Levels of Muscle Activation in Strength and Conditioning Exercises and Dynamometer Hiking in Junior Sailors

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[1]School of Exercise and Health Sciences, Edith Cowan University, Perth, Western Australia; [2]Department of Sport Science and Physical Education, Chinese University of Hong Kong, Shatin, Hong Kong; [3]Singapore Sports Council, Singapore; and [4]Singapore Sailing Federation, Singapore

Abstract

Burnett, AF, Wee, WK, Xie, W, Oh, PW, Lim, J, and Tan, WWK. Levels of muscle activation in strength and conditioning exercises and dynamometer hiking in junior sailors. *J Strength Cond Res* 26(4): 1066–1075, 2012—Although strength and conditioning exercises have been prescribed to enhance performance and prevent injury in sailors, little is known about these exercises in comparison to the demands placed on the sailor's musculature while hiking maximally. Because of the difficulty in collecting hiking-related data on water, a 3-minute maximal hiking test (HM_{180}) has been previously developed for use in the laboratory setting. There were 2 aims of this study. The first aim was to determine whether discriminative validity could be shown for the HM_{180} test in a group of junior sailors of differing ability level and gender. The second aim was to determine whether differences in muscle activation existed between selected strength and conditioning exercises and the HM_{180} test. Twenty-nine adolescent boy and girl sailors aged between 14 and 16 years from the Singaporean National Byte Class training squad ($n = 12$) and the Singapore High Participation Group ($n = 17$) were recruited for this study. The average levels of normalized muscle activation in selected lower limb and trunk muscles in 4 selected strength and conditioning exercises (leg extension, back squat, and back extension exercises, a 30-second hiking hold) and a maximal 3-minute hiking test (the HM_{180} test) were quantified. Discriminative validity of the HM_{180} test was shown, and it was confirmed that the strength and conditioning exercises provide an overload stimulus for the HM_{180} test. Further, similar levels of muscle activation were found for the vastus lateralis in the leg extension and back squat exercises, and the superficial lumbar multifidus in the back extension and back squat exercises. This study has the potential to inform the design of strength and conditioning programs for junior sailors.

Key Words sailing, EMG, resistance training, adolescent

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Introduction

An Olympic sailing race is typically of an hour's duration and involves sailing 7–11 legs (21). Thus, it is not surprising that elite sailors are aerobically fit athletes (5,7) with well-developed levels of strength and strength endurance (5,22). A maneuver called "hiking" is considered to be the most demanding aspect of Olympic class sailing (12). Sailors adopt both short and long hiking postures to keep the sailing dinghy upright by counterbalancing the forces of the wind on the sail through developing a "righting moment," which is generated by the sailor's bodyweight and the length of their body extending off the boat (36). The short hiking posture is where the trunk is kept rigid with the knees and hips flexed (Figure 1A), whereas the long hiking position is where the trunk, hips, and knees are relatively extended (Figure 1B). An increased righting moment enables the dinghy to capitalize upon drag forces acting on the sail, which in turn, creates greater dinghy speed (1,21,31).

Conducting investigations into Olympic sailing provides some unique challenges. First, there are a number of vessels of different weight and length specifications; namely, the double-handed classes (Mistral, Tornado, 470, and 49er) and the lighter solo classes (Laser, Europe, and Finn). Furthermore, in the 2010 Youth Olympic Games, the Byte Class was selected as the boys and girls single-handed class. Second, as stated above, there are different hiking positions used and there are various roles adopted by the sailor that are dependent upon the sailing class. Third, there are varying environmental factors such as wind conditions and wave motion (4). Hence, it can be difficult to examine factors that may prevent injury and improve performance (26).

In an attempt to address the above problems, sailing simulators have been used in the laboratory environment to better control confounding factors during data collection

