DO LAND-BASED TESTS DISTINGUISH ‘THE BEST FROM THE REST’ IN ON-WATER HIKING PERFORMANCE IN ELITE BRITISH LASER SAILORS?

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Abstract

Hiking is where sailors are required to lean out of the boat when sailing upwind to counter the force of the wind in the sails. This study examined possible relationships between land-based parameters and the ability to hike on-water in seven Laser sailors in the British Sailing team (2 females, 5 males: age = 20 ± .64 years). Two hiking bench protocols were used: a three-minute test, and a ten-minute test to measure the righting moment generated by the participants. Parameters collected in these trials and in endurance and strength tests were analysed alongside coaches' on-water rankings to determine whether the hiking bench protocols determined 'the best from the rest'. No significant correlations were seen between on-water scores and land-based testing (p>.05); however, average righting moment on the hiking bench in both tests significantly correlated with VO_{2peak} (r=.942), maximum minute power (r=.906) and 1RM (r=.795).

Although there were no significant correlations with on-water scores, the testing gave a valuable insight into the participants' ability to use their physical attributes when hiking, even in a controlled setting, indicating that mental attributes may perhaps be responsible for differences in hiking performance between sailors.

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Introduction

Sport is becoming increasingly more professional, with more funding and resources focused on improving performance. Many sports are searching for more advanced ways of measuring and predicting race performance, by introducing increasingly specific modes and testing procedures.

An understanding of the theory of performance improvement is the basis to all training. The determinants of athletic performance are well-documented, taking into account both genetic and environmental factors (Brutsaert and Parra, 2006). There are three physiological variables which are widely considered to be predictors of endurance performance: maximal oxygen consumption (VO_{2max}), lactate threshold and exercise economy (Joyner and Coyle, 2008). An increase in VO_{2max} allows for a greater volume of oxygen to reach the muscles, through a combination of cardiovascular and musculoskeletal adaptation. This benefits performance by allowing a constant supply of oxygen to the muscle for more sustained and efficient aerobic respiration (Jones and Carter, 2000). This adaptation with training is reinforced by an improved exercise economy, defined as the reduced oxygen consumption at a given work load, allowing less oxygen to be used for greater amounts of effort and therefore a more efficient power output (Jones and Carter, 2000).

Physiological testing and modelling has become a well-established tool to determine and monitor performance in sport, based on the aforementioned determinants. This can then be applied and manipulated to enhance sporting gain, while also being used to understand performance differences between athletes. An increasing number of sports have implemented this strategy as a way to predict, test and manipulate sporting performance. Many studies have reported the necessity for modelling performance in sport and, while there are subtle differences in which predictors of performance hold the greatest accuracy, many support the literature of Joyner and Coyle (2008), in that the key physiological variables (VO_{2max}, exercise economy and lactate threshold) are essential to improve athletic performance. Hiking in sailing can be compared to rowing and cycling, with similarities in the posture required for the exercise. It is possible that flexion at the pelvis seen in all three sports, may allow findings associated with occlusion of blood vessels and therefore restriction of blood flow to the quadriceps to be related.

Cycling

Cycling is arguably the most innovative sport in the world, constantly challenging the boundaries of sporting performance in an effort to improve. Hawley and Noakes (1992) sought to determine the relationship between peak power output (W_{peak}) and VO_{2max} in a test to exhaustion on a cycling ergometer and found a significant strong positive correlation between the two variables (r=.97). To further this relationship, it was concluded that VO_{2max} accurately predicted W_{peak}, and that W_{peak} is a valid predictor of time in a 20km time trial (95% and 82% variance explained, respectively) (Hawley and Noakes, 1992).

Nevill et al. (2005) overcame limitations in ecological validity of Hawley and Noakes (1992) by developing an allometric model allowing for adjustments to be made for age and wind direction, giving greater prediction of cycling performance. To control for external variables, temperature, humidity and barometric pressure were measured every five to ten minutes throughout the 25-mile time trial. Physiological data was determined through lab-based tests which were completed either before or after the road time trials. Adding ‘age’ as a covariate led to no effect on performance; however, a side wind showed a significant 5% faster time trial result (p=.008) (Nevill et al., 2005).

Rowing

Rowing has also delved into the realms of modelling to predict performance. Ingham et al. (2002) tested a sample of different gender and weight classes from the Rowing World Championships. It was found that over a 2000m rowing ergometer time trial, the power produced at VO_{2max} during a discontinuous incremental rowing test explained 95.3% of the variance in rowing speed and was therefore the greatest predictor of performance. The equation used to predict performance from physiological parameters also showed that an increase in percentage of body fat in females predicted a reduction in peak power output. Cross-validation also showed a strong positive correlation (r=.99) between predicted time trial times and real-life performance (p<.001). This suggested that this model has high validity; however, as this study took place in a highly-controlled environment, it failed to take into account environmental variables on the water. Later work by Nevill, Allen and Igham (2011) used a curvilinear model to predict indoor rowing performance in 76 elite rowers. This study found similar results to the previous study (Ingham et al., 2002) in that power at VO_{2max} was the best predictor of rowing speed and, furthermore, explained differences in weight class and sex, making it a more realistic predictor of performance.

Ingham et al. (2013) later determined which of two protocols better predicted rowing performance over a 2000m ergometer time trial. A mixed gender sample (n=18) of national and regional rowers of different weight classes took part in the study. The discontinuous incremental rowing test used in the earlier study (Ingham et al., 2002) and a ramp-wise test were compared and correlated to a 2000m time trial performance.

Results found that Maximum Minute Power (MMP) had the greatest correlation with 2000m performance (*r*=.98), ahead of power at VO_{2max}, in accordance with the findings of Nevill, Allen and Igham (2011). No differences, but strong correlations (*r*=.97), were observed in VO_{2max} between each of the incremental tests and, moreover, no differences in lactate threshold and ventilatory threshold were seen. This study suggested that a ramp test could be a more time-efficient method of monitoring the physiology of athletes, although Ingham et al. (2013) urged that further attention needed to be given to the parameters of the ramp test with the rowing time trial, to ensure greater validity.

The development of elite performance involves integrating physiology. There are large amounts of research on the muscular, cardiovascular and neurological aspects of performance physiology; however, gaps in literature were apparent when investigating the factors that govern motor unit recruitment which may limit fatigue and therefore improve performance (Joyner and Coyle, 2008).

Many of these models were developed in controlled laboratory-based conditions. This approach produced a greater controllability but failed to take into account the external environmental conditions, therefore reducing ecological validity. It was often assumed in a range of environmental conditions that the factors limiting performance were the same. However, many variables are affected by each other and the external conditions, making performance highly sensitive to change. In order to accurately predict performance from physiological variables, many models must be taken into account, reducing the confounding variables (Noakes, 2000). The lack of ecological validity is particularly identifiable in sailing, where wind conditions, sea state, start quality and decision-making all add additional noise to the performance. Compared to many sports, this makes sailing even more difficult to replicate in a laboratory and reduces the reproducibility of laboratory-based tests on the water.

Cycling and rowing, as seen by the evidence presented above, have a large body of research associated with methods of distinguishing between different athletes and their performance, as well as the main parameters that can be changed in order to understand the underlying principles of how to achieve better race results.

Sailing

Sailing is a multi-faceting sport, introduced to the Olympics in 1900. It takes into account the mental capabilities of the athletes to understand the weather conditions and the best tactical approach to racing in specific conditions. Equally as important are the physical abilities of the athletes, which are continually trying to be refined and enhanced to improve boat performance. As Olympic sailing has become more professional, in an effort to challenge other sports, there has been an increase in focus on the physical capabilities for sailing, with training aiming to improve physiological variables of muscle strength and endurance, as well as aerobic and anaerobic profiles (Bojsen-Moller, Larsson and Aagaard, 2014).

A key component of optimising speed in Laser sailing is by balancing the boat, hence increasing the wind pressure on the sails (Aagaard et al., 1998). Hiking is a technique used when sailing upwind in wind speeds greater than eight knots. It involves sailors leaning outwards, away from the sail, with the feet held in toe straps. This action increases righting moment, counteracting the force of the wind in the sail, namely the heeling moment, which is greatest when sailing upwind. Legg et al. (1999) provided evidence that when sailing upwind in conditions between five and 15 knots, elite Laser sailors spent, on average, 94% of the time hiking. It was regarded to be the greatest intensity exercise of single-handed dinghy sailors (Cunningham and Hale, 2007), and was also an area of performance receiving increased attention due to the ability to win, or lose, races by getting to the windward mark first (Bourgois et al., 2015).

Theoretically, a greater hiking ability generates more power and therefore a greater chance of speed; however, hiking ability is not the only variable in this relationship, as power must be generated at the correct time and in the correct direction to increase speed. In addition to this, resistance increases disproportionally with velocity, so significantly more power is required to increase speed and overcome the effect of drag. When hiking, the aim is to get the centre of mass of the athlete as far away from the centre of buoyancy of the boat. There are several anecdotal factors which influence the ability to do and sustain this position, with the greatest success. Firstly, anthropometric characteristics of the athlete are important. With greater height, the athlete's centre of mass (CoM) can be further from the centre of buoyancy of the boat (CoB), yielding a greater peak righting moment, utilising the greater lever (Putnam, 1979). However, it has also been suggested that with increased height, athletes may require greater strength to hold an optimal hiking posture (Tan et al., 2006). Tan et al. (2006) also found correlation between body mass and maximum righting moment generated over three minutes (r=-.69, -.62).

The force through the toe straps is equal to the force produced through hiking and could therefore be a variable in hiking ability. Looser toe straps allow the athlete to be further out of the boat, increasing the distance between the athlete's CoM and the CoB. This also makes the hiking position more difficult to sustain and puts greater strain on the quadriceps. In contrast, if the toe straps are tighter, the position held may not be as far out but as it may be held for a longer period of time. With this adjustment, more strain is put through the hip flexors. These differing toe strap lengths may have a large impact on injuries and career longevity. Anecdotally, it has been suggested that hiking off the hip flexors, sometimes due to abdominal muscle weakness (Blackburn, 1994), as seen when toe straps are tighter, leads to greater progression of hiking ability during development; however, it increases chances of lower back injury due to a greater load on the lumbar spine (Bojsen-Moller et al., 2007), the most highly reported injury in hiking sailors (Neville and Folland, 2009).

It has also been suggested that the environmental conditions are more of a limiting factor to hiking performance in wind speeds less than 11 knots. However, in higher wind speeds, hiking becomes a limiting factor and human performance becomes a more dominant determinant of performance. Aside from wind speeds, a key environmental variable influencing hiking performance is sea state. Choppy seas increase drag through the waves, increasing the importance of generating power at the correct times. Different amounts of hiking are required at different parts of the wave. Waves have a kinetic component and an important part of hiking performance is the ability to react and determine when the power is best utilised.

Decision-making is arguably the most important variable to performance in sailing and the largest confounder to hiking performance, accounting for the greatest performance gain. In order to make decisions during racing, it is important to have the vision to interpret the information to inform decision-making. This may mean that athletes have to lean further in or further out than conditions dictate in order to see other boats or important environmental features that may lead to a gain in speed. This gain in information allows for race tactics to be implemented.

Physiology of Hiking

The physiology of hiking has long been disputed. Described as a sustained ‘quasi-isometric’ contraction, comprising a series of static body postures and dynamic actions on the water (Aagaard et al., 1998; Spurway, 1999), hiking accounts for gusts and lulls in the wind, tacking, trimming and hip rotation. A gust of wind may require the sailor to further extend their body and increase righting moment, through hip extension; while reducing the righting moment by bringing body mass towards the boat, through hip and knee flexion, will be required for a lull in the wind. Meanwhile, trimming involving the movement of the upper body to adjust the sail and hip rotation is also a common action on the water to compensate for waves. The occurrence of tacking upwind will also vary on the tactics being employed and involves moving body weight to the other side of the boat (Cunningham and Hale, 2007).

