor strength through a conditioning programme. Whereas, in a real situation such as on the water, they would be working at a lower % of MVC due to their increased strength. This principle is heavily based on the notion that the external loading remains the same, this has not been measured in this thesis work and is not reported elsewhere in the literature, but is considered a safe assumption if body weight and hiking style do not change.

The endurance testing protocols were introduced into the testing procedures of the British Olympic sailing squads (hiking sailors only) in March 2000. The respective forces that the different classes are required to hold are Europes 450 Newtons, Lasers 600 Newtons and Finns 666 Newtons. These values were established from pilot trails over a period of 6 months. The aim was to establish a force that would on average obtain volitional fatigue after approximately 60 seconds. Mean fatigue times and mean percentages of MVC across the three classes are: Europe 49.3 ± 11.9 seconds and 66.2% MVC, Laser 46.7 ± 16.3 seconds and 70.0% MVC and Finn 65.3 ± 27.0 seconds and 63.6% MVC. Such a static contraction at a relatively high percent of MVC obtains rapid fatigue. Such prolonged isometric testing is not without its difficulties with anterior patella femoral pain being reported, blood pressure reaching excessive levels and some subjects suffering from nasal bleeding, the latter presumably being caused by excessively high systolic blood pressures. The test can be heavily criticised for being totally isometric in nature as this is not an exact replication of what happens on the water. However, the purpose of this test is to have a definite measure of knee extensor endurance that is quick to administer, is sensitive to changes in maximal knee extensor strength and is relevant in some degree to hiking endurance. Table 7.4 details the changing maximal knee extensor strength along with the changes in endurance times for one sailor after changing classes from a Laser to a Finn. This provides support that the test is sensitive to changes in maximal strength advocating the hypothesis that hiking endurance increases when MVC increases provided the external loading remains the same which subsequently results in the work being performed at a lower percent of MVC. This concurs with the work of Spurway and Burns (1993) where they report that increased knee extensor strength over a winter period, without sailing, is directly related to increased hiking performance.

One interesting point to arise from isometric endurance testing of the knee extensor is how rapidly fatigue sets in when the contraction is maintained statically at approximately 65% MVC. The mean %MVC across the three classes was 66.6% and the mean time to fatigue averaged 53.8 seconds. In conversation with the sailors it has been suggested that the test was demanding due to its isometric nature and it was commonly stated that if the test was conducted with both legs performing the hiking that endurance times would increase significantly, even if the working at an increased absolute load that equated to the same percentage of MVC recorded from a maximal contraction from both legs. The main reason being that they felt the majority of the load would be able to be alternated from leg to leg which would probably be sufficient enough to allow some form of recovery during the rested legs 'off' period. This alternated hiking action commonly takes place on the water but is not reported in the scientific literature. The data reported in this chapter concurs with that reported by Wright et al., (1976) where male sailors from various sailing classes maintained an isometric contraction of the knee extensors at 50% and 75% MVC for 117.3 and 45.8 seconds, respectively. These data were collected after completing a 14 week training programme. Larsson et al., (1996) reported significantly higher hiking endurance times for elite hiking sailors when compared to elite non-hiking sailors and non-sailing trained controls. This, they advocated was possibly due to elevated levels of strength in isometric knee extensors, hip flexors and abdominal muscles, although these were not measured. They concluded that endurance capacity in hikers is high in muscles being used during the sport activity, which is in accordance with other sports where a specificity in regard to muscle adaptation has been demonstrated (Saltin, 1987).

7.4.4 General strength measures, protocols and profiles.

In addition to the measures reported above for maximal isometric knee extensor strength the British Olympic sailing squads undergo three measures of general strength on the Concept Dyno® machine. Other researchers have used similar types of devices, such as biokinetic swim benches, to determine such general upper-body strength (Plyley et al., 1985). The three dynamic tests described in this chapter look at maximal concentric contractions involved in knee extension, seated bench pressing and seated bench pulling (see 7.2.4 for details of protocol). Knee extensor strength is clearly important as the quadriceps play an important role in prolonged hiking performance (Niinimaa et al., 1977; Plyley et al., 1985). Sailors spend much time in trimming their sails to optimise the angle of the sail to the wind and this trimming primarily involves muscles of the back and arms. The seated pull on the Concept Dyno is a good measure of the strength involving these muscles and as such should be high in dinghy sailors. The Concept Dyno bench push is principally looking at strength in the chest muscles and these muscles only play a minimal role in sailing performance as upper-body pushing tasks are scarce in dinghy sailing. The three measures provide a good base line value of all-body strength and are useful in determining the effectiveness of strength and conditioning programmes.