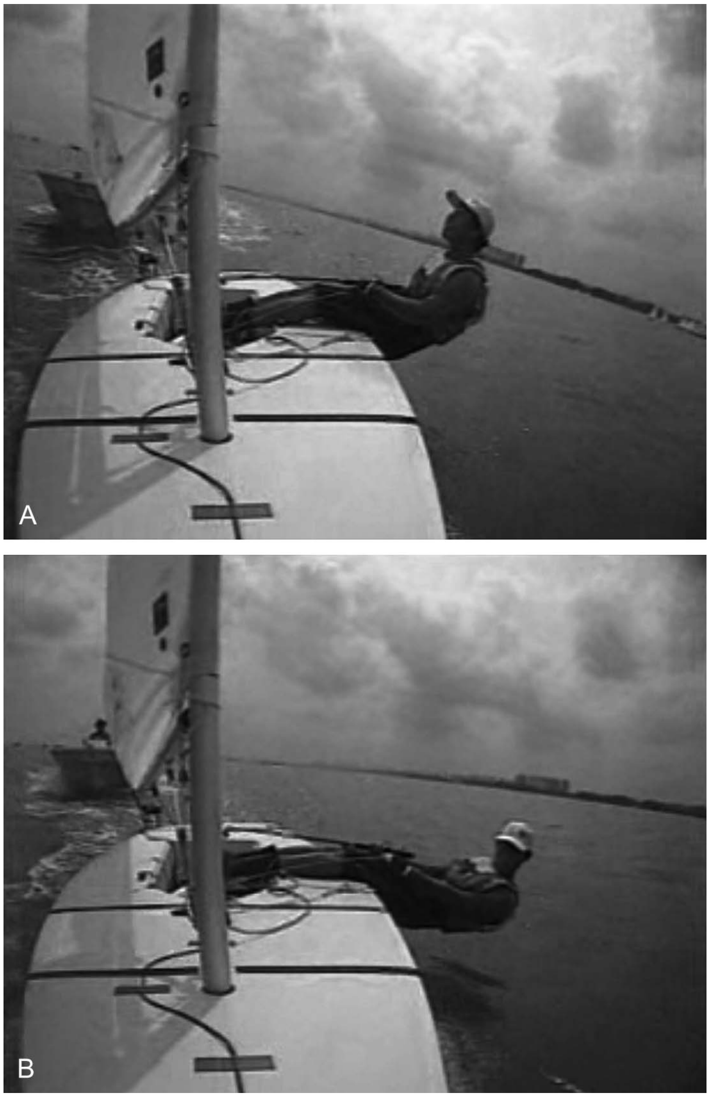

Figure 1. The A) short and B) long hiking positions adopted by a sailor in a dinghy.

(6,16). This development has allowed researchers to replicate factors such as boat position (6,16) and orientation (30), and allowing better control over the measurement of kinetic variables such as torque generated while hiking and forces exerted on the sailor's foot strap (24). A recent study (36) found that maximal hiking performance measured on a hiking dynamometer over 3 minutes (the HM_{180} test) was associated with better results in a race. Although this is a promising development, the discriminative validity of the HM_{180} test between various subgroups of junior sailors has yet to be determined. For example, the question of whether levels of performance differ in the HM_{180} test between junior sailors of differing ability level and gender has not been examined. Data resulting from a controlled laboratory environment may lead to a better understanding of the physiological and biomechanical demands of the sport (7,34) and allow for the evaluation of sport-specific factors that lead to better performance in junior sailors (5).

Previous authors have reported that the quadriceps, hamstrings, Para spinals, and the abdominals are the main muscles of importance in sailing (2,6,26,31). Hence, in line with the recommendation that adolescents should use a variety of exercises and training modalities (11), general strength and conditioning exercises such as leg extensions, back squats, and back extensions would be considered appropriate for junior sailors. Also, in an attempt to provide a specific exercise for on-water hiking, the 30-second hiking hold may be used. Although previous studies have compared muscle activation during lower limb strength and conditioning exercises (10,18,19), little is known regarding how active selected lower limb and trunk muscles are in strength and conditioning exercises used in junior sailors in comparison to hiking itself. In adolescent populations, it is recommended that 1–3 sets of 6–15 repetitions are performed with strength training exercises (11) and it also needs to be considered that in many talent identification and junior development programs there can be athletes of differing ability levels. To our knowledge, no studies have examined muscle activation in strength and conditioning exercises at the lower end of the recommended range for repetitions (i.e., 6 repetition maximum [6RM]) in junior sailors. Further, although there is some evidence that low back pain (LBP) may affect levels of muscle activation during maximal and submaximal tasks (9), LBP is rarely considered as a factor that alters level of muscle activation in lower limb and trunk strength and conditioning exercises. Such information gained from surface electromyography (EMG) recordings of key muscles involved in strength and conditioning exercises used in the training of junior sailors would provide an increased evidence base to make training-based decisions.

There were 2 hypotheses examined in this study. First, it was hypothesized that discriminative validity would be shown for the HM_{180} test in a group of sailors of differing ability level and gender. Second, for the 4 strength and conditioning exercises examined in this study, it was hypothesized that they would show greater levels of muscle activation when compared with the HM_{180} test.

Methods

Experimental Approach to the Problem

To examine the first hypothesis of this study, a between-groups (between-ability group and between-gender) comparison was conducted for hiking moment values generated during the HM_{180} test.

To examine the second hypothesis of this study, a repeated-measures design was used to enable comparison between levels of muscle activation as measured by surface EMG for selected strength and conditioning exercises (leg extension, back squat, back extension, and 30-second hiking hold) and the HM_{180} test. Electromyographic signals were collected from selected lower limb (vastus lateralis [VL], bicep femoris [BF]) and trunk muscles (rectus abdominis and lumbar multifidus). The mean level of normalized muscle activation of these muscles was calculated during the concentric and eccentric phases of the strength and conditioning exercises (where appropriate) and for three 30-second periods of the HM_{180} test (30–60, 90–120, and 150–180 seconds).

Subjects

Twenty-nine sailors aged between 14 and 16 years were recruited from the Singaporean National Byte Class training squad ($n = 12$, 8 adolescent boys, 4 adolescent girls) and High Participation Group ($n = 17$, 9 adolescent boys, 8 adolescent girls). Mean ($\pm SD$) characteristics of adolescent boys in this study were as follows: age 14.1 ± 0.7 years, height 167.8 ± 4.5 cm, and mass 55.5 ± 7.7 kg. Adolescent girls in this study were of age 14.3 ± 1.0 years, height 158.6 ± 6.8 cm, and mass 51.1 ± 10.0 kg. Significant differences ($p < 0.05$) existed between gender for height (adolescent boys were taller) and between ability group for mass (national-level sailors had greater body mass). There was a trend of greater height evident in between-ability group ($p = 0.059$). The majority of the National Byte Class sailors had at least 1 year of extra sailing experience when compared with the High Participation Group. At the time of testing, the national-level sailors were participating in 8 training sessions per week and had a minimum of 6 months resistance training experience, whereas their High Participation Group counterparts undertook 3 training sessions per week and had no structured resistance training experience. Ethical approval for the study was obtained from the Edith Cowan University Human Research Ethics Committee. Subjects and a parent or guardian signed and approved the informed consent document after having the risks and benefits of the study explained to them.