It is notoriously difficult to accurately measure the physical demands of hiking on the water due to methodological limitations (Bourgois et al., 2015). In order to gain a greater understanding of the physiology of hiking, land-based hiking simulators have been produced. This allows for a more controlled environment, reducing the effect of confounders, such as decision-making and conditions on the water, allowing for greater reliability and measures of hiking ability. This research approach has given an insight into how hiking can be improved and which physical parameters have the closest correlation with hiking performance (Blackburn, 1994; Tan et al., 2006). Many studies have used hiking benches to replicate and mimic the demands of on-water hiking; however, that failed to take into account the dynamic nature of and only used isometric contractions, questioning the reliability of the measure (Vangelakoui et al., 2007). Despite this criticism, trying to replicate hiking on-land has proved invaluable, allowing researchers, coaches and athletes to have a greater understanding of the physiological demands of hiking, gathering information which was not possible to be measured on the water.

VO_{2max} is a common predictor of endurance performance in many sports, as discussed by Hawley and Noakes (1992). Blackburn (1994) conducted a study whereby sailors were required to complete three sets of twenty-minutes on a hiking ergometer to gain a greater understanding of the physiological demand of hiking in upwind sailing. During this study, participants (n=10) were required to mimic video footage of an upwind leg on the water, to make the simulation as ecologically valid as possible. Within the twenty-minute set, sailors were required to 'tack' every 90 seconds, as shown in the video, moving in from their hiking position and touching the opposite side of the boat with one hand, before returning to their maximal hiking position. Results showed that VO_{2max} during this trial rarely increased above 30%VO_{2max}, averaging 25 ± 5%VO_{2max}. There was, however, a large blood pressure response. Systolic blood pressure observed during the upwind simulation was shown to be comparable to maximal dynamic exercise, though diastolic blood pressure was shown to be greater than that seen in treadmill running or ergometer cycling, which could be attributed to restrictions in blood flow (Palatini et al., 1998).

A later study by Callewaert et al. (2013) compared oxygen uptake (VO_2) data from an incremental cycling test and a simulated upwind sailing test, with the aim to develop an on-land test to accurately mimic on-water hiking performance. The ten male National Youth Laser sailors were required to complete 18x90s sets with 10s between each one to allow for 'tacking'. During this test, VO_2 and heart rate were measured, as well as righting moment as a percentage of their maximum (%RM_{max}). Average righting moment throughout the trial was 89 ± 2.2%RM_{max}, VO_2 over the trial was reported as 39.5 ± 4.5% VO_{2peak}, and heart rate as 80 ± 4%HR_{peak}, supporting the findings of Blackburn (1994). Limitations to this study were highlighted by participants of the study, stating that although the simulation gained a strong score to say the test mimicked the on-water demands, seven participants commented that ten seconds allocated to 'tack' was too long to accurately represent upwind sailing, and perhaps five second ‘tacks’ would be more representative to predict on-water hiking performance, as used in other studies (Vogiatzis et al., 2008; Vangelakoudi et al., 2007).

Earlier studies measured heart rate and VO_2 of on-water hiking (De Vito et al., 1996; Vogiatzis et al., 1995), and it was concluded that, although VO_2 and heart rate measures showed similar correlations on the water and in simulations, the results gathered on the water were greater than those seen in controlled laboratory conditions (Spurway, 2007).

Taking into account the dynamic nature of hiking and disputing the ‘quasi-isometric’ concept, Cunningham and Hale (2007) incorporated a video simulation to increase the validity of the Laser sailing ergometer. Six elite male Laser sailors were recruited from the RYA British Olympic Development Squad to take part in this study. The athletes were required to ‘hike’ for 30 minutes using the ergometer and video simulation provided, having previously performed a test to volitional exhaustion on a cycle ergometer. Ventilatory measures and heart rate were collected at rest and every five minutes throughout the trial. The conclusion of this study showed that although heart rate and blood lactate measures were not significantly different from other ergometer and on-water studies, a significantly greater VO_2 and VO_{2peak} was reported. This suggested that hiking in Laser sailing is a more dynamic activity than originally thought due to the increased aerobic demand compared to static hiking protocols (Cunningham and Hale, 2007). Blackburn (1994) concluded that dynamic aerobic training, as well as static training, can improve hiking performance by improving endurance, facilitating recovery and also promoting cardiovascular adaptation. This study reported approximately half the $\%VO_{2max}$ seen by Cunningham and Hale (2007), which showed an average oxygen intake of 50% VO_{2max}, peaking at 59.8% over the course of the 30-minute simulation protocol; however, similar changes in heart rate were seen between the two studies. On-water oxygen data from Vogiatzis et al. (1995) during upwind sailing in different conditions showed that oxygen uptake only reached 39% of VO_{2max}, supporting results found by Blackburn (1994) and the ‘quasi-isometric’ theory. There were several proposed explanations for the differences between these studies. Many of the studies investigating the physiology of hiking used non-elite samples. Cunningham and Hale (2007) used an elite sample, with comparable size and fitness measures to Blackburn (1994) and Vogiatzis et al. (1995), perhaps suggesting that with greater skill and sailing experience, hiking becomes more dynamic, creating greater whole-body physiological strain, thus, a more proportional relationship between VO_2 and heart rate, opposing the ‘quasi-isometric’ theory of Spurway (2007) in elite populations.

Muscle endurance and strength have been shown to be of significant importance to hiking performance in the trunk and quadriceps. Evidence showed that the musculoskeletal demand of hiking summated to a sustained contraction of approximately 30% maximal voluntary contraction (MVC) in the quadriceps and 15% MVC in the tibialis anterior and rectus abdominis (Vogiatzis, 1995). These results were gathered during a protocol of four sets of three-minute hiking bouts, interspersed with 15 seconds rest on a hiking simulator. The results gathered from the participants (n=8) concluded that there was a relationship between the onset of fatigue throughout the hiking bouts, and electromyography (EMG) activity and ventilation, although more research on the extent of this relationship needed to be carried out. Due to the nature of this activity, there was continual strain put on the hip flexors and knee extensor muscles (Spurway, 1999), supporting other studies (Aagaard et al., 1998; Chicoy and Encarnacion-Martinez, 2015) in that quadriceps muscle endurance was the most important variable in hiking ability.

Moderate to strong correlations between hiking performance and strength in knee extensor muscles have been found in several studies using bespoke hiking benches; however, this has never been correlated to on-water performance (Tan et al., 2006; Blackburn, 1994; Aagaard et al., 1998). The importance of quadriceps endurance has been highlighted by Larsson et al. (1996) who found that elite hiking sailors had a greater capacity to sustain isometric contractions compared to non-hiking sailors. This perhaps suggested that quadriceps muscle endurance correlates to improved hiking. Aside from finding correlations between isometric and concentric knee extensor strength, and dynamic and static hiking performance, Aagaard et al. (1998) also reported correlations between trunk endurance and hiking performance. This study was conducted on male (n=15; n=8 hiking sailors) and female (n=8) sailors, compared to a matched male control group (n=8). Tests involved static and dynamic tests to exhaustion on a hiking bench, where 'dynamic' was defined as changing angle of the hip between 45˚ and 60˚ at a frequency of 1Hz. Results showed that static hiking performance was significantly associated with maximum isometric knee extension strength in male hiking sailors (r=.67; p<.05), male non-hiking sailors (r=.46; p<.05) and female sailors (r=.88; p<.025). Dynamic hiking scores in male sailors showed a greater correlation to knee extensor strength than females, with male sailors also showing greater trunk and knee extensor strength than the matched control group, perhaps due to specific training adaptation on the water (Aagaard et al., 1998). Vangelakoudi et al. (2007) also found that elite sailors were able to sustain static and dynamic muscle contractions for 50-100% longer than club level sailors, further reinforcing the importance of muscle endurance in hiking performance.

Hiking has also been shown to impair blood flow. This reduced oxygen availability and saturation, limiting hiking performance (Vogiatzis et al., 1995), as shown by discrepancies in the effect of hiking on VO_2 and heart rate. This was shown in a study by Vogiatzis et al. (2011), taking more accurate measures by directly measuring oxygen saturation in the quadriceps during hiking, compared to a cardiac output-matched cycling trial. This study recruited six male national Laser sailors who completed a hiking test on a Laser simulator, followed by a constant intensity cycling test at a cardiac output that matched the hiking test. An hour's rest was left between hiking and cycling. The hiking test involved completing three three-minute hiking bouts with five seconds rest to simulate tacking on-water. The cycling test also involved three three-minute bouts. Blood flow index in the *vastus lateralis* was measured in both tests using near-infrared spectroscopy (NIRS). Matching cardiac output allowed differences in quadriceps blood flow to be assessed between hiking and cycling, while keeping systemic blood flow the same, controlling changes seen by Blackburn (1994). Results of this study showed that blood flow in the quadriceps only increased from baseline in the final hiking bout by approximately two-fold; however, there was a six-fold increase in *vastus lateralis* blood flow during the cycling trial. This discrepancy suggested that the quasi-isometric activity in the quadriceps during hiking resulted in restricted blood flow which limited oxygen delivery and therefore availability, leading to a premature onset of fatigue (Vogiatzis et al., 2011). Vogiatzis et al. (2011) suggested that sailors 'cycling' their legs when hiking, relieved demand on alternating legs, allowing increased perfusion to working muscles, thus allowing for improved hiking endurance and reducing the effect of muscle fatigue.

Fatigue resistance has also been noted as an important factor in hiking which differentiated hiking abilities in Laser sailors. Vangelakoudi et al. (2007) conducted a study to determine a difference between the capacity to resist fatigue in top-ranked hiking sailors (n=8) and club sailors (n=8). This data was then correlated to their

National Rankings. As expected, endurance time and isometric endurance was significantly greater in elite sailors; however, final minute heart rate and mean arterial pressure were no different between groups. This suggested that elite sailors can expend a greater intensity of lower limb isometric contraction with comparable cardiovascular responses suggesting greater fatigue resistance and efficiency. This study also showed that mean and maximum anaerobic power scores from a Wingate tests correlated with National Ranking, suggesting that power output was an important variable for sailing performance (Vangelakoudi et al., 2007). No significant difference was identified between National Ranking and hiking endurance. This could have been attributed to National Ranking which took into account all aspect of performance, with no specific focus on hiking. It has also been proposed that this could have been due to the differences between on-land and on-water hiking, with simulated hiking reducing the dynamic component seen on the water (Vangelakoudi et al., 2007). However, despite these limitations, it was concluded that nationally-ranked sailors sustained fatiguing isometric contractions for a longer period of time, suggesting greater fatigue resistance.

Furthering this research, Bourgois et al. (2016) sought to investigate whether sailing ranking was determined by neuromuscular fatigue, as defined by a decrease in Mean Power Frequency (MPF), on a hiking simulator, and whether this decrease was influenced by aerobic capacity and quadriceps strength. These national sailors (n=10) were ranked by their coaches to determine sailing level and completed an incremental cycling test, a quadriceps strength test and an upwind sailing test, repeating the protocol used by Callewaert et al. (2013). Heart rate, breath-by-breath data, blood lactate concentration, EMG and oxygen saturation measures were taken throughout the test. This study concluded that coaches' rankings correlated significantly with a decrease in MPF (r=.724, p=.010). To gain a greater understanding of the physiology parameters behind MPF, correlational analysis was carried out. It was determined that maximum isometric and concentric quadriceps strength was significantly correlated to MPF, with no significant relationship between MPF, and VO_{2peak} and peak power output (Bourgois et al., 2016). This study supported findings of Aagaard et al. (1998) in that maximum isometric quadriceps strength was an important attribute of hiking performance; however, it exceeded previous research by suggesting neuromuscular fatigue has a greater impact on performance on a hiking simulation, over and above other physiological measures.