The loads in the mainsheet for single handed sailing have been measured by various researchers and they all concur that the greatest forces are generated whilst sailing upwind (Blackburn, 1994; Mackie & Legg, 1999). Blackburn (1994) summarised that in winds of approximately 12 knots the static loadings on the Laser class mainsheet whilst sailing upwind were 98 N with dynamic loadings of up to 549 N when trimming or pumping the sail. Mackie and Legg (1999) have reported mean upwind forces in the mainsheet of 111 N (35% MVC) with peaks of 289 N (90% MVC). There are no data reporting the mainsheet loads for either Europe or Finn sailors.

The results for upper body pulling strength were greater than those for upper-body pushing in each class: Europes 57.5 ± 7.7 kg and 55.2 ± 9.0 kg; Lasers 88.2 ± 7.8 kg and 80.2 ± 9.8 kg ; and Finns 103.1 ± 8.6 kg and 94.8 ± 12.2 kg. These results are to be expected due to the task specific nature involved in upper-body pulling exercises relevant to a dinghy sailor adjusting the mainsheet. Converted to Newtons the values for maximal upper-body pulling strength are 564 ± 76, 865 ± 77 and 1011 ± 84 Newtons for Europe, Laser and Finn sailors, respectively. The differences between the classes are to be expected due to the differences in body weights but they have not been reported elsewhere in the literature with the exception of Mackie et al., (1999). They reported mean values for maximal elbow flexion of 430 ± 97.1 N for Europes (n=3); 535 ± 228 for Lasers (n=3); and 673 ± 35 for Finns (n=2). These values show a similar trend to the values reported in this chapter but are considerably lower than the values reported here [23%, 38% and 57% less for Europe, Laser and Finn, respectively]. The differences are likely to be related to the differences in testing protocols, for example it is not clear whether their data are for single or double armed elbow extension.

In a similar pattern as seen for measurements of isometric leg strength the Finns have recorded the highest values for both upper-body pulling and pushing strength and Laser sailors obtaining higher values than those recorded by Europe sailors. If the values are scaled against body weight raised to the power of $^2/_3$ (Nevill et al., 1992), the results between the Lasers and Finns are not statistically significant ($p>0.05$) but are both still significantly greater ($p<0.05$) than the values reported for Europe sailors. Scaled against body weight the values for bench pull and bench push were: Europes 3.45 ± 0.46 and 3.32 ± 0.54; Lasers 4.68 ± 0.41 and 4.26 ± 0.52; and Finns 4.84 ± 0.40 and 4.45 ± 0.57 (units are per kg body weight$^{0.67}$).

Other researchers have tended to measure upper-body strength and endurance by performing exercises related to body weight such as pull-ups, press-ups and sit-ups (Niinimaa et al., 1977; Plyley et al., 1985; Legg et al., 1997). The latter two researchers are the only ones that have split their results into separate classes. Using pull-ups (chins) as a measure of upper-body pulling strength they report similar trends to those reported here for pulling strength with Finn sailors performing marginally more chins than Laser sailors and Europe sailors performing significantly less. Plyley et al., (1985) and Legg et al., (1997), concur with our data, by also reporting a similar trend between the classes for press-ups, which can be considered a measure of muscular strength/endurance of principally the Pectoralis Major muscle group. Thus, the findings of this chapter seem to concur with other literature to advocate that Finn sailors have additional strength and endurance in the upper-body compared to Laser sailors and both have significantly elevated levels compared to Europe sailors. Upper-body strength, in general, seems to be much lower in female sailors; Plyley et al., (1985) reported a mean number of chins of only 3 (n=4) whereas Legg et al., (1999) established values of 2 and zero for two elite New Zealand Europe sailors. The values presented in this thesis, scaled to body weight, also suggest a big difference between male and female values.

The results for concentric leg extension performed on the Concept Dyno were: Europes 151.0 ± 32.4 kg (1481 ± 318 N); Lasers 196.1 ± 33.2 kg (1934 ± 326 N); and Finns 220.4 ± 32.8 kg (2162 ± 322 N). There are trends here similar to previous presented results with Finn sailors having significantly greater ($p<0.05$) knee extensor strength than both Laser and Europe sailors, and Laser sailors being significantly greater ($p<0.05$) than Europes. Scaled against body weight raised to the power of $^{2}/_{3}$ (Nevill et al., 1992), the results are: Europe 9.07 ± 1.96; Laser 10.42 ± 1.76; Finn 10.36 ± 1.54 (units are kg's per kg body weight$^{0.67}$). In contrast to the results presented for maximal isometric knee extensor strength these results for dynamic knee extensor strength are not significantly different ($p>0.05$) between the Laser and Finn sailors. It is difficult to suggest why this is the case given the differences reported for isometric knee extensor strength. One possibility could be that the dynamic knee extensor strength is more indicative of the strength changes occurring from lower body conditioning programmes that are dynamic in nature, whereas the isometric knee extensor strength is more reflective on specific adaptations from sailing itself.