Procedures

In this study, there were 2 testing sessions separated by at least 48 hours. All testing was conducted by one member of the research team (W.K.W.). During the first session, subjects performed a 6RM strength test for 2 lower limb exercises (back squats and leg extension). These tests were performed in a randomized order to prevent any sequencing effect. The values recorded in these tests were used during the second session.

As a warm-up to the second session, subjects cycled for approximately 5 minutes on an exercise bike and also performed their usual stretching routine. They were then requested to undertake a familiarization session on the hiking simulator (which is described below). Electromyographic signals were collected from selected lower limb and trunk muscles while subjects performed 3 sets of 6 repetitions of the strength and conditioning exercises. A 2-minute break was taken between sets to prevent fatigue, and each exercise was completed in its entirety before moving to the next. The sequencing of the exercises was randomized to prevent any ordering effects. After all exercises were completed, subjects then completed a single, HM_{180} test (36).

Measurements

Low Back Pain Status. If subjects reported having LBP at the time of testing, they completed a visual analog scale (VAS). The VAS consists of a 100-mm horizontal line, anchored by word descriptors at each end, ranging from "no pain" to "severe pain." The reliability and validity of this instrument has been previously described (29).

Six Repetition Maximum Testing. A 6RM strength test for the leg extension and back squat exercises based on National Strength & Conditioning Association guidelines (3) was undertaken. The 6RM was recorded as the weight that could be lifted throughout the full range of motion using good form. Subjects initially performed 10 repetitions with a relatively light load, then 8 repetitions with a heavier load, and finally a series of 6 repetitions was undertaken with increasing loads. A rest period of 3 minutes was taken between sets. If the weight was successfully lifted with the proper form, the weight was then increased by approximately 2.5–5 kg, and subjects attempted another set. Typically, 5–7 sets (including the warm-up sets) were required to achieve the 6RM for both exercises. A conservative rest period of 10 minutes was provided between the 6RM tests to allow adequate recovery. The High Participation Group was adequately familiarized with the necessary exercises before testing. Excellent test-retest reliability for leg extension and back squat 6RM tests have been reported previously with intraclass correlation coefficient (ICC) values of 0.96 (17) and >0.95 (39), respectively. Mean 6RM testing results were 59.1 ± 17.3 kg and 40.8 ± 13.1 kg for leg extension, and 47.5 ± 15.7 kg and 32.3 ± 12.6 kg for the back squat for adolescent boys and girls, respectively.

Selected Strength and Conditioning Exercises and Maximal Hiking Test. Three sets of 3 repetitions of the leg extension and back squat exercises were performed at the predetermined 6RM values. Three sets of 3 repetitions of the back extension exercise were also performed. These exercises were all performed at a 2–1–2 tempo to ensure controlled execution of each exercise. The order of testing for these exercises was randomized to prevent any ordering effects, and a 3-minute rest period was taken between sets to minimize the effect of fatigue. Multiple sets for all exercises were performed to determine between-set reliability.

The specific protocols for selected strength and conditioning exercises were as follows. (a) Leg extension: This exercise was performed with subjects in a leg extension machine with their feet firmly hooked under the padded bar. From a starting position of 90° of knee flexion, subjects were required to fully extend their knees and then return to the starting position. (b) Back squat: This exercise was executed in the confines of a power cage, with participants performing back squats using an Olympic bar and weights. Subjects were required to bend their knees and lower their body until the top of their thighs was lower than the top of their knee joint. The end phase of this exercise was when the body was in an upright position with the knees locked. (c) Back extension: For this exercise, subjects adopted a supine position, with feet firmly secured by the padded rollers. The starting position was with the trunk flexed and relaxed over the end of the bench then their upper torso was raised until their hips and waist were fully extended. Subjects then returned to the starting posture. (d) Thirty-second hiking hold: Subjects adopted a long hiking posture for 30 seconds on a hyperextension machine with their feet firmly secured.

A single HM_{180} test was performed on a hiking bench (36) that was modified for the Byte Class. Two force plates (model OR6-6-2000; Advanced Medical Technology Inc., Watertown, MA, USA) were separately secured to metal plates (1 × 1 × 0.1 m) (Figure 2). The average hiking moment was determined from the hiking forces produced by the 2 components (each mounted separately on the 2 force plates) of the hiking bench. During this test, subjects were permitted to adopt long or short hiking postures, jerk, crouch, or alternate their body weight on either leg. However, during the 30-second data collection periods, only long hiking postures were adopted.

Electromyography. During the above tests, EMG signals were collected bilaterally from 4 muscles. These data were collected using a ME3000 P8 data logger (Mega Electronics, Kuopio, Finland). Each subject's skin was shaved, abraded, and cleaned with alcohol to reduce skin impedance to below 5 kΩ. Pregelled red-dot 20-mm-diameter Ag–AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN, USA) were placed in a bipolar configuration parallel to muscle fibers. These data were acquired at 1,000 Hz.

