The lower-body muscle activation of intermediate to experienced kayakers when navigating white-water.

Abstract

In white-water kayaking, the legs play a vital part in turning, stabilizing and bracing actions. To date there has been no reported information on neuromuscular activation of the legs in an authentic white-water environment. The aim of the current study was to identify lower body muscle activation, using 'in-boat' electromyography, whilst navigating a white-water run. Ten experienced male kayakers (age 31.5 ± 12.5 yr, intermediate to advanced experience) completed three successful runs of an international standard white-water course (grade 3 rapids), targeting right and left sides of the course, in a zig zag formation. Surface EMG (sEMG) outputs were generated, bilaterally, for the rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF) and gastrocnemius (G), expressed as a percentage of a dynamic maximal voluntary contraction (dMVC). Only RF showed any difference between right and left sides of the body, solely when navigating to the left of the course (P=0.004; ETA^2 = 0.56). Other results showed no significant difference between muscle activation in the right and left legs during each run, nor when assessed at either the right or left side of the course (P>0.05). These findings indicate that contralateral symmetry in lower-limb muscle activation is a key performance component of white-water kayaking. This will certainly provide a stable base to allow more asymmetrical upper body and trunk movements to be fully optimised. Lower body symmetry is an essential element of targeted training programmes for kayakers when navigating technical water.

Keywords

Kayaking, Electromyography, White-water, Bilateral, Lower body, Bracing

Introduction

The sport of kayaking has evolved into a fully-fledged Olympic event, taking place on artificial water courses, allied to the more traditional 'white-water' events taking place on natural features. A kayak differs from the more traditional canoe by having an enclosed cockpit, and preference for using a twin-blade paddle versus single-blade oar. Perhaps a key difference between styles is that the kayaker sits in the boat, whilst the canoeist kneels. Together with expansion of other disciplines such as 'play boating' and 'rodeo' races, the sport continues to attract an ever increasing number of participants. Despite such popularity, there is very limited academic research into white-water kayaking, due to the complex nature of the sport (Begon, Colloud, & Lacouture, 2009) and the environments which athletes are exposed (Palomo, 2013). Whilst laboratory-based testing is an attractive setting to control for extraneous factors such as weather and water variance, and also will allow for advanced kinetic/kinematic responses to be assessed, field-based testing will truly allow an ecologically valid assessment of the demands of the sport to be made.

Kayaking requires the upper body, the trunk and the lower body muscles working in unison, to execute a complex multiplanar motion (Begon et al. 2010). Alternate submersion of paddle blades is effected via pulling and pushing movements (Mann and Kearney, 1980), with an intermediate phase where the paddle is not submerged. With the kayak often moving in multiplanes, involving pitch, roll and yaw, controlling the orientation of the boat is a major component of performance. The great majority of published work relating to muscle activation when kayaking has focussed on upper body/trunk contribution. It has been reported that the upper and lower body work separately to provide an effective and sufficient performance (Vohra, 2014). The upper body and trunk require dynamic movements to enable the propulsion of the boat in the direction necessary. Lower body contribution is reported to be a more static isometric contraction connecting the individual to the boat, thus helping transfer energy and power to deliver an effective performance (Begon et al., 2010). This activation aids increased stroke length (Begon et al., 2009) via an asymmetrical movement of the left and right upper limbs to execute a successful and effective stroke cycle. To facilitate this stroke cycle, it has been proposed that there should always be a rigid connection between the blade to body down to the foot plate (Workman, 2010).The asymmetrical movement allows the boat and the individuals to maintain a balanced performance as the legs counterbalance the upper body's dynamic movements. Therefore, a high level of co-ordination between the upper and lower body is required (Begon et al., 2010). Hip and knee extension helps drive the hips backwards and produces torso rotation (Michael, Smith, & Rooney, 2009). Allied to this drive, the connection of the lower body, combined with trunk and pelvic rotation, will influence force production in the resulting stroke (Lok, 2013).

