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

3 **Abstract**

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

24

25 **Keywords**

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

27

28

29 **Introduction**

30

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

46

47 Kayaking requires the upper body, the trunk and the lower body muscles
48 working in unison, to execute a complex multiplanar motion (Begon et al. 2010).
49 Alternate submersion of paddle blades is effected via pulling and pushing
50 movements (Mann and Kearney, 1980), with an intermediate phase where the
51 paddle is not submerged. With the kayak often moving in multiplanes, involving pitch,
52 roll and yaw, controlling the orientation of the boat is a major component of
53 performance. The great majority of published work relating to muscle activation when
54 kayaking has focussed on upper body/trunk contribution. It has been reported that
55 the upper and lower body work separately to provide an effective and sufficient
56 performance (Vohra, 2014). The upper body and trunk require dynamic movements
57 to enable the propulsion of the boat in the direction necessary. Lower body
58 contribution is reported to be a more static isometric contraction connecting the
59 individual to the boat, thus helping transfer energy and power to deliver an effective
60 performance (Begon et al., 2010). This activation aids increased stroke length
61 (Begon et al., 2009) via an asymmetrical movement of the left and right upper limbs

62 to execute a successful and effective stroke cycle. To facilitate this stroke cycle, it
63 has been proposed that there should always be a rigid connection between the blade
64 to body down to the foot plate (Workman, 2010). The asymmetrical movement allows
65 the boat and the individuals to maintain a balanced performance as the legs
66 counterbalance the upper body's dynamic movements. Therefore, a high level of co-
67 ordination between the upper and lower body is required (Begon et al., 2010). Hip
68 and knee extension helps drive the hips backwards and produces torso rotation
69 (Michael, Smith, & Rooney, 2009). Allied to this drive, the connection of the lower
70 body, combined with trunk and pelvic rotation, will influence force production in the
71 resulting stroke (Lok, 2013).

72

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

95

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

111

112 **Methodology**

113

114 *Research Design*

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

127

128 *Insert figure 1 about here*

129

130 *Participants*

131 Ten male kayakers (age 31.5 ± 12.5 yr, stature 177.8 ± 9.8 cm, total body
132 mass 85.90 ± 8.77 Kg), all of similar paddling abilities (BCU 3* remit working towards
133 4*, or already 4* qualified, with the ability to execute an 'Eskimo roll') provided written
134 informed consent to take part in this study. British Canoe Union competency
135 standards operate on a rising scale of 1-5, with grades 3-4 reflecting white-water
136 intermediate competency and leadership skills. All participants were right-hand
137 dominant. This hand was stated as the preferred control hand of the paddle. The
138 study was approved by the Ethics Committee at the University of Central Lancashire,
139 and all processes were undertaken in accordance with the principles outlined in the
140 Declaration of Helsinki.

141

142 *Instrumentation*

143 EMG data was collected with an eight channelled Biometric Data Log,
144 (M08842, UK) in which 8 bipolar electrodes (Biometrics, SX-230 EMG Sensors, UK)
145 and a R506 earth band were used. Samples were recorded at 1000 Hz, with all

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

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

174

175 *Testing Sequence*

176 Dynamic maximal voluntary contractions (dMVC) for each muscle were
177 identified using an open-water protocol. The dMVC consisted of a 20 second
178 maximal paddling effort, against fast-flowing water, at the 'inlet gate' of the course,
179 paddling just behind the 'upstream' wave. This provided a constant water flow

180 resistance, allowing for a truly dynamic determination of maximal effort to be
181 generated. Participants were instructed to paddle as hard as possible for 20
182 seconds, with the kayak remaining in a single location.

183

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

192

193 *EMG Data Reduction*

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

208

209 *Data Analysis*

210 Statistical analysis was undertaken using SPSS 21.0 (SPSS inc. Chicago).
211 EMG values obtained for each muscle were examined using a repeated measures
212 ANOVA assessing muscle activation of the right and left legs during each completed
213 run, and also an average of right and left sided navigation of the course. Normality of

214 all data sets was assessed using Kolmogorov-Smirnoff tests. A significant main
215 effect for average values during the entire run*right or left leg was determined.
216 Significance level was set at $P<0.05$. Effect size was determined using the partial
217 ETA^2 .

218 **Results**

219

220 There were no significant differences in time spent navigating each 'Eddie'
221 (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
222 significant differences in muscle activation by individual Eddie point ($P>0.05$)
223 justifying the 'collapse' of all data into right and left sided runs ($P>0.05$). Results for
224 the average percentage dMVC recorded by right and left side, for runs along each
225 side of the course, are outlined in figures 2 and 3.