For the purpose of EMG data normalization, subjects were also required to perform 3 repetitions of a 5-second maximum voluntary isometric contraction (MVIC) trial. The specific electrode placements and MVIC procedures were as follows. (a) Rectus abdominis (RA)–electrodes were placed 1 cm above the umbilicus and 2 cm lateral to the midline (27). To generate a MVIC, subjects were positioned supine with the legs bent at 45° and secured with a belt. A resisted curl up was performed with maximal manual isometric resistance applied in a symmetrical manner through the shoulders. The within-day

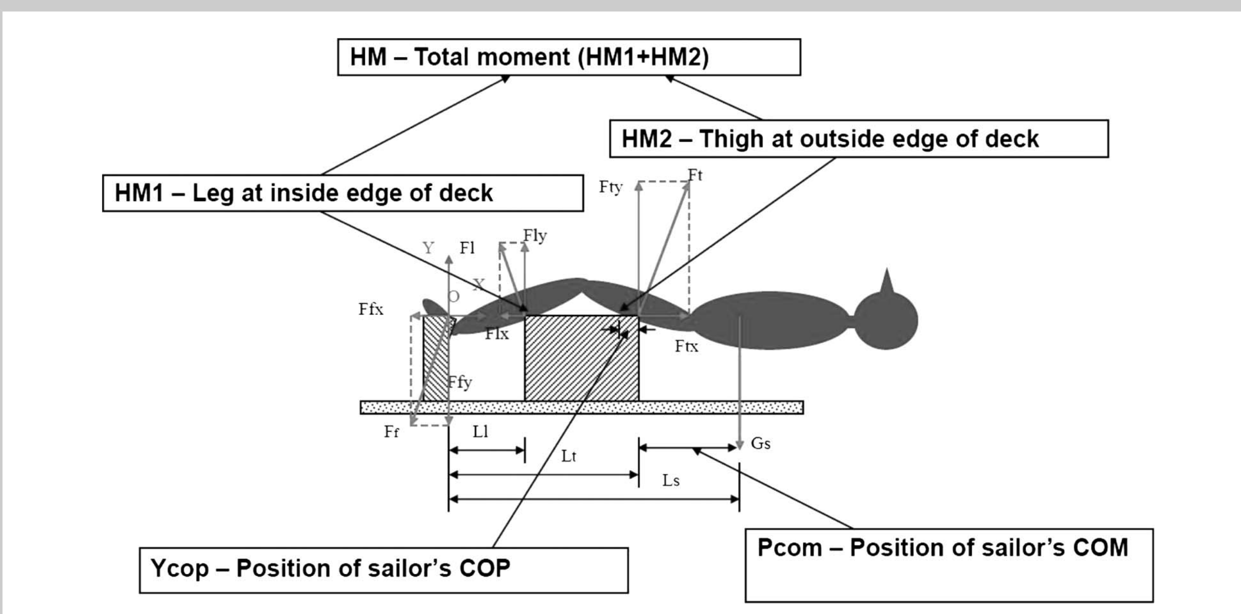

Figure 2. Schematic diagram of the hiking simulator used for the HM_{180} test.

reliability of this procedure has found to be excellent (ICC range = 0.83–0.97) (9). (b) Superficial fibers of lumbar multifidus (slim)–electrodes were placed at L5 and aligned parallel to the line between the posterior-superior iliac spine and the L1–L2 interspinous space (13). To generate an MVIC, subjects adopted a prone position, with hands behind their neck. They were then asked to lift their head, shoulders, and elbows off a table while symmetrical manual resistance was provided to the scapular region. The same-day test-retest reliability of this procedure has found to be excellent (ICC range = 0.93–0.94) (9). (c) Bicep femoris–electrodes were placed at the posterior-lateral portion of the thigh, midpoint of ischial tuberosity, and the lateral epicondyle of the tibia (13). To generate an MVIC, subjects adopted a prone position with their knees flexed at 90° and hands behind their neck. Subjects performed resisted knee flexion while manual isometric resistance was applied in a symmetrical manner. The within-trial reliability of this procedure has been found to be excellent (ICC = 0.99) (28). (d) Vastus lateralis–While the cross-sectional area of VL is similar to vastus medialis (VM) (33), VL was chosen as the representative muscle of the quadriceps because of its potentially increased activation in sailing (1) and its use in previous related research (6). Correct hiking technique demands the feet to be positioned together, and when the feet are turned outward, the VM to VL ratio has been found to decrease in controls (25). Vastus lateralis electrodes were distally placed 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella, nearer to the patella region (13). To generate an MVIC, subjects were strapped onto a leg extension machine and placed their arms across their shoulders. A resisted knee extension was performed with both knees bent at 45°, with resistance applied in a symmetrical manner. The same-day test-retest reliability of this procedure has been found to be excellent (ICC range = 0.93–0.94) (23).

To identify the phases of movement (eccentric and concentric phases) during the leg extension, back squat, and back extension exercises, subjects were filmed by a digital video camera (Canon Inc., Ota, Tokyo, Japan) operating at 25 Hz while performing these exercises. A retroreflective marker placed on the padded bar (leg extension), end of the bar (back squat), and subject's ear (back extension) was tracked using Dartfish ProSuite 4.5.1.0 software (Dartfish Company, Fribourg, Switzerland). The auto tracking function of the software package was used to track these retro-reflective markers so that the start of the exercise, the turn around point or transition point, and the end of the exercise were identified for each repetition. Electromyographic data were synchronized to the video recordings by triggering a light-emitting diode visible to the field of view of the video when EMG data collection commenced.