The kinetic link between the lower body and upper body is clearly important for powerful and efficient kayaking performance. Upper extremity and trunk kinetic chains have been proposed as most influential in overcoming resistance exerted by water on the boat (Ackland et al. 2003; Garcia-Garcia et al. 2015). However, the lower body contribution to the overall performance is difficult to observe and quantify (Begon et al., 2010). Quadriceps musculature, notably, has a role to play in bracing position within the boat. This has been proposed to facilitate trunk rotation, upper body force production and propulsion (Palomo, 2013). No reported studies into the neuromuscular contribution of the lower body during white-water paddling have been undertaken thus far. Studies that have been conducted in relation to the lower body contribution to kayaking are primarily executed on flat water or on a kayak ergometer, and reflect forces on the foot plate (Lee, 2014; Begon et al., 2010; Nilsson, & Rosdahl, 2013; Ong, Elliott, Ackland, & Lyttle, 2006; Michael, Smith, & Rooney, 2009; Begon et al., 2009; 2010) seat (Begon, et al., 2010; Ong, et al., 2006; Michael et al., 2009; Begon et al., 2009) and paddles (Lee, 2013). The transferability of such laboratory/flatwater testing to unstable white-water conditions is challenging. Whilst navigating technically challenging water courses, the kayak may be laterally unstable. This will require a high level of balance control to ensure the kayak remains stable, allied to the continuing development of paddle force, again in multiple orientations. Maintaining stability in the kayak, in white-water conditions, is unquestionably a function of whole-body coordination and force production, though little is known as to lower limb muscle activation during this process.

Regarding muscle activation of the lower body, few research groups have attempted to assess this using electromyography (Gottschalk et al. 1989; Mathew, Lauder, & Dyson, 2010; Fleming, Bonne,& Mahony, 2007). Again, these studies utilised flatwater variants of kayak performance, and have very limited transferability to more 'unstable' white-water settings. Given the dearth of published data using white water settings, the aim of this study was to quantify skeletal muscle activation of the lower body during kayaking activity of some technical difficulty.. A secondary aim is to assess bilateral symmetry in activation patterns during white-water navigation. This aspect is of interest as kinetic differences between right and left sided kinetics have been proposed as influential in elite level kayakers (Limonta et al. 2010). To date, no assessment of lower body symmetry has been undertaken, though some evidence of asymmetry in muscle activation of the upper/trunk kinetic chains has been previously reported. It is proposed that such symmetry will be more clearly evidenced in the lower body due to the less dynamic nature of muscle contractions (isometrically driven), allied to greatly reduced range of motion in the enclosed cockpit.

Methodology

Research Design

Experienced participants were selected through a stratified, non-random sample process. Following a familiarisation test period, including practice efforts for the test course, participants completed three ‘runs’ of the standard white water route at the Holme Pierrepoint National White-Water Centre in England (figure 1). Prior to the three runs, dynamic maximal voluntary contractions (dMVC) were calculated for each of the target muscles. The run consists of grade three white water, using a gravity fed water flow system that is 1500 m in length. The vertical drop is four metres over the length of the course. Change of direction elements were introduced via participants navigating between four separate ‘Eddies’; two on the left of the course and two on the right. These were navigated in a ‘zig zag’ formation. Key dependent variables were associated with the percentage dMVC recorded, by the right and left side, during each run.

Insert figure 1 about here

Participants

Ten male kayakers (age 31.5 ± 12.5 yr, stature 177.8 ± 9.8 cm, total body mass 85.90 ± 8.77 Kg), all of similar paddling abilities (BCU 3* remit working towards 4*, or already 4* qualified, with the ability to execute an ‘Eskimo roll’) provided written informed consent to take part in this study. British Canoe Union competency standards operate on a rising scale of 1-5, with grades 3-4 reflecting white-water intermediate competency and leadership skills. All participants were right-hand dominant. This hand was stated as the preferred control hand of the paddle. The study was approved by the Ethics Committee at the University of Central Lancashire, and all processes were undertaken in accordance with the principles outlined in the Declaration of Helsinki.