7.4.5 Trunk strength and endurance.

Abdominal or trunk strength is an important element for the single-handed dinghy sailor as the abdominal muscles are active in hiking, sheeting and pumping the mainsheet, and for stabilising the spine through hours of unsupported sitting (Blackburn, 2000). Tests of trunk strength in the literature are relatively scarce and have been recorded in both isometric and isokinetic contractions on appropriate dynamometers (Aagaard et al., 1998). The majority of the literature details measures of muscular endurance of the abdominal muscles from either crude tests such as the number of sit-ups performed in a given time or slow sit-ups till exhaustion (Niinimaa et al., 1977; Plyley et al., 1985; Legg et al., 1997; Blackburn, 2000) or by performance during functional hiking tests (Spurway and Burns, 1993; Larsson et al., 1996). In the testing protocols outlined in this present chapter there is no mention of any measures of trunk strength or trunk endurance as they do not form any part of the physiological testing protocols of the British sailing squads. This is not an attempt to demean the importance of abdominal strength or endurance. This area is considered to come under the physiotherapy domain where instead of just looking at performance in one simple exercise such as sit-ups, that primarily recruits the rectus abdominus muscle, they are set a core stability programme aimed at training the deeper lumbar spine and trunk muscles. The physiotherapists set functional measures for each sailors core stability rather than counting the number of sit-ups that can be performed in a given time period. The lumbar spine is inherently unstable, meaning that it relies on stability on the muscles that actively support the area. The main core muscles that are targeted are the transversus abdominals, internal obliques, erector spinae and the multifidius muscles.

In contrast to this approach, BASES (1997) and Blackburn (2000) advocate that the number of sit-ups performed at a slow rate (one every 3 seconds by Blackburn 2000, and 25 per minute with a static 10 second hold at the end of every minute by BASES 1997) is a good measure of trunk endurance. In addition to these studies this approach has been widely used in many research papers reporting trunk endurance for dinghy sailors (Niinimaa et al., 1977; Plyley et al., 1985; Legg et al., 1997). It is possibly dated now with the modern approach coming from the physiotherapy world tending to be focused on core stability (Brandon, 2004).

7.4.6 Training programmes for elite single-handed dinghy sailors.

For an elite sailor much time is spent on boat preparation, sailing practice, equipment development and tactical understanding, thus making spare time to perform physical training relatively scarce. Also, in common with other elite athletes, much time is spent travelling between regattas, but unlike most other elite athletes much of this travelling time is spent in a car towing the boat as opposed to flying. Thus, it is important that the time committed to any physical training programme is effective and is targeted at the area which will have the most effect on sailing performance. To be able to administer such an optimal training programme it is important that regular fitness assessments are administered to evaluate the effectiveness of the training regimen. The British system of recommending optimal training regimens is similar to that proposed by Bojsen et al., (2003) for the elite Olympic sailors from Denmark in the sense that there is a need to have optimal markers for each different aspect of fitness and once that level has been achieved the emphasis of the training programme can advance onto another fitness aspect where input is required whilst putting into place a maintenance type programme for the area where the optimal level has been achieved. Such a system is useful for optimising effective use of training time but the main problem is establishing what are the optimal levels for each different aspect of fitness.

British sailors achieved an unprecedented clean sweep of the gold medals at the 2000 Sydney Olympics in all three single-handed dinghy classes. Results such as these not only highlight the skill of the sailors involved but also provides good evidence that the fitness levels of the sailors in each class was satisfactory to achieve the desired result. Thus, some of the optimal levels that other British elite single-handed dinghy sailors aspire to are centred around the fitness levels of previously highly successful sailors in each individual class. For example it is known that aerobic fitness is an important element to an elite single-handed dinghy sailor (Blackburn, 1994; Larsson et al., 1996; Bojsen et al., 2003; and Castagna and Brisswalter, 2004) but none of the papers suggest what an acceptable level of aerobic fitness is. From a combination of the work forming the basis of this thesis and the results achieved at the highest level it is proposed that an elite Laser sailor needs a maximal aerobic fitness level of approximately 60 $ml.kg^{-1}.min^{-1}$, a Finn sailor of approximately 56 $ml.kg^{-1}.min^{-1}$ and a female Europe sailor approximately 52 $ml.kg^{-1}.min^{-1}$. A greater level of aerobic fitness may be beneficial to performance but this is not known. What is known is that elite British sailors have won Olympic Gold medals and World Championships with these levels of aerobic fitness. Although these levels are approximately 20% lower than that of typical elite endurance athletes such as distance runners or cyclists (Åstrand and Rodahl, 1986) they are sufficient for elite dinghy sailors to win at the highest levels. Thus, it is necessary for dinghy sailors to conduct some aerobic training off the water as a part of a formal off-water training programme. Moderate levels of aerobic fitness measured for elite Laser sailors would suggest that aerobic training was warranted in order to facilitate muscular recovery, to boost cardiac endurance and to aid the dynamic activities involved in elite dinghy sailing (Blackburn, 1994). Larsson et al., (1996) and Bojsen et al., (2003) have suggested that elite dinghy sailors require aerobic fitness levels similar to athletes from aerobically demanding team sports.