Data Processing

Electromyography. Raw EMG data were demeaned, full-wave rectified and low-pass filtered at 4 Hz using a second-order Butterworth filter to produce a linear envelope (38). Electromyographic signals for each muscle were normalized to the MVIC obtained for that particular muscle to allow for comparison between the prescribed exercises. The MVIC value for each muscle was considered as the greatest mean value recorded for a 200-millisecond window of the linear envelope measured in any of the 3 MVIC trials for each muscle. Critical event data obtained were used to identify the concentric and eccentric phases for each exercise in the EMG data. Electromyographic data for the concentric and eccentric phases were then time normalized (0–100%) using cubic spline interpolation, and the ensemble average was calculated. For the hiking hold, the mean level of muscle activation was calculated between the 10- and 15-second period for the hiking hold, whereas for the HM_{180} test, the mean level of muscle activation was calculated between 30- to 60-second, 90- to 120-second, and 150- to 180-second periods. All analyses were conducted using a customized software program written in LabVIEW V8.5 (National Instruments, Austin, TX, USA).

The main muscles of interest for EMG analysis for each exercise were as follows: back extension (biceps femoris and lumbar multifidus), back squat (BF, lumbar multifidus, and VL), leg extension (VL), isometric hiking hold (lumbar multifidus, rectus abdominis, and VL), and the HM_{180} test (lumbar multifidus, rectus abdominis, and VL).

Maximal Hiking Test. The total hiking moment for the subjects during the HM_{180} test was produced by the following equation: HM = HM1 + HM2; HM was defined as total hiking moment produced, HM1 as moment produced via the outside deck, and HM2 as moment produced via the inside deck (40). The HM1 was produced through the horizontal distance between the point at which the subject's knee came in contact with the edge of the outside deck and the foot strap, multiplied by the subject's mass. The HM2 was produced as a result of subject's mass and the horizontal distance between the subject's center of mass to the edge of the outside deck. The schematic diagram can be seen in Figure 3.

Statistical Analyses

Separate statistical analyses were conducted for the total hiking moment data and for the muscle activation data. For the total hiking moment during HM_{180} test, a 2-way between-groups analysis of variance (ANOVA; ability group and gender) was conducted. Intraclass correlation coefficients using a 2-way mixed model (32) were calculated to determine the between-set reliability for the level of muscle activation. Then, 3-way ANOVAs (muscle side, gender, pain) were initially conducted for each muscle to determine whether any significant differences existed. As no significant differences ($p \leq 0.05$), existed these groups were pooled for further statistical testing. Factorial ANOVAs with a between-groups variable (ability) and a within-groups variable (exercise that included, when appropriate, the strength and conditioning

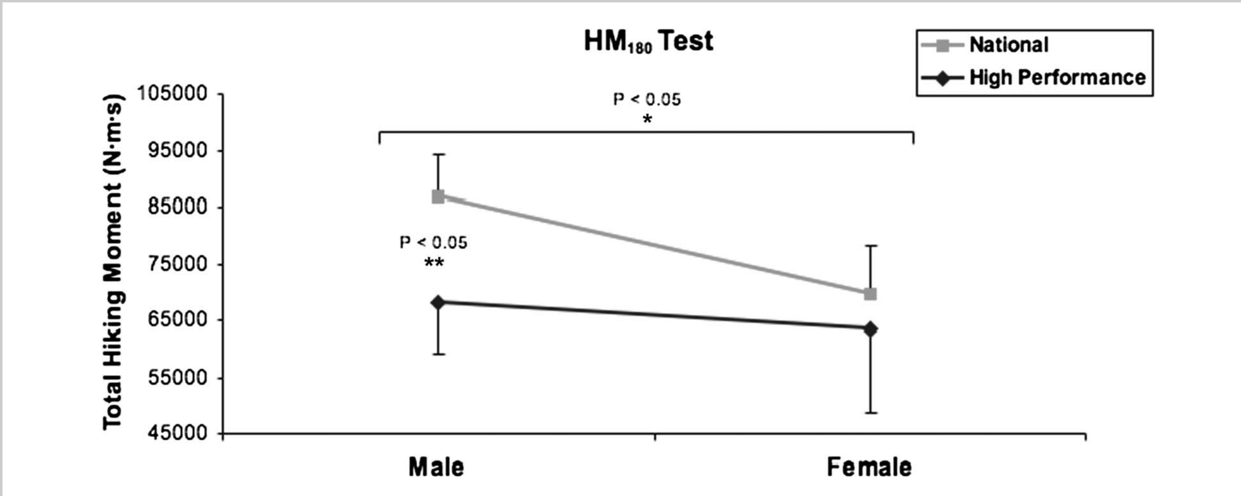

Figure 3. Total hiking moment for the HM_{180} test when examined between-gender and between-ability group. *Significant difference ($p < 0.05$) between-gender; **significant difference ($p < 0.05$) between ability group.

exercises, the concentric and eccentric phases of these exercises and the 3 periods of the HM_{180} test) were then performed for each muscle. Post hoc analysis was conducted using a least significant differences approach. Statistical analysis was performed using SPSS (version 17.0 for Windows; SPSS Inc., Seattle, WA, USA) with $p \leq 0.05$.

Results

For the total hiking moment accumulated for the HM_{180} test, there was a significant difference ($p < 0.05$) between gender and there was also a significant difference ($p < 0.05$) for adolescent boys between ability groups (Figure 3).

As all muscle activation data for each muscle showed excellent reliability (ICC > 0.75), data for the 3 sets of each exercise were averaged for subsequent analysis. Normalized (%MVIC) levels of muscle activation data for each muscle for the 4 strength and conditioning exercises and the 3 HM_{180} test periods are presented in Figures 4–7. These data show there were several significant differences of interest.