Instrumentation

EMG data was collected with an eight channelled Biometric Data Log, (M08842, UK) in which 8 bipolar electrodes (Biometrics, SX-230 EMG Sensors, UK) and a R506 earth band were used. Samples were recorded at 1000 Hz, with all channels trace sensitivity at 3mV. Muscle activity was monitored through Biometric Data Log Management and Analysis Software version 8.10, on a laptop via a Bluetooth USB adapter (DG07A, China) as well as data being stored on a 2Mb SD card. Even when out of the 50m Bluetooth range, data is still stored on the SD card and transmitted to the software; synchronising when back in range. The Biometric Data Logger was programmed to collect data up to 90 minutes when out of Bluetooth range. The electrodes were positioned on the right and left Rectus Femoris (RF), Vastus Lateralis (VL), Biceps Formoris (BF), and Gastrocnemius Lateralis (G) muscles, with reference to the SENIAM guidelines (www.seniam.org). Attempts to measure hip flexor and extensor muscles were deemed unsuccessful, due to problems in the electrodes maintaining contact/location. This was associated with the much greater level of dynamic movement in the lumbopelvic region during the white-water navigation when compared to the more ‘braced’ lower limb muscles. Our use of a ‘wired’ EMG collection system was a limitation when accommodating such dynamism, and it is expected that advanced in wireless systems may alleviate these challenges for future researchers. with. Prior to attachment of the electrode, a small sample area was shaved, the skin abraded and then cleaned using an alcohol wipe. Electrodes were affixed with double-sided sticky pads. An earthing band was then attached above the ankle Participants wore a waterproof cagoule jacket and trousers, together with helmet and buoyancy aid. The data logger was placed in a dry bag,sealed against water ingress, and clipped inside the kayak just behind the seat.

Timing of each test run was undertaken using a global position system (Catapult Sports, Leeds, England) sampling at 5Hz. The GPS unit was worn in a bespoke cropped training vest, and secured in a Velcro pocket affixed at a level equal to the inferior medial border of the scapula. Time spent at each data collection point were determined by synchronous alignment of GPS time-stamps and timings of entry and exit at each Eddie point using a standard stopwatch.

Testing Sequence

Dynamic maximal voluntary contractions (dMVC) for each muscle were identified using an open-water protocol. The dMVC consisted of a 20 second maximal paddling effort, against fast-flowing water, at the ‘inlet gate’ of the course, paddling just behind the ‘upstream’ wave. This provided a constant water flow resistance, allowing for a truly dynamic determination of maximal effort to be generated. Participants were instructed to paddle as hard as possible for 20 seconds, with the kayak remaining in a single location.

Test runs were completed on three occasions, separated by a period of 20 minutes minimum. From a pre-determined start point (1^{st} wave of the inlet gate, Figure 1), participants navigated between four separate 'Eddies' (2 right, 2 left), in sequence. An 'Eddie' is a turbulent area of water formed on the downstream, face of an obstruction such as a rock. The 'Eddies' were used as stable reference points to ensure change of direction was accommodated consistently and also to allow 'resistance to movement' during the maximal voluntary contraction trial. Participants were instructed to complete the run as quickly as possible.

EMG Data Reduction

Raw data were cut and filtered using Biometrics DataLink software (Management & Analysis, SW380-1111 V8.10). Raw EMG signals, by muscle, were full wave rectified and filtered using a 20 Hz Butterworth low pass filter top create a linear envelope. The average of peak muscle activation, for each muscle used, was considered to be both dMVC and peak amplitude during the test run. Each individual run was identified by cross matching the times recorded by GPS to the EMG time line, deleting all irrelevant data. Individual run data were filtered through Root Means Squared (RMS) at 100ms, followed by identifying the entrance point for each of the 'Eddies' and by cross matching the GPS time with the EMG recording time. At the 'Eddie' entrance, time ± 5 seconds was selected to ensure all data for entering and exiting the 'Eddie' was accounted for. Post-processing of EMG signal data saw values expressed as percentage of peak dMVC by the average of right and left sides of the course. This allowed for the representation of right and left sided manoeuvres on open water.