Tan et al. (2006) conducted a study using a hiking dynamometer with the primary aim of correlating hip flexor and knee extensor muscle performance with hiking endurance to determine which performance parameters best predicted hiking. The hiking test used, HM_{180}, required athletes to produce their maximal righting moment in three minutes. A second test was also used to measure hiking performance. This was an incremental test where weight was added every one-minute to make hiking more challenging. The test was concluded when athletes could no longer hold the correct position, and the time was recorded. Laboratory-based performance measures included: vertical jump, three-repetition maximum (3RM) knee extension, cycling to exhaustion, quadriceps and abdominal strength endurance, and maximal voluntary isometric contraction. Results of this study showed that in Laser sailors of National level, body mass and score in the HM180 correlated significantly with better race scores (r= -.69 and r= -.62, respectively, for body mass and HM180). In addition to this, it was seen that knee extension strength, maximum voluntary isometric quadriceps strength and body mass also correlated to an increased HM180 score. These scores suggested that there may be a relationship between leg strength and body mass to improve hiking bench scores, which in turn, may improve race scores. This study, however, did not determine cause and effect, so, therefore, no conclusions could be drawn.

The hiking bench used in this study (Tan et al., 2006) was more sophisticated that those used in previous studies, acting as a training mode to increase hiking ability of the water. The main advantage of a hiking dynamometer is that is quantitatively measures hiking performance based on posture, meaning that optimal hiking posture will generate the greatest righting moment. This allows differences to be observed between hikers that are able to hold the position for a shorter period of time, compared to people who compromise form in order to hike for longer.

Many of the aforementioned studies used National Rankings or results from a single regatta in order to measure hiking performance on the water (Vangelakoudi et al., 2007; Tan et al., 2006). However, this took into account all aspects of performance including technical ability and decision-making. Piedmont, Hill and Blanco (1999) also inferred the importance of subjective coach ratings to support quantitative data. Using coach rankings to quantify on-water hiking ability provides a more specific measure of hiking, rather than assessing overall sailing performance.

Advancing on findings from Tan et al. (2006), the primary aim of the study is to distinguish the ‘best from the rest’ in on-water hiking performance, using on-land hiking protocols, physiological, strength and anthropometric data, against coaches’ ratings of on-water performance in Laser sailors within the British Sailing Team. Secondly, this study aims to evaluate the relationships between other relevant land-based parameters. Finally, it aims to outline which of two different hiking bench protocols best achieves this, with the aim of potentially incorporating a protocol into athlete profiling.

Methods

Participants

Seven healthy participants (two females, five males) were recruited from the RYA British Sailing Team. All athletes were free from injury, with a high level of fitness, with an average age of 20 ± .64 years. It was required that all athletes read the Participant Information Sheet and sign a consent form prior to the beginning of this study. The protocol was approved by the School of Sport, Exercise and Rehabilitation Sciences Ethics Health and Safety Committee at the University of Birmingham and permission was granted to carry out this study by the RYA British Sailing Team.

Study Design

This trial investigated how hiking performance can be predicted from on-land procedures to determine 'the best from the rest'. All visits were made to the RYA British Sailing Team Performance Unit, Weymouth. Participants were required to make six separate visits to the Performance Unit. The first two visits were used to determine VO_{2peak} and quadriceps and trunk strength and endurance. All visits were separated by a minimum of 24 hours. Upon the first visit, anthropometric measures were taken using a stadiometer (Holtain Limited, Crymych, Wales) to measure height and scales (CPWplus 150, Adam Equipment, Milton Keynes, England) to measure weight. This procedure was succeeded by VO_{2peak} test to determine a whole-body fitness parameter. The second visit required participants to complete a one-repetition maximum (1RM) on a leg press machine to measure maximum quadriceps strength, followed by an endurance leg press where participants were required to complete as many reps to fail at 60% 1RM as a measure of quadriceps endurance. Trunk scores of strength and endurance were also measured using supine, prone and side extension hold tests. The tests were conducted in this order, and maximum time for each hold was recorded.

The following three visits were used to complete two separate protocols on a hiking bench: a three-minute hold test, followed by a 10-minute hiking protocol, separated into five two-minute holds, with a 'tack' simulated every two minutes, lasting five seconds. The two tests were conducted in the same testing session. These tests were separated by thirty minutes' rest. Each visit was conducted at the same time of day to prevent circadian variance (Jeukendrup et al., 2006). In order to maximise control, all testing was conducted with participants in a fasted state, although water could be consumed *ad libitum*.

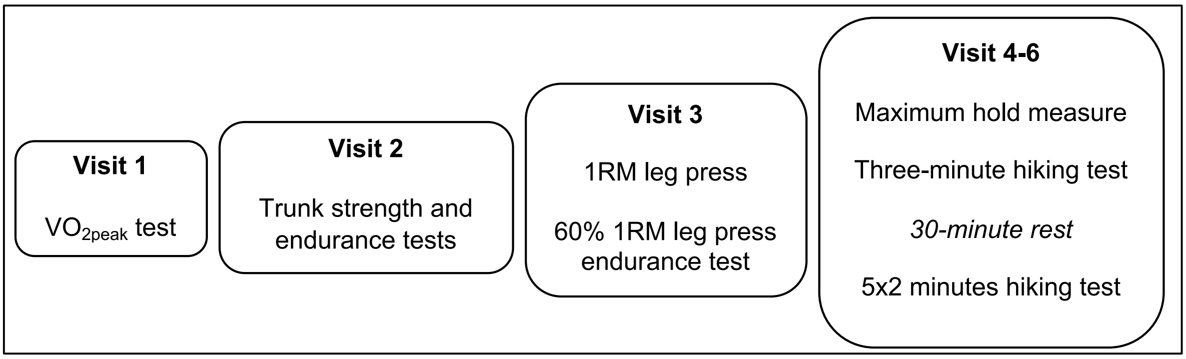

Figure 1. Schematic of study protocol

Calibration

The VO_{2peak} was completed using a Vyntus CPX (Carefusion, Germany) to collect breath-by-breath data. To control environmental conditions, pressure and temperature of the physiology laboratory were standardised and calibration of gas volume and concentration was required before each test was carried out. Concentration of CO_2 and O_2 in the air was calibrated using a gas analyser function, calibrated against an 100% oxygen control. Gas volume was calibrated using a 3L syringe to ±.05%.

VO_{2peak}

Once calibration of the Vyntus CPX (Carefusion, Germany) had taken place, participants completed a cycle incremental step test on a cycle ergometer (SRM, Germany). Throughout the test, participants were required to keep a cadence of above 80RPM. The test began with a ten-minute warm-up at 75W, and workload increased from 100W by 5W every 15 seconds thereafter until volitional exhaustion. For every test, the Vyntus CPX (Carefusion, Germany) collected breath-by-breath data: volume of oxygen inspired (VO_2; ml/min), volume of carbon dioxide expired (VCO_2; ml/min), minute ventilation (VE; l/min) and respiratory exchange ratio (RER). Maximum Minute Power (MMP; W), calculated by the highest one-minute power average, and heart rate (BPM) were collected by analysis software (SRM, Germany), and a self-reported Rated Perceived Exertion (RPE) was also recorded every minute to add another measure of physical effort. The test was terminated when a substantial fall in cadence was seen, accompanied by a RER reading of greater than 1.0 and RPE of 9-10. Heart rate also gave an indicator of when participants were approaching volitional exhaustion. On completion of the test, participants were encouraged to continue to cycle at a low workload. VO_{2peak} was calculated using the peak oxygen intake during the test, relative to body weight (ml//kg/min). Verbal encouragement was given throughout and music played to provide motivation.

Trunk strength and endurance tests

Trunk strength and endurance tests were completed to add an additional layer of testing. These tests included prone supine and side holds. For the supine hold, the participant lay supine on a physio bed with their posterior superior iliac spine on the edge of the bench. Participant maintained a position with arms crossed over their chest chest with head and neck in a neutral position, nose pointing towards the ceiling. The participant began the test sitting upright and then lowered upper body until parallel with the floor. Time began when the body was parallel, mimicking the movement adopted when maximally hiking. The test was terminated when the participants' shoulders dropped below the hip or if there was excessive flexion of the spine. They had to maintain thoracic extension and neutral head position. The athletes had to aim to hold this position for 180 seconds, although they were not informed of the time at any point during the test. This is a test regularly used to monitor performance progress within the British Sailing Team.

The prone test was carried out in an identical manner but with athletes lying prone on the physio bed with anterior superior iliac spine (ASIS) on the edge of the bed facing the floor. A chair was positioned in front of the bench bench to support the athlete when they fell and shoes were removed. Posture had to be maintained with shoulder extension and neck in neutral position. For this test, the clock was started when hips were in unsupported extension and body parallel to the ground. Hyperextension of the hips was recorded as a warning, and thoracic and shoulder extension had to be maintained. The clock was stopped when shoulders dropped below the hips. Similar to the supine hold, the athletes had to aim to hold this position for 180 seconds.

This test was also carried out on each side to determine general trunk strength. The participants lay on their side with ASIS over the bench and arms across their chest. The top hip and shoulder had to stay aligned and above the bottom hip and shoulder throughout this test. For this test, the maximum time was recorded, or the test terminated after 120 seconds. For every test, two cues were given to the participants to correct posture. After this, the clock was stopped when posture was not adjusted a third time.

One-repetition maximum test

A one-repetition max (1RM) test was conducted on a 45° leg press machine (Sportesse, Somerset, England) in the gym at the Performance Unit. The leg press had to be at least parallel, as assessed by ensuring that the greater trochanter of the hip joint was level with the knee joint (lateral epicondyle). The participant was able to adjust the seat angle as they felt appropriate in order to mirror a normal squatting back position. The depth had to be kept consistent for every repetition, defined as hip and knee at 90°. Feet had to be shoulder width apart and this was kept consistent throughout the test, and for every test. The participant had to have their back flat on the seat, holding the grip handles and feet flat on the footplate. The repetition had to be discounted if the participant failed to perform knee flexion to the correct depth and if they failed to return to the start position without intervention. Baechle (1994) provided guidelines to enable the best 1RM score to be collected. The athlete was to complete a warm-up to ensure that injury was not inflicted during this test. This warm-up involved 2-3 sets of 1-2 repetitions with no weight, followed by adding light weight to practise. The participant then had to perform 2-3 repetitions at 40, 75 and 85% of their predicted load. This had to be calculated by taking into account previous 1RM scores. Participants began single test reps at 90% of their predicted 1RM load. There was 2-3 minutes' rest between each warm up set and between test reps. Final weight achieved was recorded at the participant's 1RM.

Endurance test

The endurance test was completed in the same testing session as the 1RM, with 30-minutes' rest. Participants were required to complete as many repetitions at 60% of their 1RM as possible, a protocol used by Wax et al. (2012) to measure muscle endurance. The same criteria were used to define a correct repetition and the number of repetitions was completed as a measure of lower leg endurance. During this test, a metronome was used to prevent the influence of movement velocity and ensure greater control. The metronome was set to 40bpm.

Table 1.

Participant anthropometric and maximal test measurements

	Participant								
	1	2	3	4	5	6	7	Average ± SEM	
Sex	Female	Female	Male	Male	Male	Male	Male		
Age (years)	20	20	19	20	18	22	23	20	± .64
Height (m)	1.70	1.76	1.88	1.83	1.76	1.84	1.85	1.80	± .02
Body Mass (kg)	67.35	76.18	79.25	79.38	79.77	84.50	84.00	78.63	± 2.17
VO_{2peak} (ml/kg/min)	45	42	58	55	58	62	63	54.71	± 3.15
HR_{peak} (bpm)	187	192	192	183	197	188	192	190.14	± 1.71
MMP (W/kg)	4.37	3.77	4.67	4.67	4.79	5.39	5.49	4.74	± .22
1RM (kg)	260	260	415	360	440	380	420	362.14	± 28.20
60%1RM (reps)	48	54	24	30	33	23	33	35.00	± 4.44

Values are expressed as mean ± standard error of the mean (SEM)

Hiking bench

In order to increase the specificity of the testing, a hiking bench was used as a measure of on-land hiking performance. This hiking bench was attached to a force plate, allowing the area under the curve to be calculated, representing work done, and therefore righting moment.