First, significant differences ($p < 0.05$) were evident between the concentric and eccentric phases of the back extension and back squat exercises for the VL muscle. Further, significant differences ($p < 0.05$) were also evident for this muscle between these 2 exercises and hiking-related

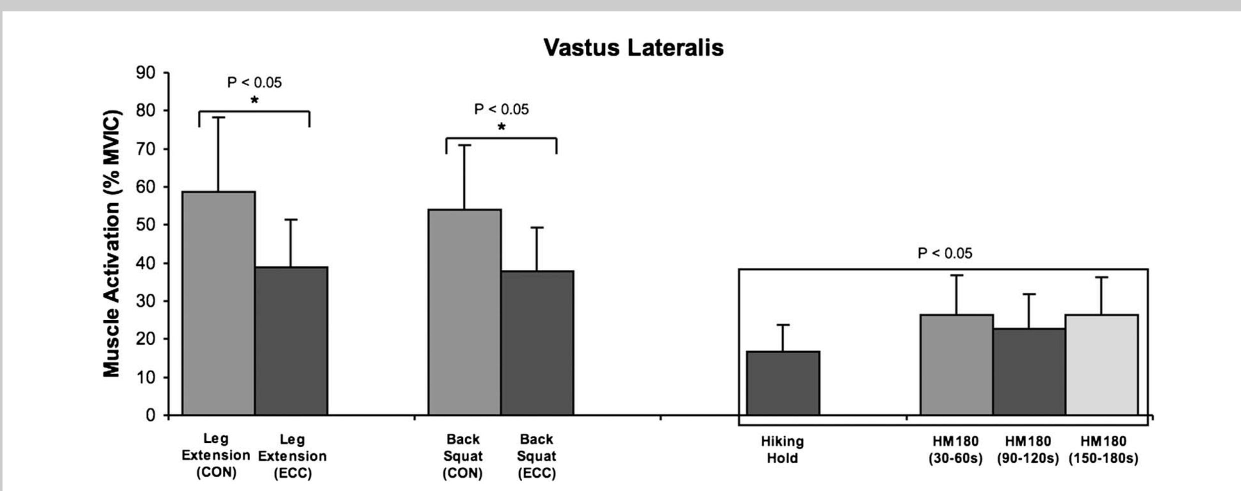

Figure 4. Normalized muscle activation of the vastus lateralis (% maximum voluntary isometric contraction) for selected strength and conditioning exercises and the HM_{180} test. *Significant difference ($p < 0.05$) between exercise phase. Both phases of the 2 exercises were significantly different ($p < 0.05$) to all conditions bound by the box.

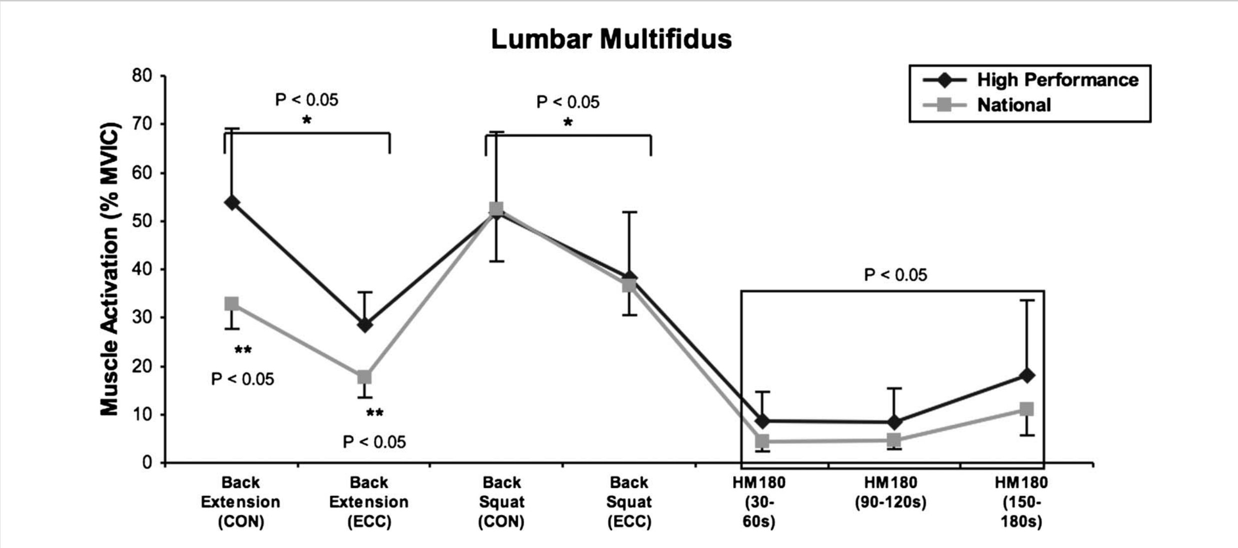

Figure 5. Normalized muscle activation of the lumbar multifidus (% maximum voluntary isometric contraction) for selected strength and conditioning exercises and the HM_{180} test. *Significant difference ($p < 0.05$) between-exercise phase; **significant difference ($p < 0.05$) between ability group.

activities, namely, the hiking hold exercise and the 3 sampled periods for the HM_{180} test (Figure 4). Second, significant differences ($p < 0.05$) were evident between the concentric and eccentric phases of the back extension and back squat exercises for the superficial lumbar multifidus muscle. Significant differences ($p < 0.05$) were also evident between these exercises and the 3 sampled periods for the HM_{180} test. Further, there were significant differences ($p < 0.05$) evident between ability groups for the eccentric and concentric phases of the back extension exercise (Figure 5). Significant differences were also found for the rectus abdominis muscle ($p < 0.05$) between the hiking hold and the 3 sampled periods for the HM_{180} test (Figure 6). Finally, significant differences ($p < 0.05$) were evident between the concentric and eccentric phases of the back extension and back squat exercises for the biceps femoris (Figure 7).