Data Analysis

Statistical analysis was undertaken using SPSS 21.0 (SPSS inc. Chicago). EMG values obtained for each muscle were examined using a repeated measures ANOVA assessing muscle activation of the right and left legs during each completed run, and also an average of right and left sided navigation of the course. Normality of all data sets was assessed using Kolmogorov-Smirnoff tests. A significant main effect for average values during the entire run*right or left leg was determined. Significance level was set at $P<0.05$. Effect size was determined using the partial ETA^2.

Results

There were no significant differences in time spent navigating each 'Eddie' (E1 8.1+1.4 s, E2 6.2+1.7, E3 8.8+1.9, E4 7.4+1.9). Similarly, there were no significant differences in muscle activation by individual Eddie point ($P>0.05$) justifying the 'collapse' of all data into right and left sided runs ($P>0.05$). Results for the average percentage dMVC recorded by right and left side, for runs along each side of the course, are outlined in figures 2 and 3.

Insert figure 2 about here

Insert figure 3 about here

A significant difference was identified for right leg RF activation when navigating the left side of the course only ($P=0.004$; $ETA^2 = 0.56$). There were no further main interaction effects between right/left leg by right or left side of the course for VL ($P=0.32$; $ETA^2 = 0.12$), BF ($P=0.94$; $ETA^2 = 0.01$), or G ($P=0.23$; $ETA^2 = 0.18$). It is also reported that no participant reported the equipment set-up and location, whilst paddling, to be burdensome or an encumbrance.

Discussion

The current study aimed to identify whether there was a difference in muscle activation of the lower body between the left and right legs when paddling grade 3 white-water. We also sought to identify if there was a difference between the left and right muscle activation when associated with paddling on left or right sides of a white-water run.

Our findings showed that there was consistently no significant difference between right and left leg muscle activation, irrespective of side of the course that was navigated. This was similar to previous findings of Mathew et al., (2010) when paddling on flatwater courses, and also emphasises the kinetic differences reported by Limonta et al. (2010). Clearly, a bilateral symmetry in lower limb muscle activation was evidenced in intermediate to experienced kayakers. Given the requirements of white-water kayaking, and relative unpredictability of navigating such courses, this suggests a high level of adaptation is needed to ensure technical competency. This is particularly necessary when considering the need to establish a strong force-producing base for dynamic upper body movements, allied to the role the lower limbs will have in stabilising the kayak in rough water.

The only significant effect found, by muscle, was for RF when paddling the left side of the course only. Despite the relative similarity of VL, BF and G activation, between sides, the kayakers did clearly engage RF more readily when paddling on the left side of the course. The variation of muscle activation between left and right legs may be a consequence of kayaker ‘sidedness’ (Zakaria, 2013; Michael et al., 2012), potentially producing asymmetrical engagement (Begon et al., 2010). Further study is required to accommodate the effect of such ‘sidedness’ when assessing bilateralism in kayakers. However, the role of RF in stabilising the lower limbs, and hence allowing an isometric base for balance in the kayak when riding rough water, is of interest. The biarticular nature of the RF lends itself greatly to control of both the knee and hip. Such engagement has implications in potentially mediating pelvic stabilisation when the kayak is in an unstable orientation. In the absence of measurements of hip flexor/extensor musculature, it is assumed that activation of the

RF may assist in pelvic stabilisation, though further research is clearly needed to assess relative contribution when compared to more localised hip musculature.