Aerobic training is also an important area for those either trying to lose body weight or those reducing body fat but trying to maintain body weight. As suggested in chapter 3 of this thesis each single-handed sailing class has an optimal body weight and considerable emphasis of the aerobic training programme is aimed at weight management with long duration aerobic training at relatively low heart rates being common. If body fat can be reduced there is potential for increased muscle mass whilst maintaining the body weight in the right area for the class, this gives a logical advantage which should culminate in increased strength and muscular endurance.

Weight training forms an important part of the elite British sailors training regimen. Weight training tends to be normal dynamic weight training exercises as opposed to isometric strength training as proposed by Spurway and Burns (1993). It is advocated that increased strength in the lower body will assist hiking endurance (Larsson et al., 1996; Bojsen et al., 2003) whilst upper-body strength will clearly assist in playing the mainsheet (Legg et al., 1997). Weight training programmes tend to vary between strength training, hypertrophy training and muscular endurance work depending on the requirements from each individual sailor and on the timing to important championships. Hypertrophy training containing eight to 12 repetitions, four to five sets, short rest periods, and drop sets, are primarily performed by those either looking for additional body weight gains or by those looking for an increased upper-body muscle mass. Pushing exercises working the chest muscles such as bench press, inclined bench press, press-ups and flys commonly form an important feature in the hypertrophy stage of training programmes for single-handed sailors. This is mainly aimed at increasing upper-body muscle mass in these areas as this will assist in increasing the sailors centre of gravity and thus improve the righting moment when hiking. These pushing exercises are also performed to keep the body in balance with the development on the upper-back muscles that is a consequence of pulling on mainsheets over long time periods.

Weight programmes aimed at pure strength improvements are normally performed over the winter period or during the sailors off season. Strength programmes typically consist of low repetitions (four to five repetitions) with heavy loads, four to six sets, big rest periods between sets and only four or five exercises performed per session. Such training is seen as an important area for those wanting to improve leg strength to aid hiking performance. Exercises commonly consist of back squats, front squats, leg press, dead-lifts, leg extension, Olympic cleans, and lunges. An increase in leg strength should result in the sailor hiking at a lower % of MVC as the external loading should remain the same assuming that body weight hasn't changed. If the hiking muscles can work at a lower % MVC this should lead to an increase in hiking endurance. When approaching or during the racing season the weight training emphasis turns to muscular endurance and power weights where 15-20 repetitions are performed on each exercise in a circuit style set up with short rest periods and approximately eight exercises per session. During the concentric lifting phase speed of movement is emphasised. Explosive power development forms an important aspect in this phase of the training with Olympic lifting (cleans and snatch) and light weight plyometric training being an important part of the programme. This is not only aimed at increasing explosive power but also at increasing lactate tolerance and as such the exercises should emphasise the sailing specific muscles that are used in both hiking and sheeting the mainsheet.

What is not known is whether the increased leg strength commonly reported for single-handed hiking sailors (Larsson et al., 1996; Aagaard et al., 1997; Aagaard et al., 1998; and Bojsen et al., 2003) is due to the specific adaptation from sailing itself or from the adaptation to strength and conditioning programmes performed in the weights room. This thesis has not set out to answer this question, but the elevated values reported in the literature are possibly a reflection on both sailing and weight training. Some of the elite sailors tested for this thesis, and whose results are contained in this chapter, have never done leg weights but still have exceptionally high levels of leg strength, particularly when measured in the hiking position. Thus, it is clear that some individuals have adapted from sailing itself. This is not surprising as some of the elite sailors have sailed hiking boats from the age of six and some 20 years later are still sailing hiking boats and spending on average 18 hours per week sailing (Mad for sailing interview with Iain Percy, Finn gold medallist Sydney Olympics 2000, www.madforsailing.com). Wright et al., (1976) have also suggested that during the sailing season the sailors developed the necessary physiological components simply by sailing long hours. As sailing has become more professional over the past 10-15 years sailors are spending more time on the water sailing than they have ever done before.