All participants were fasted for these trials. Three trials were conducted in each session: five second maximum hold test to give us a measure of maximum righting moment, a three-minute maximum hold and a ten-minute sub-maximal test. There was a minimum of 24 hours between testing sessions. To collect the maximum righting moment of each participant, every participant adopted the correct hiking posture, where force through the hiking bench was the greatest. The toe straps could be adjusted as the participants felt necessary to their optimal length to gain the greatest righting moment; however, they were then kept the same for subsequent testing, to ensure higher levels of control. The maximum righting moment was recorded for every participant. The three-minute test (HM_{180}), adopted from Tan et al. (2006) was conducted first to replicate off-the-line hiking, whereby athletes were required to hike as hard as possible for three minutes. Participants were required to hike maximally for three-minutes. This test was followed by five sets of two minutes hiking, interspersed with five seconds rest to simulate tacking on the water. This test was designed to replicate the first leg of a race, the upwind leg, which typically lasts for approximately ten minutes (Callewaert et al., 2013), and was conducted after the HM_{180} to most accurately replicate actions on the water. Verbal encouragement was given throughout both tests. It was acceptable for the athletes to rest and adjust body weight as they felt necessary. For these tests, heart rate and breath-by-breath data were collected. Athletes were required to wear their hiking pads, as used on the water, and instructed to wear trainers.

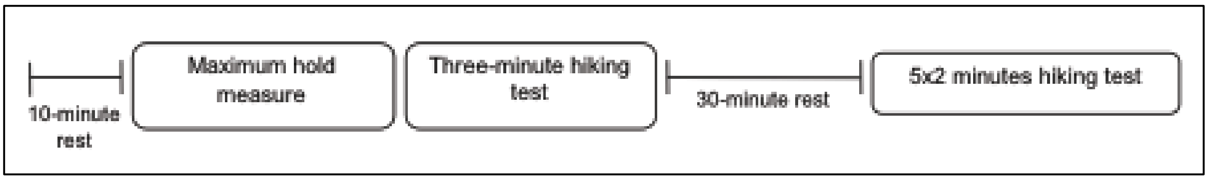

Figure 2. Schematic of hiking bench protocol

Moment is defined as the downward force (f) multiplied by the length of the lever from the pivot (d). In order to calculate the righting moment (RM) produced on the hiking bench, the force reading (f) was multiplied by the distance between contact points of the hiking bench – from the toe straps to where the hiking bench was in contact with the force plate (d).

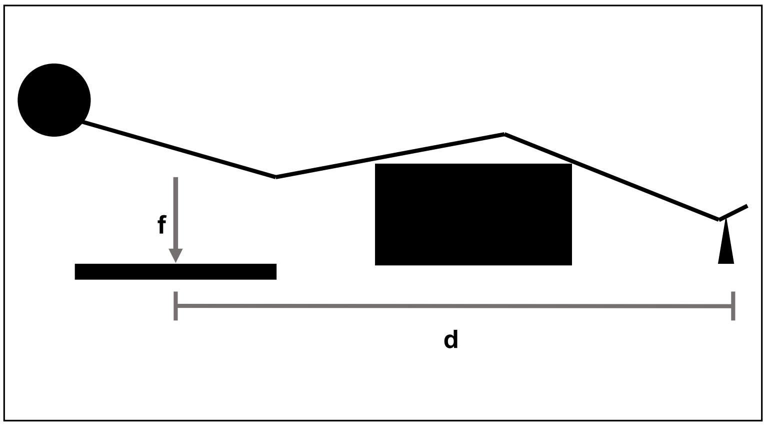

Figure 3. Diagram to demonstrate the set up of the hiking bench and the measurements required to calculate righting moment (RM=dxf).

Coach subjective scores

Five coaches from the British Sailing Team who coached hiking boat classes were asked to define their criteria when distinguishing the athletes' on-water coaching ability. After gathering this information, criteria were established for the coaches to use to rank their sailors. This increased standardisation and, therefore, control, allowed for both coaches to mark off the same criteria, with reduced variability. Coaches agreed that hiking position was the largest predictor of hiking performance. Toes should be slightly pointed in the toe straps, with ankles neutral. Straight legs show that quadriceps are engaged, and glute activation means that hips are extended. From this position, the spine and shoulders should be neutral, with arms high, giving greater control of the tiller and the mainsheet. In addition to this desired position, it was also important to distinguish sailors hiking ability based on the length of time the position could be held for. Taking all these factors into account, the coaches scored the athletes and then ranked them against the other participants in their class.

Statistics

IBM SPSS (Version 24) was used for statistical analysis of data. Bivariate analysis was used to establish correlational relationships between variables. Subjective coach rankings were analysed against other measures using Spearman's Rank Correlation Coefficient, while other variables were analysed against each other using Pearson's Correlation Coefficient. Significance was set at $p<.05$.

Results

Key findings are reported as both tables and figures, with individual scores and correlation coefficients where significance is reported as $p<.05$.

Table 2.

Descriptive results of test variables

Participant	1	2	3	4	5	6	7	Average
Coach's Ranking	1	2	5	3	4	1	2	
Prone hold (s)	180	180	180	180	180	180	180	180.00
Supine hold (s)	155	180	177	180	128	180	123	160.43
Left hold (s)	120	120	100	120	120	120	97	113.86
Right hold (s)	111	120	100	120	120	120	120	115.86
Maximum potential righting moment (Nm)	697	699	772	795	834	897	871	794.90
3min								
Total work done (J)	116971	119723	134026	133312	140288	152716	145997	134719.07
Average righting moment (Nm)	646	665	744	741	779	855	811	748.82
Average percentage of maximal righting moment (%)	92.72	95.14	96.35	93.22	93.49	95.32	93.13	94.20
Average percentage VO_{2peak} (%)	22.08	25.57	19.89	25.58	35.79	24.03	13.33	23.75
Average percentage HR_{max} (%)	49.29	69.48	48.67	52.34	56.12	46.45	48.18	52.93
5x2min								
Total work done (J)	354812	380344	400578	428514	456135	479744	469559	424240.79
Average righting moment (Nm)	591	634	668	704	754	800	783	704.69
Average percentage of maximal righting moment (%)	84.85	90.67	86.44	88.63	90.40	89.13	89.88	88.57
Average percentage VO_{2peak} (%)	26.48	35.61	24.59	35.54	40.07	26.66	20.81	29.97
Average percentage HR_{max} (%)	51.97	71.04	49.19	60.73	60.00	47.95	55.21	56.58

Table 3.

Standard deviations (SD) and coefficients of variation (CV) of repeated test variables

Participant	**1**		**2**		**3**		**4**		**5**		**6**		**7**	
	SD	**CV**	**SD**	**CV**	**SD**	**CV**	**SD**	**CV**	**SD**	**CV**	**SD**	**CV**	**SD**	**CV**
Maximum potential righting moment	25.89	4.57	62.73	11.04	6.72	1.07	20.37	3.15	23.39	3.45	4.81	0.66	29.43	4.16
3min														
Total work done	3282.45	2.81	12688.97	10.60	1805.92	1.35	1402.61	1.05	2194.32	1.56	3252.11	2.13	9120.72	6.25
Average righting moment	11.08	2.59	70.49	10.60	9.36	1.26	7.80	1.05	12.19	2.56	29.70	3.47	50.67	6.25
Average percentage of maximal righting moment	3.22	3.47	0.46	0.48	2.24	2.33	0.78	2.81	1.84	1.97	3.95	4.15	1.95	2.09
Average percentage VO_{2peak}	1.17	5.32	3.23	12.65	3.61	18.13	3.79	5.54	3.33	9.30	0.77	3.21	0.69	3.29
Average percentage HR_{max}	3.79	7.69	0.79	1.14	1.10	2.27	2.07	3.96	5.18	9.23	0.75	1.63	0.37	0.76
5x2min														
Total work done	15582.45	4.39	38441.12	10.11	14255.27	3.56	15460.62	3.61	9136.75	2.00	4024.16	0.84	23340.59	4.97
Average righting moment	25.97	4.39	64.07	10.11	23.76	3.56	11.65	1.65	12.09	1.60	6.71	0.84	38.81	4.96
Average percentage of maximal righting moment	2.22	2.61	1.05	1.15	4.00	4.63	5.34	5.99	2.72	3.01	0.47	0.53	0.72	0.80
Average percentage VO_{2peak}	1.84	6.93	2.60	7.29	0.40	1.61	2.33	6.55	1.66	4.15	1.82	6.82	1.67	5.10
Average percentage HR_{max}	2.27	4.37	2.10	2.96	1.84	3.74	1.55	2.55	3.38	5.63	0.75	1.57	2.21	4.00

Table 4.