We have identified similarity in lower limb muscle activation when undertaking white-water kayaking. This contradicts the relative asymmetry noted in upper body/trunk muscle activation when measured on more stable water/ergometers. There is clearly a very different role that the legs play in effecting a successful white-water navigating, associated it would appear with a more isometric type of contraction. This lower limb 'bracing' would potentially act as a base from which the trunk/upper body can generate force, and emphasises the need to consider conditioning the whole-body kinematic chain. Our findings would support bilateral symmetry in lower limb muscle activation, thereby allowing individuals to be able to execute both left and right sided manoeuvres with the same amount of mechanical force production. The more similar bilateral power is, the greater the muscular force that can be applied (Workman, 2010). Such bilateralism will ensure not just technical symmetry, but also potential benefits throughout the complete kinematic chain, notably with regard to the development of stronger postural bracing during kayaking. The appropriate conditioning and strengthening of the kayaker's lower body should not be underestimated (Akca, & Munirogly, 2008).This association between lower limbs and the 'core' is of great interest to conditioners and trainers alike, and further work is required to assess the contribution of the core to whole chain kinematics.

The movement coordination required by kayakers is important in ensuring a balance of technical movements needed to execute the navigation of open-water courses (Rynkiewicz, & Starosta, 2011). As waves disrupt the balance of the boat, kayakers are required to adjust their paddling technique rapidly, notably with changing conditions and water hydraulics (Rynkiewicz, & Starosta, 2011). The process of navigating white water, for example on the left side, will see a larger activation of the right leg musculature to push against the thigh rest and foot plate of the boat, thereby lifting the boat onto its left edge. The left leg would then see a more 'relaxed' muscle activation to allow steering to occur. This process will clearly be magnified depending on technical characteristics of the run and also flow dynamics at play. Therefore, a strong and coordinated muscle activation in the lower body is essential for successful performance (White, 2015). Unlike in flat water runs, where asymmetry in muscle activation has been reported previously (Mathew et al., 2010), we clearly have identified symmetry throughout the run.

A key feature of this study is the attempt to test kayaking performance on a genuine white-water course. Field-based testing present many challenges, and data collection can be difficult (Palomo, 2013). Such challenges are further amplified when dealing with more 'extreme' sports such as kayaking. The research team were keen to assess EMG signals from hip flexors and extensors, though this was very limited due to the design of thigh rests within boats. This reinforced the practicality of having full access to all surface muscles when undertaking performance in a closed-boat environment (Clarys, Scafoglieri, Tresignie, Reilly, & Roy, 2010; Turker, & Sozen, 2013). In addition, a comfortable but secure place for the EMG data logger to be positioned was difficult when wearing full personal protective equipment (PPE), notably when a spray deck was worn. Therefore, constant repositioning of the data logger was required. On occasion, participants were required to disrobe between runs to gain access to the EMG equipment and ensure it was recording correctly. Such challenges require further consideration in ensuring a more efficient process of both securing and verifying the effectiveness of measuring systems. Our analysis utilised a wired EMG system, yet recent advances in wireless technology may make it easier to apply electrodes across all lower body locations rather than those opportunistically afforded by the design of dry suits and PPE.

To conclude, our results showed no significant difference between the left and right muscle activations when paddling a section of grade 3 waters, irrespective of side of the course navigated. The role of the lower limbs in bracing the body may have direct implications for the performance of more dynamic upper body/trunk motion associated with white-water kayaking. Coaches are encouraged to optimise engagement of the lower limbs, during training interventions, to ensure this base is enhanced, and allow a greater transfer of force through the more dynamic upper body.

Disclosure Statement

The authors do not have any financial interest or benefit arising from this research.

References

Ackland, T.R., Ong, K.B., Kerr, D.A. and Ridge, B. (2003) Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science & Medicine in Sport,* 6**,** 285-94.

Akca, F., & Munirogly, S. (2008) Anthropometric-Somatotype and Strength Profiles and On-Water Performance in Turkish Elite Kayakers. *International Journal of Applied Sports Science,* 20, 22-34.

Begon, M.,Colloud, F., & Sardain, P. (2010) Lower Limb Contribution in Kayak Performance: Modelling, Simulation and Analysis. *Mulitbody System Dynamics,* 23, 387-400.

Begon, M., Colloud, F., & Lacouture, P. (2009) Measurement of Contact Force on a Kayak Ergometer with a Sliding Footrest-Seat Complex. *Sports Engineering,* 4, 67-73.

