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Profiling the sport of stand-up paddle boarding

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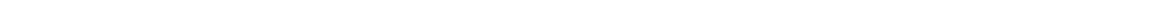
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Title: Profiling the Sport of Stand Up Paddle Boarding

Running Title: Profiling Stand Up Paddle Boarding



1 **Abstract**

2 Stand up paddle boarding (SUP) is a rapidly growing activity where only anecdotal evidence
3 exists for its proposed health and fitness benefits. The purpose of this study was to profile elite
4 and recreational SUP with respect to anthropometric, physiological and musculoskeletal
5 measurements. A total of 30 SUP participants (15 recreational, 15 elite) and 15 sedentary
6 controls participated in this study. Elite and recreational (rec) SUP participants had significantly
7 lower body fat than sedentary (sed) individuals, elite had significantly higher HDL and
8 significantly lower triglycerides than other groups during lipid profiling ($P>0.05$). There were
9 significant differences ($P>0.05$) between all groups in maximal oxygen uptake (elite 43.7, $s =$
10 5.89ml/kg/min vs rec 31.9, $s = 7.7$ ml/kg/min vs sed 20.4, $s = 3.7$ ml/kg/min) and anaerobic
11 power outputs (35.7, $s = 11.1$ W vs 25.0, $s = 11.7$ W vs 13.5, $s = 7.1$ W). The elite group
12 displayed significantly longer endurance than the recreational and sedentary group in the prone
13 bridge (elite 253.4, $s = 67.6$ sec vs rec 165.6, $s = 42.2$ sec vs sed 69.7, $s = 31.2$ sec) right sided
14 bridge (elite 107.9, $s = 34.0$ sec vs recreational 68.2, $s = 24.1$ sec vs sed 34.6, $s = 15.5$ sec) left
15 sided bridge (elite 99.8, $s = 24.9$ sec vs rec 68.2, $s = 27.2$ sec vs sed 32.5, $s = 15.2$ sec) and Biering
16 Sorensen test (elite 148.8, $s = 35.4$ sec vs rec 127.2, $s = 43.2$ sec vs sed 71.1, $s = 32.9$ sec). Elite
17 SUP had significantly better static and dynamic postural control when compared to the other
18 groups. This study demonstrates the anthropometric, physiological and musculoskeletal values
19 representative of elite and recreational SUP. SUP appears to be associated with increased levels
20 of aerobic and anaerobic fitness, increased static and dynamic balance and a high level of
21 isometric trunk endurance.

22

23 **Key words:** *profiling, water sports, aquatic, paddle boarding*

24

25

26 **Introduction**

27 Stand up paddle boarding (SUP) is a new sport and recreational activity, which is increasing in
28 popularity around the world due to its proposed health and fitness benefits and enjoyment
29 (Hammer, 2011). SUP is a hybrid of surfing and paddling in which participants can either
30 distance paddle and/or surf waves (Walker, Nichols, & Forman, 2010). Many websites
31 anecdotally advocate the use of SUP to increase strength, fitness, core stability, balance and
32 decrease back pain. However, our recent review of the literature found no scientific evidence to
33 substantiate the proposed benefits.

34

35 Stand up paddle boarding is an activity in which the participant maintains a standing position on
36 a board similar to a surfboard. However, SUP boards are longer in length (~8-15ft, 2.4-4.6m),
37 thicker (4-8in, 10-20cm) and wider (26-31in, 66-78cm) than traditional surfboards. The SUP
38 participant propels the board across the surface of the water by the use of a long, single-bladed
39 paddle. While the standing position is unstable initially, it is continuously disturbed by the
40 motion of the board and the movement of the arms whilst paddling, providing a constant postural
41 challenge.

42

43 Stand up paddle boarding is low impact, making it suitable for all ages. Participants can utilize
44 almost any body of water to either paddle distances or surf waves and it is therefore an ideal
45 aquatic activity. Advantages to SUP include that it is performed whilst standing and that the
46 participant paddles bilaterally, alternating sides when required. It is a dynamic activity primarily
47 utilising the upper limbs with an isometric trunk muscle component.

48

49 As SUP can be performed in a competitive environment, it is assumed that participants would
50 require both aerobic and anaerobic fitness to be successful in distance competition. With a

51 number of competitive SUP endurance events lasting in excess of five hours (Molokai2Oahu), a
52 high level of aerobic fitness appears to be required from its elite participants. Anaerobic fitness
53 is essential for short speed bursts and to catch waves.

54

55 A high level of dynamic balance and trunk muscle endurance is required by its participants and
56 are both considered important attributes of a SUP participant. Research has shown that dynamic
57 exercise with isometric contraction of the core muscles can increase the strength of core muscles
58 (Danneels, Vanderstraeten, & Cambier, 2001) and that improved core stability occurs when
59 training on unstable surfaces (Behm, Leonard, Young, Bonsey, & Mackinnon, 2005). Core
60 stability training is commonly integrated in later stages of rehabilitation programs due to higher
61 demands on the motor control system and increased electromyographic (EMG) recordings from
62 the abdominal musculature (Vera-Garcia, Grenier, & McGill, 2000).