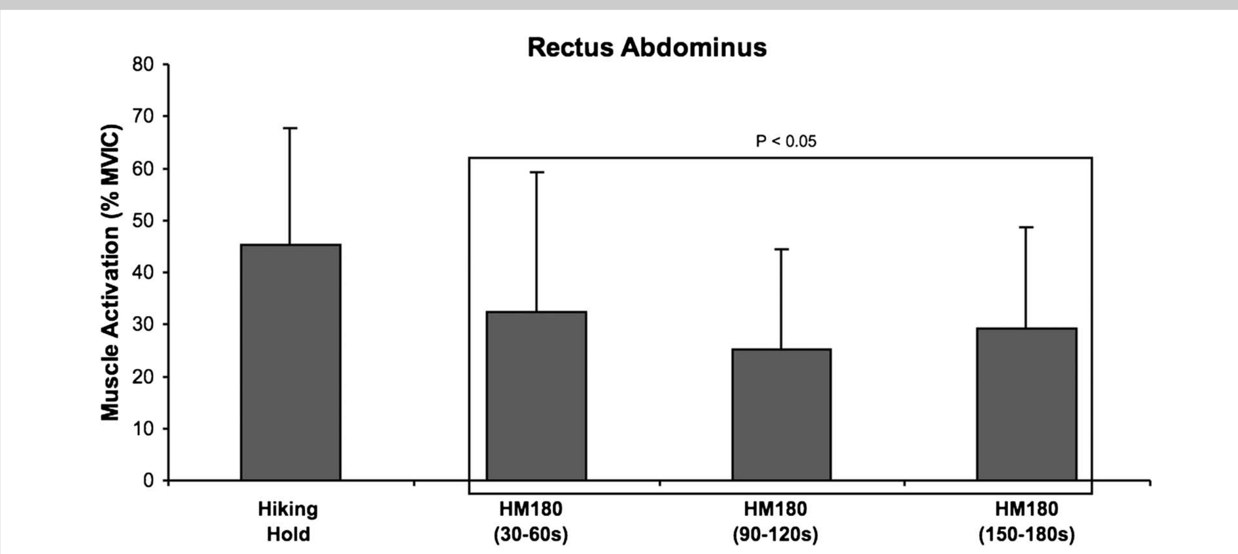

Figure 6. Normalized muscle activation of the rectus abdominis (% maximum voluntary isometric contraction) for selected strength and conditioning exercises and the HM_{180} test. The hiking hold exercise was significantly different ($p < 0.05$) to all conditions bound by the box.

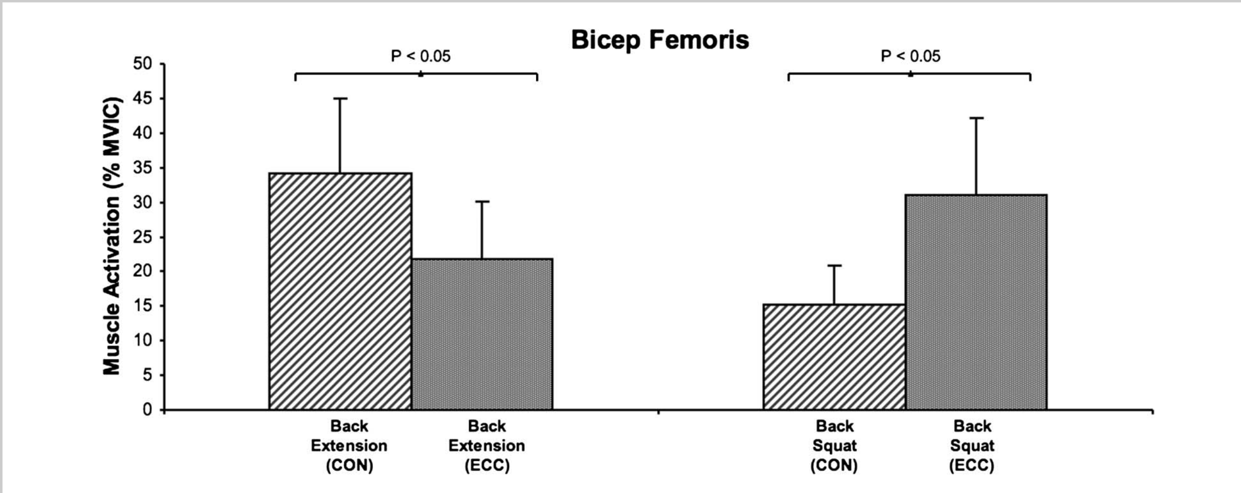

Figure 7. Normalized muscle activation of the biceps femoris (% maximum voluntary isometric contraction) for selected strength and conditioning exercises. *Significant difference ($p < 0.05$) between exercise phase.