Clarys, J.P., Scafoglieri, A., Tresignie, J., Reilly, T., & Roy, P.V. (2010) Critical Appraisal and Hazards of Surface Electromyography Data Acquisition in Sport and Exercise. *Asian Journal of Sports Medicine,* 1, 69-80.

Fleming, N., Bonne, B., & Mahony, N. (2007) *Electromyographic and Kinesological Analysis of the Kayak Stroke: Comparison of On-Water and On-Erogometer Data across Exercise Intensity.* 12th Annual Congress of the ECSS, Jyvaskyla, Finland.

García-García, O., Cancela-Carral, J.M., & Huelin-Trillo, F. (2015) Neuromuscular Profile of Top-Level Women Kayakers Assessed Through Tensiomyography. *Journal of Strength and Conditioning Research*, 29, 844-853.

Lee,C-H. (2014) The Effects of Kayak Foot brace on Forward Stroke and Stability of Boat in the Kayak Sprinting. *International Journal of Bio-Science and Bio-Technology,*6, 223-228.

Limonta, E., Squadrone, R., Rodano, R., Marzegan, A., Veicsteinas, A, Merati, G. and Sacchi, M. (2010) Tridimensional kinematic analysis on a kayaking simulator: key factors to successful performance, *Sports Science Health*, 1, 27-34.

Lok, Y.L. (2013) *Biomechanics Study in Sprint Kayaking Using Simulator and On-Water Measurement Instrumentation: An Overview*. Proceedings of the 3rd Malaysian Postgraduate Conference, Sydney, Australia, 216-223.

Mathew, B., Lauder,M., and Dyson, R., (2010) *Activation and Contribution of Trunk and Leg Musculature to Force Production During on Water Spring Kayak Performance.* 28th International Conference on Biomechanics in Sport, Marquette, Michigan.

Michael, J.S., Rooney, K.B., & Smith, R.M. (2012) The Dynamics of Elite Paddling on a Kayak Simulator. *Journal of Sports Science,* 30, 661-668.

Michael, J.S., Smith, R., & Rooney, K.B. (2009) Determinants of Kayak Paddling Performance. *Sports Biomechanics,* 8, 167-179

Nilsson, J.E., & Rosdahl, H.G. (2013) New devices for measuring forces on the kayak foot-bar and on the seat during flat-water kayak paddling. *International Journal of Sports Physiology and Performance,* 7, 1-14.

Ong, K., Elliott, B., Ackland, T., & Lyttle, A. (2006) Performance Tolerance and Boat Set-up in Elite Sprint Kayaking. *Sports Biomechanics,* 5, 77-94.

Palomo, D.L-P. (2013) *The Effect of Seat Type on Stroke Kinematics and Trunk Rotator Activity During Kayak Ergometer Paddling,* (unpublished Masters by Research thesis). University of Lincoln, England.

Rynkiewicz, M., & Starosta, W. (2011) Asymmetry of Paddling Technique Its Selected Conditions and Changeability in Highly Advanced Kayakers. *International Association of Sports Kinetics,* 35, 1-148.

Turker, H., & Sozen, H., (2013) *Surface Electromyography in Sports and Exercise. Electrodiagnosis on New Frontiers of Clinical Research* [Online]. Available at:http://cdn.intechopen.com/pdfs-wm/44778.pdf (Accessed: 27th June 2015).

Vohra., S. (2014) *The basics of white water kayaking ,* Available http://www.outdoorjournal.in/how-to-2/the-basics-of-whitewater-kayaking/ (Accessed: 8th February 2015).

White, G. (2015) *Riding Rough Waters*. American Fitness, 8, 26-29. .

Workman, G. (2010) *Dry Land Training for Kayaking and its Implications on Longevity and Performance.* Journal of Sports Therapy, 3, 19-24.

Zakaria, P. (2013) *Whole-body Kinematics During Paddling on Kayak Ergometer in Elite Able-bodied Athletes.* (unpublished Masters thesis) The Swedish School of Sports and Health Science, Sweden.