226

227 *Insert figure 2 about here*

228

229 *Insert figure 3 about here*

230

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

237

238

239 **Discussion**

240

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

246

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

258

259 The only significant effect found, by muscle, was for RF when paddling the left
260 side of the course only. Despite the relative similarity of VL, BF and G activation,
261 between sides, the kayakers did clearly engage RF more readily when paddling on
262 the left side of the course. The variation of muscle activation between left and right
263 legs may be a consequence of kayaker 'sidedness' (Zakaria, 2013; Michael et al.,
264 2012), potentially producing asymmetrical engagement (Begon et al., 2010). Further
265 study is required to accommodate the effect of such 'sidedness' when assessing
266 bilateralism in kayakers. However, the role of RF in stabilising the lower limbs, and
267 hence allowing an isometric base for balance in the kayak when riding rough water,
268 is of interest. The biarticular nature of the RF lends itself greatly to control of both the
269 knee and hip. Such engagement has implications in potentially mediating pelvic
270 stabilisation when the kayak is in an unstable orientation. In the absence of
271 measurements of hip flexor/extensor musculature, it is assumed that activation of the

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

274

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

293

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

306 asymmetry in muscle activation has been reported previously (Mathew et al., 2010),
307 we clearly have identified symmetry throughout the run.

308

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

327

328

329

330

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

339

340 **Disclosure Statement**

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

342

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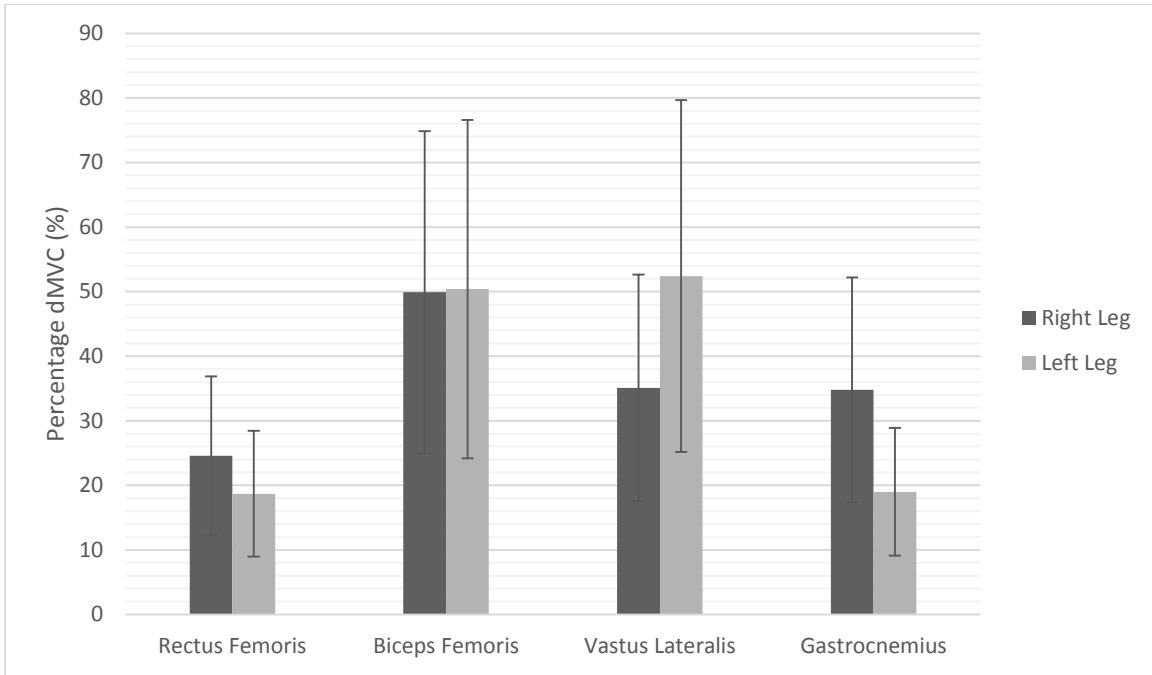
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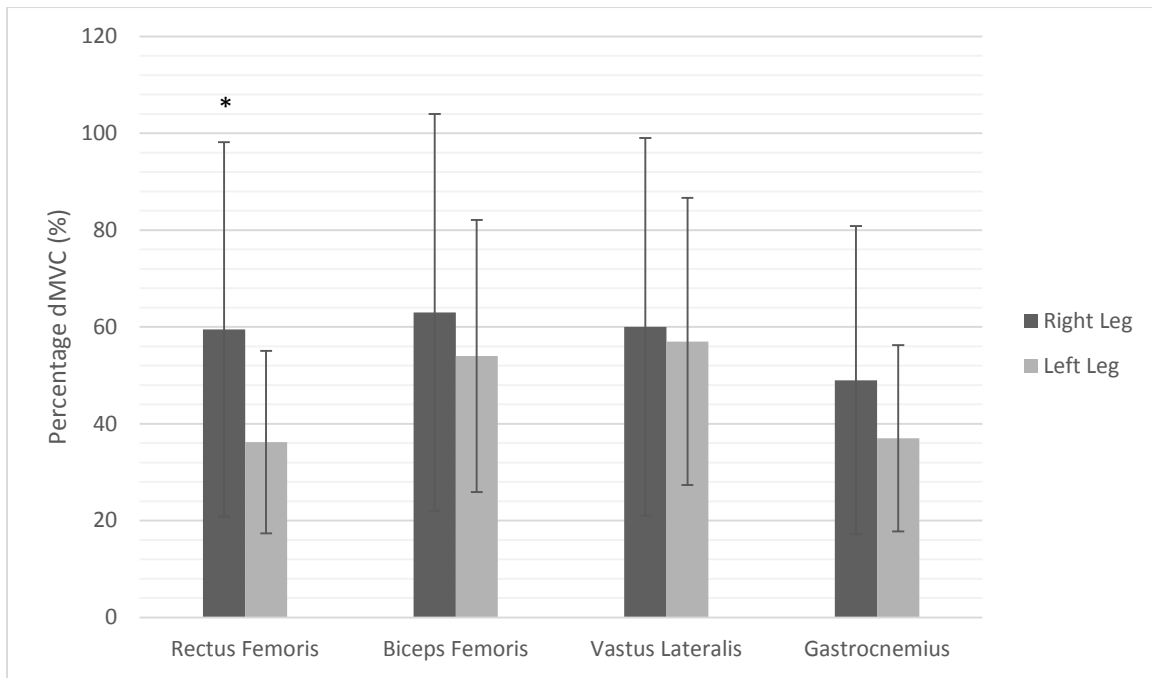