Training of the trunk muscles primarily consists of performing the core stability exercises administered by physiotherapists. In addition, training of the rectus abdominis does take place with exercises like sit-ups, crunches, catching and throwing the medicine ball whilst in a simulated hiking position. Hip rotation is included by putting twisting movements into the exercises particularly into the medicine ball work where the sailors catch the ball on one side (whilst in a simulated hiking position) but have to throw it as quickly as possible to the other side. It is felt that this rapid hip rotation is an important aspect of dynamic single-handed dinghy sailing and off-water training programmes have to replicate these movements.

7.5 Conclusion

An effective off-water training regimen is important for single-handed dinghy sailors. The training advice needs to reflect on the physiological demands of the sport and the physiological condition of the sailor. The fitness profile of the sailor needs assessing with an appropriate battery of fitness tests and then training advice governed in the area which would make the most impact on subsequent sailing performance. There are numerous factors that are important to the sailor ranging from aerobic fitness, muscular strength and endurance of both the upper and lower body, hiking endurance and trunk stability. Deciding an optimal level for each aspect of fitness that is relevant to a specific class and competition is difficult to establish but this needs to be done to enable the applied sports scientist to offer training advice that will optimise the returns for the sailor considering the effort they are expending.

CHAPTER 8

Chapter 8.

General Discussion and Conclusion.

This thesis set out to investigate a practical problem which was essentially the need to establish the physiological demands of elite single-handed dinghy racing and then advocate appropriate training regimens to improve subsequent sailing performance. At the commencement of this thesis in October 1993 research detailing the physiological demands of single-handed dinghy sailing was limited and the general consensus of opinion was that it was primarily a static sport with the major physiological challenge arising from the hiking action of keeping the boat upright in moderate to strong winds (Niinimaa et al., 1977; Plyley et al., 1985; and Shephard 1990). Previous research was clear in outlining the muscles that played a major role in hiking, these were predominantly the quadriceps and abdominals (Wright et al., 1976; Putnam, 1979; Marchetti et al., 1980; Plyley et al., 1985; Shephard, 1990; Spurway, 1993). What seemed to be lacking was detailed physiological data from on-water racing situations. The notion that the sport was purely static in nature did not ride well with either the elite sailors forming the British Olympic squads back in 1993 or with the Royal Yachting Association's (RYA) National single-handed racing coach of the same era. The direction for this thesis was, in the early stages, led by the RYA National Racing coaches who were keen to get first hand knowledge of the physiological demands of elite single-handed dinghy racing. At that time they were advocating training regimens, both on and off the water, without the support of any sports science input and there was little scientific research underpinning their recommendations. Indeed at the commencement of this thesis the statement from Durnin and Passmore (1967) was probably still correct where they advocated that they knew no-one who had measured the energy cost of sailing and that such an activity probably offered most sailors with exercise of a light grade with only occasional periods of moderate or heavy exercise.

During the course of this thesis, a considerable number of scientific studies have been conducted into the physiology of dinghy sailing and in particular into single-handed dinghy sailing. Ioannis Vogiatzis under the guidance of Professor Neil Spurway has probably been the most prominent in this area. Their work has principally been conducted with sub-elite Laser sailors and their research highlights the alleged isometric nature of the sport and the low aerobic demands which they measured at 39 ± 6 % of $\dot{V}O_{2max}$ during 10 minutes of upwind Laser sailing in winds of 4-12 m.s^{-1} (Vogiatzis et al., 1995a). These findings are considerably different to those reported in this thesis. The reason for such discrepancies is difficult to fully appreciate but may in part be due to the lower standard of sailing expertise, the non-racing situation in which data were collected, the lack of any tacking and the shortness of the upwind legs of 10 minutes duration during which the on-water data were collected. Very recently Castagna and Brisswalter (2004) have also suggested that both the skill level of the sailor and length of the upwind leg are crucial in determining the aerobic demands. At the end of 10 minutes of upwind sailing the oxygen uptake for sub-elite French Laser sailors was 45.1% $\dot{V}O_{2max}$ – similar to the data reported by Vogiatzis et al., (1995a) – whereas at the end of 30 minutes the elite sailors were working at a mean oxygen uptake of 68.4% compared to 51.3% $\dot{V}O_{2max}$ for the sub-elite sailors after 30 minutes (Castagna and Brisswalter, 2004).