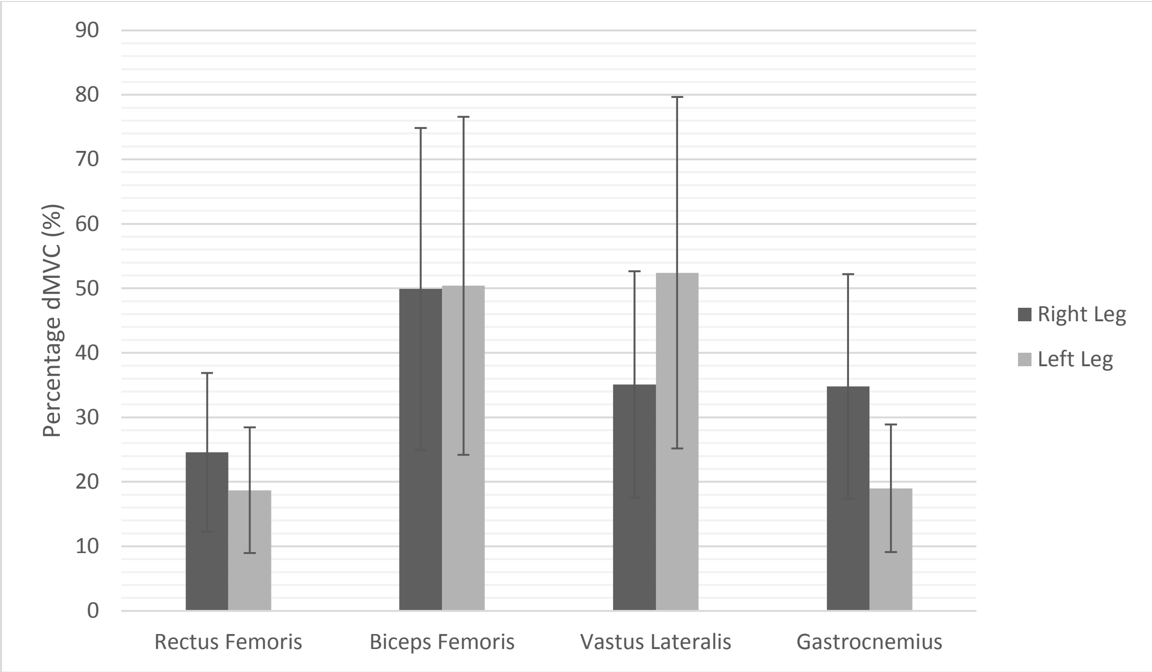

Figure 2. Percentage (%) of dMVC identified using sEMG by right and left sides of the body, for navigating the right side of the course only.