Correlation coefficients between testing parameters

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Coach's Ranking
1	Height (m)		.826*	.782*	.737	-.829*	.726	.597	-.088	.646	-.527	.130	-.638	-.185	.708	.706	.500	-.359	-.357	.610	.614	.211	-.353	-.350	.164
2	Body mass (kg)	.826*		.843*	.759*	-.705	.878*	.710	.065	.878*	-.068	-.144	-.396	.309	.909*	.911*	.337	-.127	-.139	.905*	.911*	.633	-.152	-.144	-.255
3	VO_{2peak} (ml/kg/min)	.782*	.843*		.912*	.891*	.962*	.935*	-.047	.941*	-.170	-.334	-.494	.067	.949*	.942*	.098	-.186	-.640	.887*	.890*	.236	-.345	-.595	-.273
4	1RM (kg)	.737	.759*	.912*		-.823*	.785*	.734	.249	.792*	-.312	-.434	-.507	-.040	.807*	.795*	.119	.038	-.422	.774*	.767*	.290	-.101	-.378	.294
5	60% 1RM endurance (reps)	-.829*	-.705	.891*	-.823*		-.802*	-.785*	.055	-.777*	.413	-.041	.259	.188	-.815*	-.812*	-.307	.083	.716	-.694	-.690	.011	.262	.657	.460
6	MMP (W)	.726	.878**	.962*	.785*	-.802*		.960*	-.173	.979*	.020	-.294	-.418	.248	.978*	.975*	.060	-.261	-.596	.935*	.943*	.329	-.393	-.557	-.418
7	MMP (W/kg)	.597	.710	.935*	.734	-.785*	.960*		-.265	.929*	.039	-.374	-.397	.158	.912*	.906*	-.093	-.298	-.796	.847*	.856*	.106	-.487	-.741	-.376
8	HRmax (bpm)	-.088	.065	-.047	.249	.055	-.173	-.265		-.066	-.270	-.163	.103	-.145	-.010	-.009	.418	.628	.381	-.001	.002	.307	.474	.205	.523
9	Maximum potential righting moment (Nm)	.646	.878*	.941*	.792*	-.777*	.979*	.929*	-.066		.127	.031	-.260	.365	.991*	.990*	.020	-.068	-.492	.980**	.983*	.430	-.215	-.438	-.346
10	Prone trunk hold (s)	-.527	-.068	-.170	-.312	.413	.020	.039	-.270	.127		-.286	.580	.902*	.028	.023	-.684	.250	.236	.209	.220	.434	.335	.404	-.612
11	Supine trunk hold (s)	.130	-.144	-.334	-.434	-.041	-.294	-.374	-.163	.031	-.286		.329	-.238	-.317	-.223	-.243	.602	.021	.172	-.337	-.336	-.212	.092	-.075
12	Left trunk hold (s)	-.638	-.396	-.494	-.507	.359	-.418	-.397	.103	-.260	.580	.329		.453	-.283	-.298	-.212	.737	.387	-.212	-.190	.092	.711	.352	-.136
13	Right trunk hold (s)	-.185	.309	.067	-.040	.188	.248	.158	-.145	.365	.902*	-.238	.453		.291	.286	-.461	.291	.319	.484	.498	.755*	.422	.505	-.340
	3min																								
14	Total work done (J)	.708	.909*	.949*	.807*	-.815*	.978*	.912*	-.010	.991*	.028	-.317	-.283	.291		1.000*	.149	-.081	-.484	.966*	.972*	.418	-.240	-.462	-.255
15	Average righting moment (Nm)	.706	.911*	.942*	.795*	-.812*	.975*	.906*	-.009	.990*	.023	-.223	-.298	.286	1.000*		.163	-.075	-.475	.965*	.971*	.423	-.235	-.456	-.255
16	Average percentage of maximal righting moment (%)	.500	.337	.098	.119	-.307	.060	-.093	.418	.020	-.684	-.243	-.212	-.461	.149	.163		-.053	.033	-.006	.016	.043	-.129	-.188	.382
17	Average percentage VO_{2peak} (%)	-.359	-.127	-.186	.038	.083	-.261	-.298	.628	-.068	.250	.602	.737	.291	-.081	-.075	-.053		.345	.032	.002	.304	.910*	.439	.273
18	Average percentage HR_{max} (%)	-.410	-.233	-.670	-.473	.709	-.627	-.785*	.437	-.541	.236	.172	.387	.319	-.523	-.532	.119	.423		.383	-.375	.515	.659	.930**	.319
	5x2min																								
19	Total work done (J)	.610	.905*	.887*	.774*	-.694	.935*	.847*	-.001	.980*	.209	.172	-.212	.484	.966*	.965*	-.006	.032	-.302		.999*	.593	-.065	-.232	-.346
20	Average righting moment (Nm)	.614	.911*	.890*	.767*	-.690	.943*	.856*	.002	.983*	.220	-.337	.190	.498	.972*	.971*	.016	.002	-.308	.999*		.587	-.102	-.254	-.346
21	Average percentage of maximal righting moment (%)	.211	.633	.236	.290	.011	.329	.106	.307	.430	.434	-.336	.092	.755*	.418	.423	.043	.304	.629	.593	.587		.448	.647	-.073
22	Average percentage VO_{2peak} (%)	-.353	-.152	-.345	-.101	.262	-.393	-.487	.474	-.215	.335	-.212	.711	.422	-.240	-.235	-.129	.910*	.642	-.065	-.102	.448		.789	.273
23	Average percentage HR_{max} (%)	-.355	-.162	-.564	-.380	.659	-.512	-.673	.219	-.427	.404	.031	.352	.505	-.451	-.455	-.151	.374	.930**	-.261	-.242	.602	.689		-.543

** indicates a significant correlation between variables (p<.05)*

Pearson correlation for variables 1-19, Spearman correlation was used for Coach's Ranking.

On-water coaches' ranking

The primary aim of this study was to establish whether hiking bench protocols distinguished performance ability on-water. Results showed that there were no significant relationships between on-water coaches' rankings and performance on the hiking bench, in both the three minute (*r*= -.255, *p*=.582) and 5x2 minute test (*r*= -.346, *p*=.448), as shown using work done of the duration of each test (Fig. 4). No other testing parameters showed a significant relationship with on-water performance ranking.

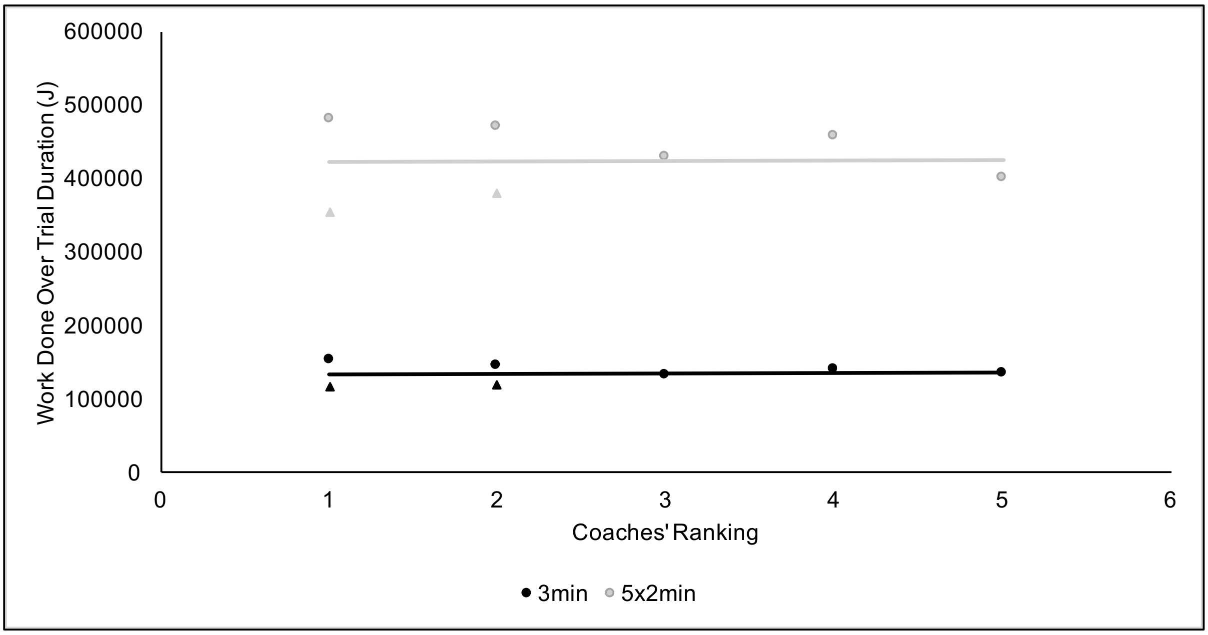

Figure 4. The correlations displayed as a scatter graph between work done over the trial and coaches' ranking. Female participants are shown by ▲.

Figure 5 shows the correlation between the effort of each participant during the two test protocols, measured by the percentage of potential maximum righting moment held. There was no significant correlation in both the three-minute and the 5x2-minute tests, in both males and females. The correlation coefficient for the three-minute hiking bench test was reported as $r=.382$ ($p>.05$); furthermore, the 5x2-minute trials reported similar results with a correlation coefficient of $r=.073$ ($p>.05$).

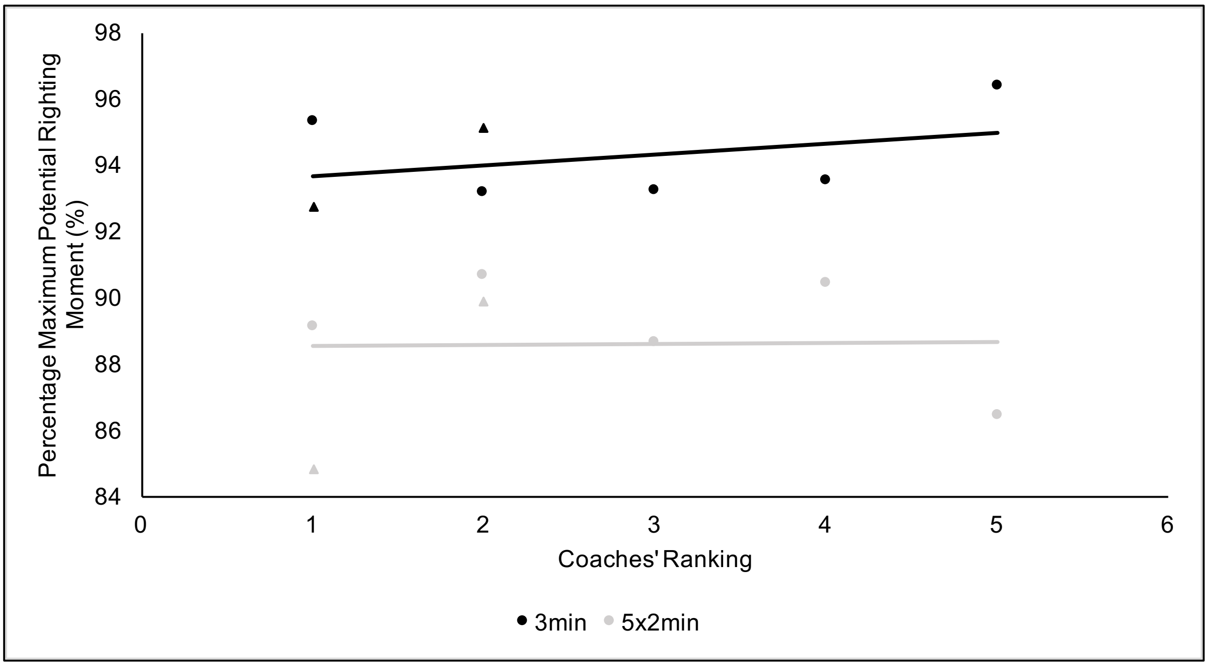

Figure 5. The correlations shown between the coaches' scores and the percentage of maximum potential righting moment in both land-based trials. Female participants are shown by ▲.

Average righting moment

Average righting moment in both testing protocols was the variable showing the greatest correlation with other parameters. In the three-minute protocol, VO_{2peak} showed a significant correlation with average and total righting moment with a correlation coefficient of $r=.942$ ($p=.002$) and $r=.949$ ($p=.001$), respectively (Fig. 6). Maximum Minute Power per kilogram of body mass (MMP/kg) showed a correlation coefficient with average and total righting moment of $r=.906$ ($p=.005$) and $r=.912$ ($p=.004$), respectively (Fig. 7), while 1RM showed average righting moment correlated with a coefficient of r=.795 (p=.033) and total righting moment with a coefficient of r=.807 (p=.028) (Fig. 8).

The longer 5x2-minute protocol also showed significant correlations with the same variables. VO_{2peak}, MMP/kg and 1RM correlated significantly with both average and total righting moment over the duration of the trials. VO_{2peak} reported correlation coefficients of r=.890 (p=.007) and r=.887 (p=.008) for average and total righting moment, respectively (Fig. 6). MMP/kg showed significant correlations of r=.856 (p=.014) and r=.847 (p=.016), respectively (Fig. 7), and 1RM scores correlated with average and total righting moment with coefficients of r=.767 (p=.044) and r=.774 (p=.041), respectively (Fig. 8).

Maximum potential righting moment also had statistically significant strong positive correlations with VO_{2peak}, MMP/kg and 1RM. A correlation coefficient of r=.941 (p=.002) was shown when correlated with VO_{2peak} (Fig. 6), MMP/kg showed a correlation coefficient of r=.979 (p=<.001) (Fig. 7), and finally 1RM complimented these findings by showing a correlation coefficient of r=.792 (p=.034) (Fig. 8).