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407

408

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.

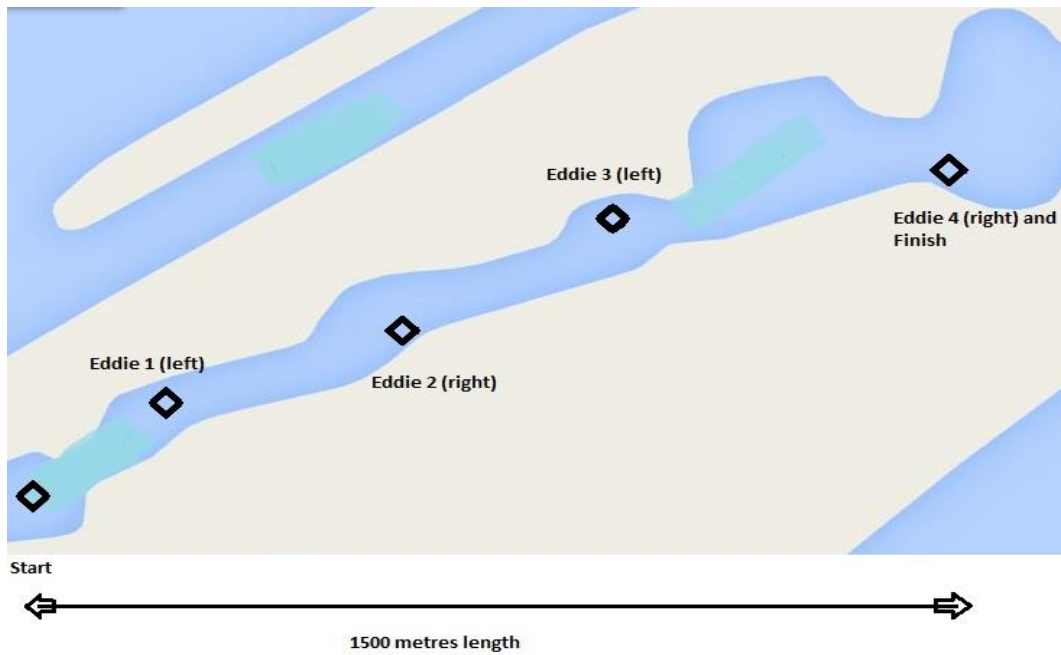


409

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

413

414



415

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

418

419

420

421