Early on-water studies conducted by Cudmore, (1969); Piehl-Aulin et al., (1977); Niinimaa et al., (1977); Dierck and Rieckert, (1980); Pudenz et al., (1981); Bachemont et al., (1984); and Harrison & Coleman, (1987) produced some equivocal findings. Some studies advocated that heart rates during racing were so low that the sailors concerned should participate in other forms of exercise to promote cardiovascular fitness (Dierck and Rieckert, 1980). Others suggested that heart rates were significantly elevated during racing (Piehl-Aulin et al., 1977; Pudenz et al., 1981; and Harrison & Coleman, 1987) reaching as high as 168 beats.min^{-1} for Laser sailing (Pudenz et al., 1981). It was decided that any investigation into the physiological demands of elite single-handed dinghy sailing needed to have a starting point based in the field to establish what happens during racing.

Chapter 4 of this thesis details a comprehensive collection of heart rates and blood lactates during national and international regattas. The results are in agreement with most other researchers in providing evidence that upwind sailing is considerably more physically demanding than downwind sailing (Piehl-Aulin et al., 1977; Pudenz et al., 1981; Gallozzi et al., 1993; and Vogiatzis et al., 1995a). The results are also similar in magnitude to those reported by other researchers with mean whole race averaged values of 84% and 78% of heart rate max for Laser sailing in strong winds and Finn sailing in moderate winds, respectively (Pudenz et al., 1981; Piehl-Aulin et al., 1977). In all cases heart rates increased as wind speed increased. Post race blood lactates were also elevated reaching values of 4.64 and 3.53 $mmol.l^{-1}$ for Laser sailing in strong winds and Finn sailing in moderate winds, respectively. These results suggest that both aerobic and anaerobic metabolism play a role in energy provision for elite single-handed dinghy racing.

It has been suggested that the elevated heart rates reported from these on-water studies are merely a result of the isometric muscular contractions involved principally in the quadriceps and abdominal muscles in performing the hiking action and are therefore misleading when evaluating overall energy demands (Vogiatzis et al., 1993; Gallozzi et al., 1993; and Vogiatzis et al., 1995a). However, this does not explain why blood lactates were also significantly elevated. If hiking is solely isometric in nature then low oxygen uptakes would be a true reflection of the physical demands of the sport as it is well documented that $\dot{V}O_2$ only increases modestly during isometric exercise despite marked increases in ventilation (Petrofsky & Phillips, 1986; Wiley & Lind, 1971; Myhre & Anderson, 1971). However, studies have reported that heart rate response during isometric exercise is only modest in nature and rarely exceeds 120 $beats.min^{-1}$ (Petrofsky & Phillips, 1986). Thus, taking the stance that sailing is primarily a static sport where the major physiological challenge is an isometric contraction of principally the quadriceps and to a lesser extent the abdominal muscles, it is difficult to explain why so many studies have reported elevated heart rates during racing and training. Indeed in a purely static simulation of hiking, reported in chapter 5 of this thesis, heart rates are only modestly increased to a peak value of 101 ± 9 $beats.min^{-1}$ during a strenuous 30 minute hiking simulation. This is in agreement with the suggestion of Petrofsky & Phillips (1986). Also in agreement with some classical studies reporting the physiological responses to static exercise, values for blood pressure were significantly elevated, peaking at 160 mmHg for systolic and 95 mmHg for diastolic, and hyperventilation was evident with increased ventilatory equivalents for both O_2 and CO_2 (Assmusen, 1965; Lind and McNichol, 1967; and Petrofsky & Phillips, 1986). High ventilatory equivalents for O_2 and CO_2 are indicative of hyperventilation that commonly accompanies isometric exercise (Pendergast, 1989). Despite a large degree of local muscular discomfort, with Rates of Perceived Exertion (RPE) values peaking at 15.3, blood lactate values were only elevated to a peak value of 1.47 ± 0.42 $mmol.l^{-1}$. It may be argued that due to the large isometric contraction within the quadriceps and the associated elevated intramuscular pressure, blood flow through the capillaries is severely reduced and although lactate may be accumulating in the muscle bed it is not evident in the blood due to this severe restriction in blood flow. Thus, a post simulation blood sample might have shown some evidence of blood lactate washout after completing the exercise task, but unfortunately such samples have not always been recorded. Vogiatzis et al., (1993) offers some credence to this theory in reporting that mean blood lactate values increased from 3.84 ± 1.52 $mmol.l^{-1}$ at the completion of a laboratory based hiking task to 4.83 ± 1.89 and 5.26 ± 1.90 $mmol.l^{-1}$ in the 3rd and 5th minutes of recovery. Notwithstanding this possible post exercise blood lactate washout, it would seem that isometric hiking is not responsible for the elevated heart rates or blood lactates reported from on-water studies of single-handed dinghy sailing. This would suggest that other mechanisms are responsible for these elevated values established on the water.