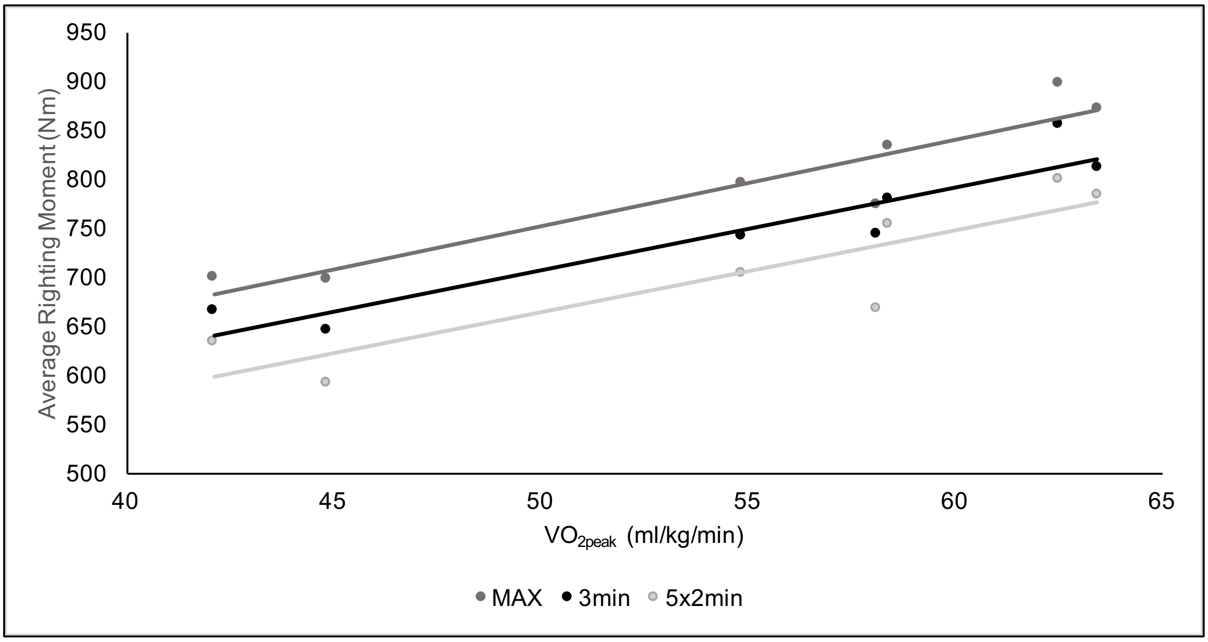

Figure 6. The correlations between average righting moment and VO_{2peak} shown over maximum potential righting moment, the three-minute trial and 5x2-minute trials.

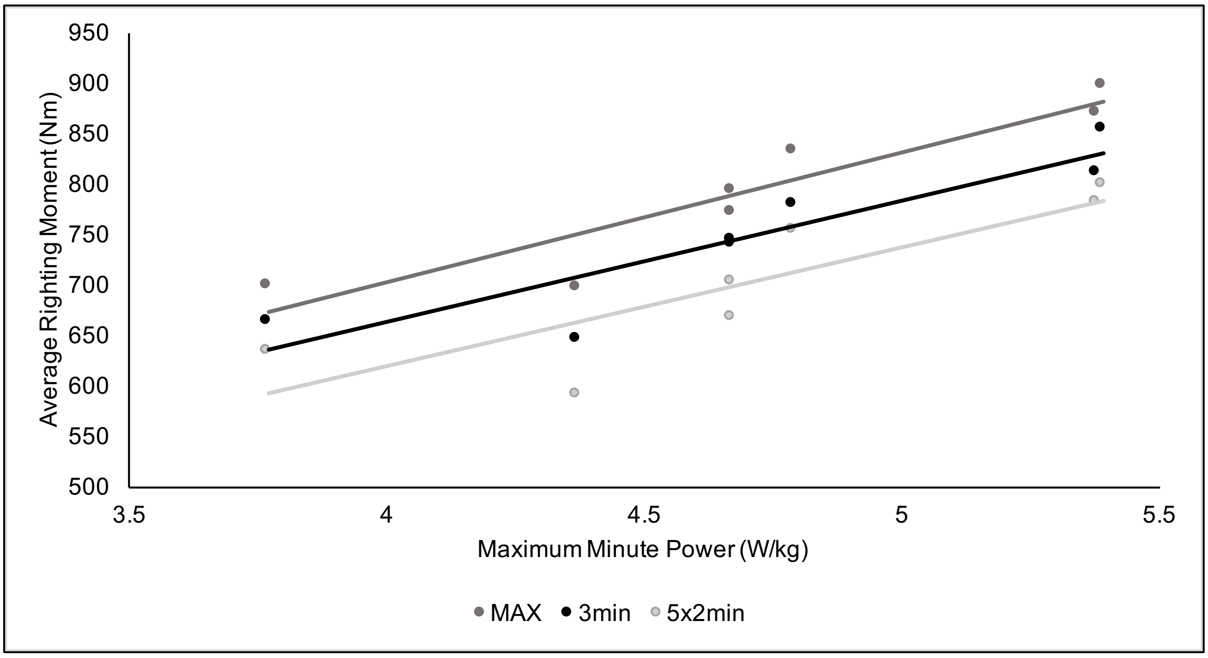

Figure 7. The correlations between average righting moment and maximum minute power per kg shown over maximum potential righting moment, the three-minute trial and 5x2-minute trial.

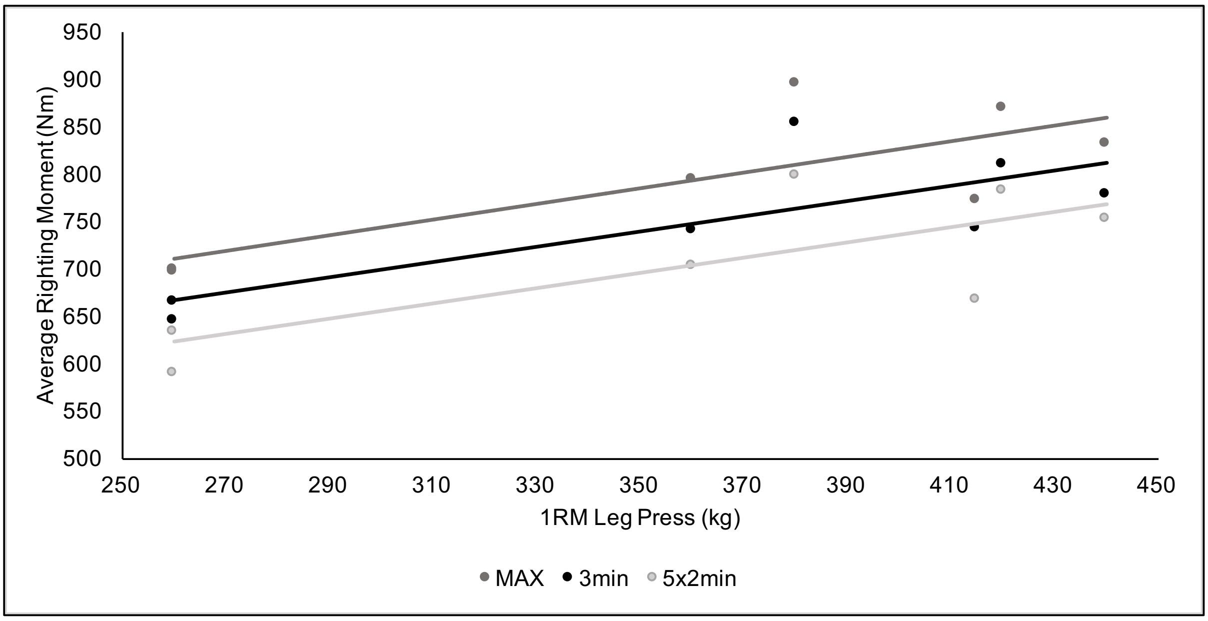

Figure 8. The correlations between average righting moment and leg press 1RM shown over maximum potential righting moment, the three-minute trial and 5x2-minute trial.

VO_{2peak} and heart rate

For both hiking bench tests, the percentage of VO_{2peak} that the participants worked at in both trials showed no significant correlation with percentage HR_{max}, as collected during the incremental cycling test. The correlation coefficient for the three-minute hiking test was r=.345 (p>.05), while the 5x2-minute trials showed a correlation coefficient of r=.789 (p>.05) (Figure 9).

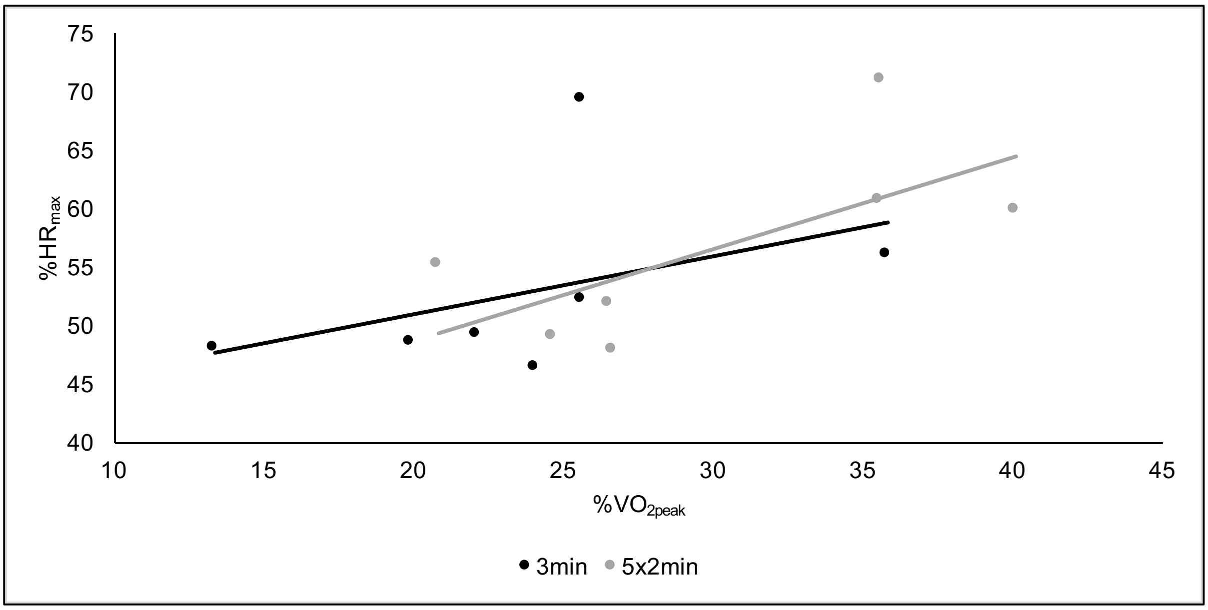

Figure 9. The correlations between average percentage of maximum heart rate and average percentage VO_{2peak} in both three-minute and 5x2-minute trials.

Hiking bench protocols

Figure 10 shows the difference in the percentage of maximum potential righting moment sustained throughout each hiking bench protocol. There is a significant decrease of 5.95 ± 2.62% from the three-minute test to the more prolonged 5x2-minute test. Participant 3 saw the largest decrease in percentage of maximum potential righting moment (10.28%), while Participant 5 saw the smallest decrease in effort (3.31%) between the three-minute and 5x2-minute trials.