Discussion

Strength and conditioning exercises have been postulated as being useful in preventing and rehabilitating sailing-related injuries and improving performance (21,22). Although previous studies have examined muscle activation in various lower limb conditioning exercises (10,18,19), to the author's best knowledge no studies have compared muscle activation in lower limb and trunk exercises with the postural demands of hiking, a key movement in the sport of Olympic sailing. Because of the logistical difficulties of obtaining muscle activation data on water, this study compared the mean level of normalized muscle activation from selected lower limb and trunk muscles during 4 strength and conditioning exercises with a laboratory-based test (the HM_{180} test).

During the HM_{180} test, a greater total hiking moment generated by the national class junior sailors was an expected finding as previous research has found that greater hiking moment has been related to superior race performance (36). These better test scores may be because of a combination of superior hiking technique and physical conditioning. Further, as the computation of the hiking moment is highly dependent upon the subject's body mass and height, it is not surprising that the adolescent boys (who were heavier and taller than the adolescent girls in this study) produced higher HM_{180} performance. When translated to on-water racing, greater hiking ability is of a distinct advantage in combating strong winds that act upon the mainsail during a race. To use an assessment such as the HM_{180} test in the applied sports environment, its reliability and validity should be established (14,15). Although discriminative validity of the HM_{180} test has been demonstrated in this study, other factors such as test-retest reliability and temporal sensitivity should also be assessed.

The knee extensors have previously been identified as being an important muscle group in sailing (6,8,35,37), and both the leg extension and back squat exercises are frequently used to develop knee extensor strength in physical conditioning programs. In this study, although differences were found between the concentric and eccentric phases for each exercise, these exercises showed similar levels of VL muscle activation when compared with each other. Further, as hypothesized, these exercises provided an overload stimulus for the VL muscle in simulated hiking. This is of interest when considering the findings related to the superficial lumbar multifidus. Surprisingly, the superficial lumbar multifidus showed similar levels of muscle activation in the back squat and back extension exercises. Although the angle of the trunk was not quantified in the back squat exercise, the superficial lumbar multifidus muscle may have been required to activate more than expected, as the trunk may have been excessively flexed during this exercise. It has been previously shown that increased trunk flexion in lifting results in higher levels of L5/S1 shear forces (20). In junior athletes, where sailing performance may be improved via resistance training, this should not be at the expense of exercise technique. It is important that mechanically induced LBP is prevented, as this is a risk factor for LBP later in life. It could be suggested that in this group of athletes, the leg extension exercise could be used to strengthen the quadriceps muscles while squatting technique is refined so that low back shear forces are minimized.

Although general strength exercises provide basic strength improvement in athletes, strength exercises that require similar postural demands exhibited in sailing are also used by strength and conditioning coaches for the sailors. The 30-second hiking hold is prescribed as a hiking-specific exercise to overload the abdominals for the sailors investigated in this study. The intent of this exercise was confirmed by this study, as there was a greater level of muscle activation of the rectus abdominis in the hiking hold exercise when compared with the 3 periods sampled during the HM_{180} test. Higher levels of rectus abdominis activation may be because of the force-velocity relationship where isometric contractions produce greater levels of force than those that are dynamic in nature.

The results of this study should be considered with respect to its limitations. First, hiking performance was measured on a hiking bench rather than on water; therefore, this study has reduced ecological validity. Second, the level of muscle activation is dependent upon the weight lifted during the strength and conditioning exercises examined in this study (back squat and leg extension); therefore, generalization of findings to lower weight–higher repetition work should be made with caution. Third, the level of muscle activation may be dependent upon the tempo with which exercises were executed (2–1–2). Therefore, generalization of findings to other tempos (with longer or shorter eccentric and concentric phases) should also be done with caution. Finally, the lack of a significant finding for adolescent girls between ability group may have been because of the small sample size used in this study.

In conclusion, although there were numerous significant results in this study, there were 3 main findings of interest. First, discriminative validity (between gender and between ability level) was shown for the HM_{180} test. Second, as generally hypothesized, the leg extension and back squat exercises were capable of providing an overload stimulus for the HM_{180} test. Likewise, the hiking hold has the ability to overload the rectus abdominis when compared with the HM_{180} test. Third, similar levels of muscle activation were found for the VL in the leg extension and back squat exercises and for the superficial lumbar multifidus in the back extension and back squat exercises.

Practical Applications

The findings related to discriminative validity for the HM_{180} test in this study add support to the suggestion that this test can be used as a sports-specific laboratory test for junior sailors in the Byte Class. This is of use to both coaches and sports scientists who work with this group of athletes as quantifying hiking performance in the laboratory setting is necessary because of the logistical difficulties related to on-water data collection.

It is known that muscle groups such as the quadriceps, hamstrings, Para spinals, and the abdominals are of importance in sailing and in particular, during hiking. Adolescence is a period in which the benefits of resistance training for sport are undoubted. However, optimal program design is important to maximize training efficiency at a time where junior athletes have competing demands related to academic and sporting pursuits. This is particularly the case in a country like Singapore. Although recommendations have been published (11) regarding general program design for adolescents undergoing resistance training (e.g., 1–3 sets of 6–15 repetitions), the potential of strength and conditioning exercises to overload a specific sailing-related activity such as hiking is unknown. This study quantified levels of muscle activation at 6RM intensity and showed that both general (leg extension, back squat, back extension) and specific (30-second hiking hold) strength and conditioning exercises can be used to provide an overload stimulus for hiking itself. This information may improve the knowledge base to enhance performance and prevent injury in junior sailors, and as such is of significance to coaches, sports scientists, and rehabilitation professionals.

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