The experiment described in chapter 6 simulated 30 minutes of upwind sailing in a purpose built Laser sailing ergometer, and was specifically designed to mimic the dynamic movements of the sport. The main findings were heart rates that peaked at 160 $beats.min^{-1}$ (87.4% Hr_{max}) and a mean $\dot{V}O_2$ for the simulation of 32.2 ± 3.0 $ml.kg^{-1}.min^{-1}$ (58.1% of $\dot{V}O_{2max}$). Interestingly, the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) was elevated throughout the simulation with a mean value of 29.7 ± 3.5. Given the exercise intensity of the exercise as measured by the % $\dot{V}O_{2max}$, this would suggest that there was some form of hyperventilation throughout the simulation. As suggested earlier this is common with isometric exercise and it seems possible that this accurate simulation of Laser sailing had a concomitant isometric contraction of the quadriceps and/or abdominals that underpinned the range of dynamic movements that single-handed sailors are required to produce. It is interesting to note the similarity of these findings with those recently reported by Castagna and Brisswalter (2004) of peak values 78.5% HR_{max} and 68.4% $\dot{V}O_{2max}$ after 30 minutes of upwind sailing in moderate winds for elite French Laser sailors. It is argued that the results reported by Castagna and Brisswalter (2004), and those from chapter 6 of this thesis, suggest that the sport does have an element of aerobic metabolism which is a consequence of the dynamic movements that elite sailors superimpose on the prolonged static contractions primarily found in the quadriceps. It is not clear whether this phenomenon is what some researchers have phrased 'pseudo or quasi-isometric' (Spurway 1997; Felici et al., 1999) throughout the literature as this term is used without definition.

Although not documented anywhere in the scientific literature most elite dinghy sailors mention the 'swapping' of the hiking load between the two legs whilst sailing. This is common knowledge when talking to elite dinghy sailors and is routinely done in an almost sub-conscious fashion whilst hiking hard. Personal communication with elite single-handed sailor Ben Ainslie has confirmed this process. What is happening when the load is alternated between the two legs is an attempt to make the exercise cyclic in action where the muscular contraction on the resting leg is reduced to a low percentage of MVC so as to allow blood perfusion. Such blood perfusion is essential to carry away products of metabolism and perfuse the muscle with oxygenated blood and nutrients. This intermitted muscle action may not be easily detected by the naked eye, but could be measured via surface electrodes in a typical EMG analysis. Any future research into the physiological demands of elite single-handed dinghy sailing would be well directed towards an on-water EMG study of particularly the lower body muscles involved in hiking and also the upper-body muscles implicated in playing the mainsheet. No such studies have been conducted on the water with dinghy sailing but have been conducted on the water and in the laboratory setting with windsurfing (Dyson et al., 1996 and Buchanan et al., 1996). An abstract presented by Spurway et al., (2000) detailing a further laboratory simulation of single-handed dinghy sailing added a repeated leg movement of only 5 degrees (0.087 rad) on top of a sustained isometric contraction. This they suggested significantly increased the physiological cost of the activity. It is not clear whether they were trying to replicate this swapping of the hiking loads from leg to leg, but from reading the abstract [a full paper has not been published] it does not seem that they were as they did not unload the hiking effort from the non-working leg.

8.1 Implications for single-handed sailors:

The main findings from this thesis are twofold. Firstly, elite single-handed dinghy sailing is not a static sport as the majority of the previous scientific literature suggests. Secondly, the dynamic element of dinghy sailing suggested in this thesis is supported by the recent work of Castagna & Brisswalter (2004) for elite French Laser sailors, showing that oxygen uptake is considerably taxed during elite single-handed dinghy sailing. Dynamic aerobic training to facilitate both recovery (Blackburn, 1994) and to aid the dynamic movements that typifies the activities of a single-handed dinghy sailor is evidently warranted as part of their training regimen. Aerobic training is also necessary in order to keep body weights in the narrow bands as listed earlier in this thesis (Europe: 66-68 kg; Laser: 79-81 kg; and Finn 96-98 kg). It would seem that optimal body weights in the single-handed classes are important to sailing performance.