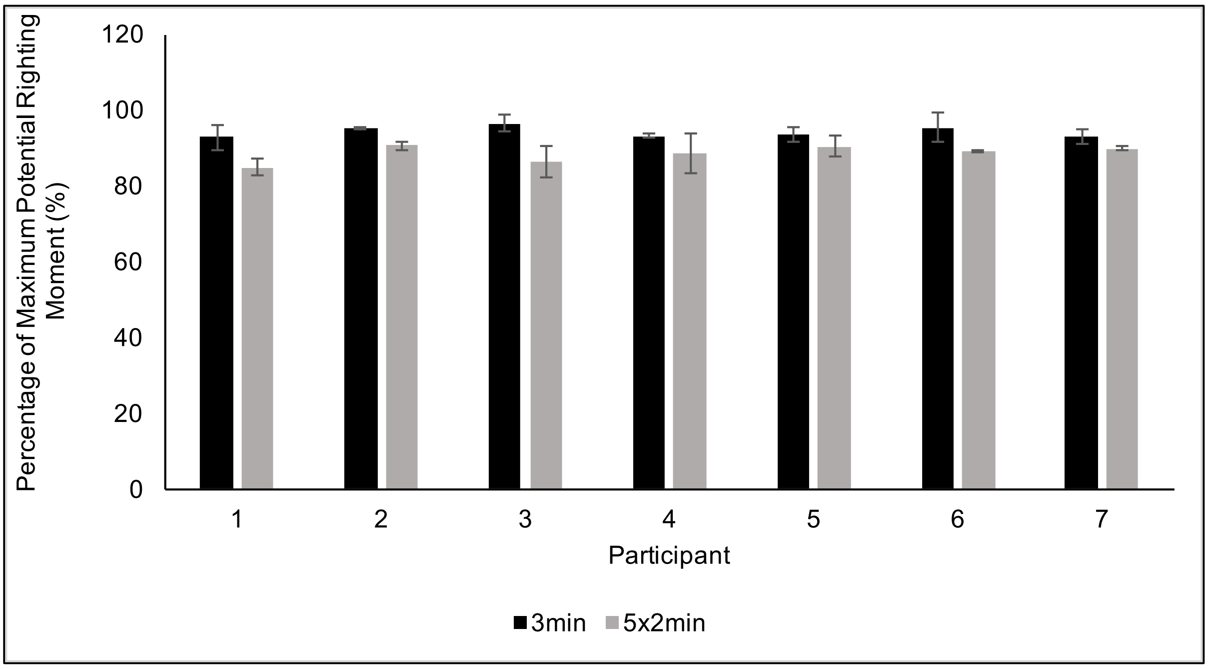

Figure 10. The differences displayed in percentage of maximum potential righting moment between each trial (three-minute and 5x2-minute trials).

Discussion

The present study was the first to try to determine 'the best from the rest' in on-water hiking performance in Laser sailors within the RYA British Sailing Team by using two land-based hiking protocols. The primary aim of this study was to determine whether results of the land-based tests provided correlations with on-water performance, as assessed through coaches' rankings. There was no significant correlation between on-water ranking and any of the measured variables; however, VO_{2peak} showed a significant correlation with righting moment generated in both the three-minute and the longer 5x2-minute test, as well as maximum potential righting moment, suggesting the physical attributes could be a predictor of performance on the hiking bench.

Previous studies have developed hiking bench protocols in an effort to monitor and predict performance (Tan et al., 2006; Vogiatzis et al., 2011). The current study used the established three-minute protocol used by Tan et al. (2006); however, it also introduced a longer trial for the purpose of increasing the representability of the hiking bench to sailing on the water. Legg (1999) stated that, using notational analysis, hiking is interrupted every 128-174s by tacking which lasts approximately 4-9s while assessing elite New Zealand sailors (n=19). Hence, the protocol established for the present study used five two-minute hiking sets, interspersed with five seconds rest. During testing, athletes also reported that the longer test was more representative of on-water hiking, while three minutes represents off-the-line hiking, further justifying the use of a longer hiking protocol, as well as the already-established three-minute test.

Coaches' ranking

Coaches highlighted three limiting factors to performance: physical attributes, the ability to use physical attributes, and the ability to translate physical attributes on to the water. For example, it is possible to have the physical attributes but if they cannot be used at the correct time on the water, it may lead to very little speed reward, and therefore reduced efficiency of energy on the water in an effort to improve boat speed. The hiking test protocols primarily test the ability to utilise the physical attributes seen in the other tests, while it fails to take into account the sailor's ability to use the physical attributes on the water.

The present study was novel in measuring hiking performance on the water using coaches' rankings. This study showed no significant correlation (p>.05) between ranking and any of the parameters measured on the hiking bench (Fig. 4). Nor did it show any correlation with anthropometric and strength and endurance measures.

Many studies have used National Rankings or single regatta results as a measure of on-water hiking performance (Bourgois et al., 2015; Callewaert et al., 2013; Vangelakoudi et al., 2007). Tan et al. (2006) used race scores to measure on-water hiking and found a significant correlation with body mass (r=-.69, p<.001) and hiking moment over three minutes on the hiking bench (r=.62, p<.001). As previously discussed, whole race scores take into account every aspect of sailing, without isolating hiking performance. Therefore, any association with race scores or National Ranking against hiking protocols could be a reflection of holistic performance, rather than solely focussing on hiking.

The most likely reason for no correlation being seen with ranking is the difference in the nature of the hiking between on-land and on-water. On-water, hiking is a vastly more dynamic activity, especially in elite sailors (Cunningham and Hale, 2007). The dynamic component of hiking increases the physiological requirements, which would perhaps lead to a significant correlation if the land-based protocols were more dynamic. With the static hiking bench, it reduces the movement needed to compensate for waves, and also gave no option to reduce some of the strain through the tiller and the mainsheet, increasing neuromuscular fatigue of the trunk, quadriceps and hip flexors on land (Bourgois et al., 2015). Mackie and Legg (1999) reported that an average of 22% of predicted MVC (78N) could be offloaded using the mainsheet, while Blackburn (1994) reported that the tiller took 15N of the load during upwind sailing. Despite the static nature of the hiking bench protocols, Vangelakoudi et al. (2007) found that static and dynamic contractions could be held for up to twice as long in elite sailors, compared to their club level counterparts, suggesting that static training could be an important training component to improve hiking on the water.

Another possible explanation for the lack of correlation between rankings and land-based results could be due to the variety of other factors which contribute to hiking performance on the water, such as decision-making and conditions on the water. Coaches have commented that greater on-water hiking performance is associated with knowledge. For example, the ability to know when to use righting moment to increase speed on the water increases efficiency and may therefore lead to greater endurance and greater overall righting moment. As these factors were not considered in the hiking bench protocols, it is only possible to speculate reasons for the results in this study; however, many of these possibilities could be addressed in further research.

Mental toughness is a large part of physical performance, defined by several different components: motivation level, coping, confidence, cognitive skill, discipline and competitiveness (Jones et al., 2002). Within this definition, motivation level may be a key difference in participants between on-water and land-based hiking. Between training and competition, achievement goals differ, and therefore, motivation is different. During training, goals are much more task-oriented, increasing the effect of effort and enjoyment (Harwood, 2002). When in a racing environment, ego orientation is greater, highlighting increased social comparison and reducing the effect of effort and enjoyment (Smith et al., 2006). When taking this theory into the context of the present study, it highlights that motivation to achieve is likely to never be as high as when in a competitive setting, perhaps proposing that differences between land-based and on-water hiking performance could be attributed to motivational differences. In addition to this, participants also emphasised an increase in attentional focus towards hiking posture which is not present during on-water hiking, due to distractions of decision-making and dynamic factors on the water.

Another factor that was also neglected during the hiking bench trials was the effect of pain tolerance. Pain tolerance is defined as the maximum level of stimulus a person is able to withstand before seeking a way to cease the pain (Woodrow et al., 1972). As a result, a higher pain tolerance may lead to a participant having a greater sustained effort and therefore greater righting moment throughout the trials.

Taking into account the psychological factors highlighted above, it is impossible to establish whether differences in results are due to pain threshold or motivation; however, it may be reasonable to assume that differences in performance are due to a large mental component, rather than physical factors. However, no conclusions can be drawn as any correlations do not assume causation.

Righting Moment

Average righting moment and work done in both hiking bench protocols showed the greatest correlation with VO_{2peak} (Fig. 6), maximum minute power (MMP) (Fig. 7) and 1RM on leg press (Fig. 8).

Tan et al. (2006) used the same three-minute protocol as the present study. It was found that there was no significant correlation between righting moment over three-minutes and the athletes' time to exhaustion (*r*=.13; *p*>.05). This result differs from those found in the present study. One reason could be due to the different types of protocol used to determine aerobic fitness. Tan et al. (2006) used time to exhaustion on an incremental cycle test to establish aerobic fitness; however, in the present study VO_{2peak} was able to be measured through an incremental cycling ramp test, increasing the accuracy of measuring aerobic capacity.

Another possible reason for differences in these results could be due to a difference in samples. Tan et al. (2006) recruited participants from a National Sailing Centre. Out of the sample, only ten of 55 participants raced internationally. In the present study, all the participants were of an international standard. It has been highlighted previously by Cunningham and Hale (2007) that as the level of sailing increased, hiking relies more greatly on physiological attributes. This could therefore explain why in the present study, a significant correlation was seen with aerobic fitness and hiking bench performance, which was not seen by Tan et al. (2006).

A significant correlation between righting moment and VO_{2peak} in the current study may be explained by blood flow restriction to the quadriceps when hiking. Due to the position of the body when hiking, blood vessels are occluded around the pelvis. This results in the restriction of blood flow, therefore less oxygen being delivered to the muscle. Bassett and Howley (2000) outlined that oxygen delivery to the muscle is the limiting factor of VO_{2peak}. Due to this phenomenon, with a greater VO_{2peak}, with blood flow still being restricted, there will be an increase in oxygen availability to the muscles, compared to a participant with a lower VO_{2peak}. With greater oxygen availability, muscle cells are able to increase mitochondrial activities in the cell leading to greater aerobic respiration. An increase in aerobic respiration prolongs the onset of fatigue and allows greater endurance (Bourgois et al., 2015). Although this is only speculation, it is possible that the association of VO_{2peak} and total righting moment in both land-based tests is as a result of increased oxygen availability to the quadriceps, even with the restriction of blood flow.

Despite the differences in results between Tan et al. (2006) and the present study when observing aerobic fitness, a significant correlation was seen by Tan et al. (2006) between 3RM leg extension and hiking test results (r=.80, p<.01). Although the present study used leg press instead of leg extension, both methods showed a measure of quadriceps strength. 30% of MVC of the quadriceps is used when hiking (Vogiatzis, 1995). This was calculated by asking participants to complete four sets of three-minutes on a hiking bench, with 15 seconds rest. Although this protocol differs from both used in the current study, it gives evidence that quadriceps are the major muscle used in hiking performance. This is closely followed by the rectus abdominis, which used 15% MVC for the specific hiking activity. This supports correlations to say that quadriceps strength, and therefore 1RM on a leg press, suggest that quadriceps strength is an important factor to predict hiking performance on land. There is limited published research documenting quadriceps strength in elite hiking sailors; however, Aagaard et al. (1998) assessed the strength profiles of hiking sailors and reported that the sample (n=21) had greater knee extensor and trunk than a control group (n=8). Although hip flexor strength was also greater in hiking sailors, the best hikers have been highlighted by coaches to bear the majority of load on the knee extensors, as this is also a way to minimise injury to the lower back due to increased pressure on the lumbar spine (Putnam, 1979). Other peripheral muscles are also involved in hiking to stabilise joints and optimise hiking performance (Aagaard et al., 1998); however, due to the present study only measuring strength by 1RM, it is impossible to isolate individual muscles to establish differences in strength. Aagaard et al. (1998) also found a positive correlation with hiking performance and maximum isometric-eccentric knee extensor strength, suggesting that optimal hiking performance demands high knee extensor strength, although no cause and effect was established. A later study (Vangelakoudi et al., 2007) reported that there was no significant correlation between hiking endurance time and isometric quadriceps strength, contradicting the earlier study by Aagaard et al. (1998). Vangelakoudi et al. (2007) suggested that this could be due to other muscle groups involved in hiking not being taken into account with the isometric quadriceps strength test, posing a question as to whether the 1RM leg press test used in the present study is a more appropriate measure of muscle strength required in hiking. With a limited sample size in the study by Aagaard et al. (1998), it is possible that these findings may not be representative of the population; however, Blackburn (1994) showed a strong positive correlation between knee extensor strength and hiking performance, supporting findings of Aagaard et al. (1998) and showing that the present study is in line with existing research.