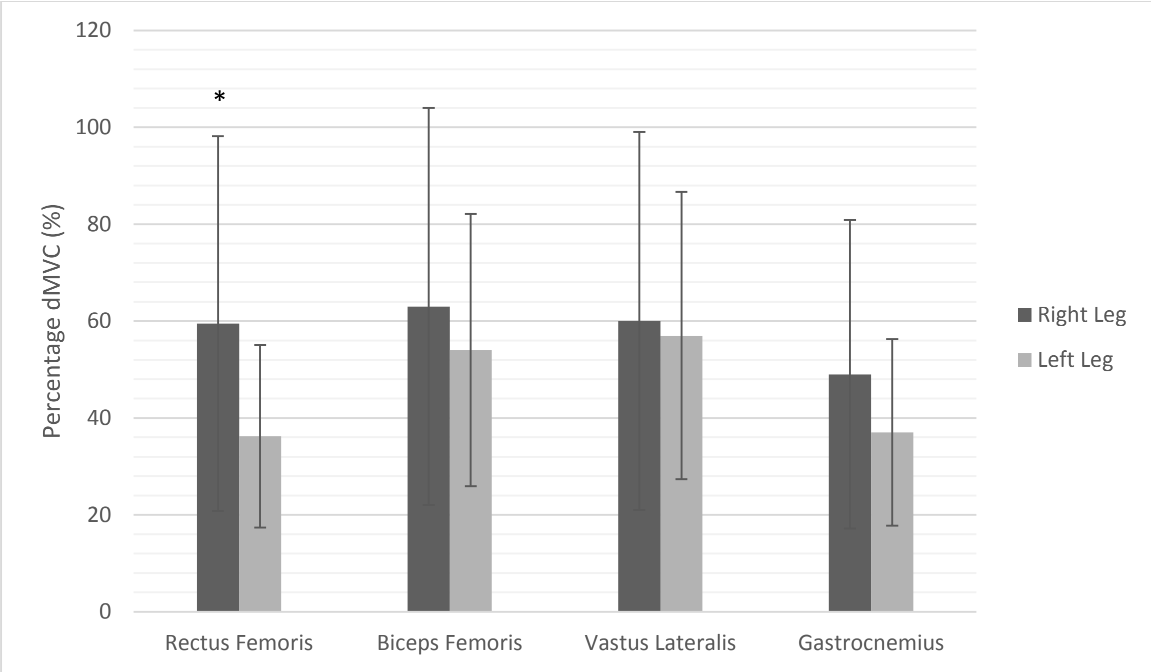

Figure 3. Percentage (%) of dMVC identified using sEMG by right and left sides of the body, for navigating the left side of the course only. (* *Significant difference in right leg RF activation between right and left side of the course*)

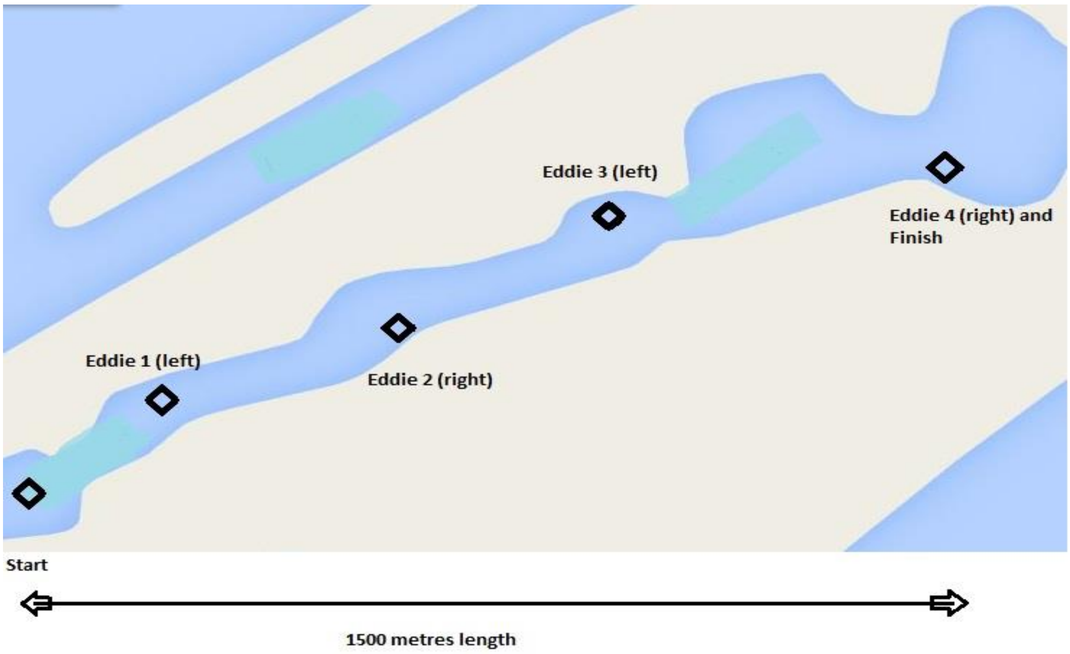

Figure 1. Holme Pierrepoint National White Water Course, warm up area, start, Each Eddies required to target, finish and point MVC data was collected