High levels of leg strength, particularly in the quadriceps, will aid hiking endurance as they will allow the sailor to work at a lower % of MVC thus allowing the hiking activity to be prolonged. This thesis has not established whether this high level of leg strength reported is a consequence of an adaptation to sailing itself or merely a reflection of the gym programme. With modern day sailors being full time athletes and spending up to 18 hours a week sailing this additional leg strength may well be an adaptation to hiking itself. What is clear is that elite sailors have typically recorded elevated values for leg strength (Larsson et al., 1996; Aagaard et al., 1997; Aagaard et al., 1998; and Bojsen et al., 2003) and that this is almost seen as a pre-requisite for elite performance. It is recommended here that elite sailors should have an assessment of leg strength made and then accordingly be prescribed with a normal dynamic weight training programme aimed at increasing lower body strength if it is felt necessary.

Upper-body strength is required for adjusting the mainsheet and for pumping the sail, the latter being particularly important for Finn sailors whilst sailing downwind. Given the mainsheet loadings reported from other studies (Blackburn, 1994; Mackie and Legg, 1999) it is doubtful whether these are sufficient enough to stimulate an adequate overload to improve muscular strength and as such upper-body strength training should form part of an off-water training programme. This should be aimed principally at the muscles responsible for movement in the pulling plane (back, shoulders and arms). Muscles on the anterior upper-body responsible principally for movement in the pushing plane need to be kept in balance with the posterior muscles, and as such should be included in an upper-body training programme. Additionally, sailors trying to increase their upper-body muscle mass to enhance their righting moment are encouraged to perform hypertrophy-type training on these muscles, particularly on the large pectoralis major group.

Not within the scope of this thesis, but necessary to mention in this context, is the fact that core stability training, trunk endurance work, agility and flexibility sessions should also form part of the training regimen of an elite single-handed dinghy sailor. Explosive training to increase both functional core stability and also to increase the powerful movements around the hip joint which will in-particular include rapid hip rotation should be encouraged. Such training should include medicine ball work in the hiking position with rapid rotation and twisting around the hip joint as well as conventional Olympic style lifting that is well documented as increasing power development.

8.2 Conclusion.

Hiking performance will not in any way be negatively affected by an increase in the amount of oxygenated blood delivered by the cardiac muscle, which will certainly assist with recovery but will also aid energy provision for the dynamic movements employed by elite single-handed dinghy sailors during the period of a typical race lasting between 45-75 minutes. Local blood flow itself may be impeded by compressed blood vessels in the contracting muscles but it does appear that sailors have adapted two strategies for dealing with this; firstly, increased leg strength thus allowing them to work at a lower % of MVC and secondly, a system of cyclicly alternating the majority of the hiking load from one leg to the other in an attempt to permit blood perfusion. Although the latter point has not been mentioned previously in the literature and falls outside the scope of this thesis, it is an important issue and is supported by strong anecdotal evidence. An appropriate assessment of a sailor's physical state by an applied sports scientist with knowledge of the physiological demands of single-handed dinghy sailing coupled with an appropriate battery of fitness tests should allow the sailor's physiological strengths and weaknesses to be evaluated. Based on this premise an appropriate training programme can be administered to maximise sailing performance whilst at the same time one is fully aware of the limited time available to any elite sailor.

8.3 Future research:

With the recent excellent on-water work conducted by Castagna and Brisswalter (2004) future research should address the issue, already raised in this thesis, of the loading and unloading of principally the quadriceps muscles during hiking. At the moment it is only anecdotal evidence from the sailors themselves which suggests that this happens. This area needs to be led by the sports scientist, and an appropriate EMG study would prove invaluable here.

An interesting development coming out of Australia is a completely new type of sailing ergometer under the guidance of Professor Norman Saunders (Walls et al., 1998; Saunders et al., 2003; and Saunders et al., 2004) that seems as if it could revolutionise the laboratory based exercise testing of sailors. This simulator is based on the original work of John Harrison (Harrison et al., 1988) but is impressive in its software and the dynamic nature of the simulation being provided by computer controlled pneumatic rams. It can discriminate between different standards of sailor and does offer a true dynamic simulation, with the added bonus that each simulation can be exactly reproduced which could make it a useful tool for further investigations into the physiological demands of elite single-handed sailing. First impressions suggest that this simulator would be very helpful in teaching beginners to sail without the attendant danger, discomfort and de-motivation of frequent capsizes. Its suitability as a training aid for use by an elite group is less clear cut, but there is great potential for further research into the varying demands of single handed sailing. A portable miniaturised telemetric EMG device – a prototype is available – suitably water-proofed, could be used to examine the nature and extent of dynamic sailing competition on-water. A matching 'indoor sail' on the simulator, involving a repeat of the on-water EMG work could validate the simulator as an effective laboratory-based research tool. This would open up possibilities for substantial valid and reliable new work in the biomechanical, physiological and psychological sciences that would enhance knowledge and refine practice as applied to sailing.

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