Maximum Minute Power expressed relative to body mass (MMP/kg) showed a significant correlation with average righting moment in both hiking bench protocols: r=.906 (p=.005) and r=.856 (p=.014), respectively for the three-minute and 5x2-minute tests. Although there is very little literature on the relationship between power in a cycling incremental exercise test and hiking performance, a significant correlation was also seen between VO_{2peak} and MMP/kg of r=.935 (p<.05) in the current study. This finding is supported by a cycling study by Hawley and Noakes (1992), reporting a correlation of r=.97 (p<.001) between Peak Power Output and VO_{2peak} in a sample of 100 cyclists. This supports the present study by reinforcing findings with a greater sample size and concluding that Peak Power Output is a predictor of VO_{2peak}. Although conclusions cannot be drawn, this may provide some evidence that suggests that MMP may predict hiking performance.

Oxygen uptake and heart rate

The findings of the present study were in line with VO_{2peak} scores seen in other land-based hiking studies, many of which reported VO_{2peak} scores of between 55 and 62ml/kg/min in elite Laser sailors (Larsson et al., 1996; Blackburn, 1994; Cunningham and Hale, 2007), while the present study showed an average VO_{2peak} of 55 ± 3.15 ml/kg/min. Previous studies also found that land-based hiking showed a $\%VO_{2max}$ of approximately 39 ± 6% and a $\%HR_{max}$ of 74 ± 11% during 18 bouts of 90s hiking (Callewaert et al., 2013), compared to an average of 23.75% and 29.97% VO_{2peak}, in the three-minute and 5x2-minute trial respectively, and a $\%HR_{max}$ of 52.95% and 56.59% in the respective trials.

The present study showed no significant correlation between heart rate and oxygen uptake during both hiking bench trials. The three-minute trial showed a correlation of r=.345 (p>.05), while the longer 5x2-minute test showed a correlation of r=.789 (p>.05). Many studies have looked at the correlations between oxygen uptake and heart rate during hiking (Spurway, 2007; Cunningham and Hale, 2006), dividing opinion on the physiological mechanisms of hiking and the association between whole-body oxygen uptake and heart rate. Vogiatzis et al. (2008) also concluded that the isometric component of hiking may limit blood flow to the quadriceps and therefore reduce oxygen availability. This study recruited six male Laser sailors, of a national standard, and through investigating oxygen saturation of the *vastus lateralis,* using surface electromyography (sEMG), saw that oxygen saturation gradually decreased throughout repeated simulated hiking bouts. From this finding, this study sought to conclude that a reduction in oxygen saturation translated to a decrease in oxygen availability, either dictated by reduced oxygen delivery, increases in demand, or a combination of the two variables (Vogiatzis et al., 2008). A later study conducted by Vogiatzis et al. (2011) aimed to establish how much blood flow was restricted to the quadriceps during simulated hiking, compared to cycling at the same cardiac output. It was found that blood flow to the quadriceps, measured using near-infrared spectroscopy (NIRS) was three times greater in cycling compared to hiking, with quadriceps' blood flow in hiking not increasing from baseline until the final bout, where there was a two-fold increase. In contrast, cycling produced a six- to seven-fold increase from baseline. This finding, along with VO_2 in hiking only being half of that seen in cycling, showed that there is a restricted blood supply to the quadriceps in simulated hiking. It was reported that despite systemic blood flow being the same between the two modes of exercise, hiking was also associated with low increase in oxygen uptake at the muscles, out of proportion to cardiac output. One limitation of the aforementioned study (Vogiatzis et al., 2011) was that both the cycling and the hiking trials were performed in the same visit. This may have given a fatigue effect, and as there were no repeats carried out and only a small sample size (n=6), this limits the reproducibility of the study.

Blackburn (1994) conducted a study previously to explore the physiological responses associated with a simulated sailing race. Ten Laser sailors participated in the study, with the main finding supporting that of Spurway (2007), concluding that VO_2 rarely exceeded 30%. It was also highlighted that in order to reduce the onset of fatigue through reduced blood flow to the quadriceps, sailors must limit %MVC so that isometric contraction can be sustained throughout the race in order to reduce fatigue. This study supported that of Vogiatzis et al. (2011) documenting that $\%HR_{max}$ reached 62% in 90 minutes' simulated sailing, with 3x20minute hiking legs, compared to only 25% VO_{2max}, again outlining the disproportional increase of heart rate and oxygen uptake in hiking.

The above hiking-based studies highlighted the disparities between heart rate and oxygen uptake during hiking performance (Blackburn, 1994; Vogiatzis et al., 2008).

Spurway (2007) proposed the ‘quasi-isometric theory’ to explain these differences. When hiking, heart rate must increase to push blood into the muscle where there is high intramuscular pressure. It has also been identified that respiratory drive increases disproportionately to oxygen demand due to inadequate perfusion to the muscle. While this shows that hiking is primarily a static isometric activity, it contains dynamic elements, such as upper body movements to compensate for waves and the subtle movement to offload the quadriceps. Spurway (2007) observed that in hiking, quadriceps strain is rarely offloaded completely to allow completely unrestricted blood flow, due to muscle contraction and the occlusion of blood vessels around the pelvis due to body position. This means that blood flow to the quadriceps is always under what is required to meet the metabolic demand, explaining differences between oxygen uptake and heart rate during hiking. Despite the present study complementing findings of other research, it should be highlighted that VO_2 and heart rate discrepancies may be exacerbated using a land-based hiking bench. When hiking on water, sailors use a variety of active recovery methods, including tacking, compensating for waves and also shifting on alternative legs. These processes are done in an effort to alleviate restrictions in blood flow, and decrease intramuscular pressure in the muscles, allowing deoxygenated blood flow out of the muscle and allowing the inflow of oxygenated blood to help stabilise the metabolic demand of the muscle, therefore reducing fatigue (Boyas and Guével, 2011). However, land-based hiking on a hiking bench is much more static and, therefore, these processes to reduce fatigue are more difficult to implement.

Individual performances

Although there were no significant correlations between on-water hiking and land-based tests, when screening the sailors' results individually, it became clear that when the physical attributes between them were similar, there were still differences in their performance during the hiking bench protocols. When physical attributes become very similar, it is possible that time is better spent trying to utilise the attributes in order to produce the most gain in overall hiking performance. One of the possible reasons for differing results could also be the aforementioned mental components.

Two of the parameters defined as physical attributes are height and body mass. It is suggested that height results in a greater righting moment. This is due to having lever, therefore resulting in a greater righting moment and therefore greater hiking ability (Putnam, 1979). Body mass will also contribute to a higher righting moment, increasing the downward force. Nevertheless, it is important to consider that with height, more strength will be required to hold up the lever. Considering this, it is possible that height may give a greater peak righting moment; however, it may be difficult to sustain this over a long duration.

When analysing the results on an individual basis, it is possible to highlight ways which could potentially help participants improve their hiking performance.

Participants 1 and 2 were the only females within the sample. Therefore, the physical attributes of both participants can be compared directly. Participant 1 has both a smaller height and body mass compared to Participant 2. However, Participant 1 has higher scores in all physical parameters, including VO_{2peak}, MMP, 1RM. Results showed that these parameters were significantly associated with average righting moment; however, when directly comparing the females, this was not the case. Participant 2, with weaker endurance and strength scores, performed better in both hiking bench protocols. Although height and weight could be an explanation for this, with Participant 2 having both the greater lever in terms of height and greater downward force from body mass, it is also possible that the explanation lies in the percentage of maximum potential righting moment in both trials. This variable was a measure of effort during each of the trials. Participant 2 worked consistently at a much higher work rate in both trials, perhaps due to mental toughness, thereby explaining the differences in performance.

From the evidence collected during the current study, it is possible to give coaching advice to each of the participants. Participant 1 scored highly on all the physical attributes, as well as being scored highest by coaches in their on-water hiking performance; however, it is possible that increased mental resilience could improve hiking performance, as well as maintained physical ability. Tan et al. (2006) also identified that hiking performance on the three-minute hiking bench test correlated with sailing performance, with more experienced sailors utilising more efficient technique in order to increase righting moment. This may be another explanation as to why Participant 2 had greater hiking results, although no conclusions can be made as cause and effect must be established.

Participants 3, 4 and 5 were all males and of the same funding level, therefore, they can be more directly compared. Participant 3 was the tallest of all participants, giving large leverage potential; however, he was also scored the lowest in his on-water hiking ability. This was reflected in the hiking bench performance. This participant was able to hold 96.35% of his maximum during the three-minute test; whereas, over the longer trial, he was only able to sustain hiking at 86.44%. It is possible that height reduces the ability to sustain hiking over longer time periods, and coaches also reported that the participant found it difficult to sustain the correct hiking position for greater lengths of time. As well as height perhaps being a limiting factor, this was complemented by the weakest trunk scores of the sample. These factors combined may contribute to his having the lowest on-water ranking and the lowest hiking bench scores.

Participant 4 was consistent over both hiking bench tests, showing an average righting moment of 740Nm (93.22%) and 704Nm (88.63%) in the three-minute and 5x2-minute tests, respectively. Despite good scores, this participant had the weakest VO_{2peak} (55ml/kg/min) and 1RM (360kg) scores out of the males, yet was ranked third in coaches' rankings. Coaching score could be reflected in good trunk scores, allowing the participant to hold the optimum hiking position on the water for longer, and also perhaps, sailing experience, which was not measured in the present study. It could be suggested that by improving overall fitness parameters, hiking performance may improve; however, conclusions cannot be drawn assuming cause and effect.

Participant 5 had the highest scores in all physical attributes between Participants 3, 4 and 5. Scores were consistently high in both testing protocols. Being the lightest and the shortest of all participants, it could be suggested that increasing body mass, as the most variable attribute, may increase righting moment significantly. As height is not a changeable variable, another way to increase righting moment is to adjust the toe straps when hiking. Longer toe straps provide a greater lever, thus increasing the righting moment. This will add greater load when hiking, and therefore better physical attributes will be required; however, it will ultimately lead to a greater righting moment being produced.

Participants 6 and 7 were of a higher calibre of sailors and therefore scored much higher than the other participants in all tests. As with the other participants, however, it was clear that the participants with a better on-water score, also had the best land-based tests. For example, Participant 6 had a maximum potential righting moment of 897Nm and was ranked the highest on-water, compared to Participant 7, who was ranked second on-water, and had the second highest potential righting moment in the sample (811Nm).

With Participants 6 and 7 taking part in the study, and being of a higher funding level, it is possible that bench marks could be set to determine when Participants 3-5 should be reaching specific world rankings. Within this, it could also work as a tool to inform athletes that in order to be at a particular international level, these physical attributes need to be reached, among improvements in other areas of Laser sailing.

Limitations and Future Research

Conducting studies in an elite population comes with several compromises in terms of validity and control. One of the largest limitations to the present study was the training load surrounding the testing. It was not feasible for the participants to take a week out of their training in order to participate in the study, and, therefore, levels of fatigue may be varied during the testing period. In an effort to control this, participants did all testing within a week to minimise intra-specific variability. An obvious limitation associated with the participants in this current study was sample size. With only seven participants, due to restrictions in athlete availability, it is difficult to draw conclusions of the whole of the population; however, the sample size was enough to provide an indication of performance on-land compared to on the water. Future research may include a greater sample size to gain better representability of the population.

Another limitation of this study was the reduced representability to on-water hiking. Future research may include developing a land-based test which better represents hiking on the water, implementing more dynamic activity, perhaps with feedback from the ergometer similar to that experienced when hiking on-water. This will give a more accurate experience to the participants, perhaps giving a significant correlation between variables.

Conclusion

In conclusion, the present study reported that the fitness parameters measured showed a significant correlation to performance on the hiking bench in both the three-minute and 5x2-minute tests; however, it must be stressed that these variables were not enough to predict on-water hiking performance. The shorter test may have given adequate insight into the participants' capabilities, but the longer test provided greater detail into the endurance required in an upwind leg, helping with athlete profiling within the RYA British Sailing Team. Although the findings of this study cannot deduce cause and effect, it is able to suggest parameters that may improve on-water hiking performance, and therefore, advance overall sailing results.

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