63

64 The importance of trunk muscle capability is twofold. Multidirectional stability is required in
65 athletic performance to optimise performance and minimize the risk of injury while endurance of
66 the muscles is required to support the passive structures of the spine (McGill, Grenier, Kavcic, &
67 Cholewicki, 2003). It has therefore been suggested that trunk muscle assessment also be
68 multidirectional to ensure that stability in all planes is confirmed (Evans, Refshauge, & Adams,
69 2007). It is assumed therefore that SUP participants would have both increased postural control
70 and high levels of isometric trunk endurance due to the training effect of the activity.

71

72 The rationale for comparison of elite and recreational SUP participants is to identify the
73 physiological and musculoskeletal attributes which differentiate the two groups. An indication of
74 the fitness attributes of elite SUP participants provides a guideline for an individual wanting to
75 succeed in competitive SUP. The profiling of SUP participants has yet to be quantified, leaving a

76 gap in the scientific literature. Therefore, the purpose of this study was to provide original data
77 regarding the physiological and musculoskeletal profiles of SUP athletes and compare it to
78 sedentary individuals with no previous exposure to the activity.

79

80 **Methods**

81 This research utilized a cross-sectional observational study design. This study was approved by
82 the University Human Research Ethics committee (RO-1550) and each participant formally
83 consented to taking part in the study prior to any tests being performed. The physiological
84 profile measures included aerobic and anaerobic capacity, blood lipid profile (total cholesterol,
85 high density lipoprotein, low density lipoprotein and triglycerides) and body composition. A
86 musculoskeletal profile included static and dynamic balance assessment and isometric trunk
87 muscle endurance.

88

89 A total of 15 elite competitive (10 males & 5 females) SUP participants and 15 recreational SUP
90 participants (10 males, 5 females) were recruited from the Stand Up Paddle Surfers Association
91 (Gold Coast, QLD, Australia). Elite participants were currently actively competing and ranked in
92 the national competition. Participants were without a history of back pain and were free from
93 any physical and psychological impairment. The recreational paddlers were required to have a
94 minimum of 1 year experience in SUP and absolutely no competitive experience in SUP events.
95 The sedentary control group were to have never had any experience on a SUP and have been not
96 participating in any exercise in the last six months.

97

98 Participants attended the human performance laboratory where they were assessed for stature (to
99 the nearest 0.1 cm) and mass (to the nearest 0.1 kg) on a standard medical balance scale (Seca,
100 700, Hamburg, Deutschland). Body composition and basal metabolic rate was assessed using
101 bio-electrical impedance (BIA), Tanita Body Composition Analyzer MC-980MA, Illinois, USA)

102 as this has been shown to successfully determine body composition (Lukaski, Bolonchuk, Hall,
103 & Siders, 1986). Participants were advised to be rested from exercise for a minimum of 24 hrs,
104 be euhydrated and bladder and bowels emptied prior to the BIA assessment. Bloods lipids were
105 analysed prior to exercise using a portable analyser (Cardiochek, P.A. Indiana, USA) to ascertain
106 total cholesterol (TC), high density lipoproteins (HDL), low density lipoproteins (LDL) and
107 triglycerides (Trigs).

108

109 A continuous graded exercise test using a specialised SUP ergometer (KayakPro SUPergo,
110 Miami, FL, USA) was used to determine maximal aerobic power (relative and absolute).
111 Maximal aerobic power (VO_{2max}) was determined using an automated expired gas analysis
112 system (Parvomedics TrueOne 2400 metabolic system, East Sandy, Utah, USA) which was
113 calibrated prior to each test. The expired gas analysis system meets Australian Institute of Sport
114 accreditation standards for precision and accuracy. The gas analysis software was configured to
115 breath by breath for collection however VO_2 max was determined from the average of 30
116 seconds of max data collected.

117

118 The SUP ergometer VO_{2max} protocol involved participants familiarising themselves with the
119 equipment with a 2 minute warm up at their chosen intensity. The test then started at an initial
120 power output of 5W with a 5W increase each minute until volitional exhaustion. Participants
121 were instructed to paddle as per normal, free to alternate paddling on each side ad libitum. Peak
122 exercise blood lactate levels were determined using a portable lactate monitor (Arkay Lactate
123 Pro Blood Lactate Monitor, Kyoto, Japan) and assessed at peak exercise, 1, 5 and 10 minutes
124 post exercise obtained from the finger. The highest blood lactate level measured was deemed the
125 peak lactate. Participant heart rates were monitored throughout the VO_{2max} test with a 12 lead
126 ECG via telemetry (Mortara X-Scribe, WI, USA).

127

128 On the subsequent visit to the laboratory, maximal anaerobic power was determined using the
129 same SUP ergometer (KayakPro SUPERgo, USA). Participants were allowed to choose their
130 preferred paddling side on the ergometer to ensure that an indication of their maximal power
131 output could be reached. Participants then paddled maximally for 10 seconds from a stationary
132 start. The maximal power was then determined using specialised software incorporated into the
133 SUP ergometer (eMonitor Pro 2 KayakPro, New Rochelle, NY, USA) which is interfaced with a
134 computer. Other anaerobic power parameters measured included distance covered in 10 seconds
135 and peak speed. A minimum of two days and a maximum of three days were allowed between
136 testing maximal aerobic and anaerobic power.

137

138 Static and dynamic postural control was assessed via a portable force platform (Kistler 2812D
139 with Bioware 4.0, 100 Hz sampling rate) with three piezoelectric force sensors used to calculate
140 the centre of pressure (COP) foot positions. The protocol was similar to methods used previously
141 by Palliard and colleagues (Palliard, Margnes, Portet, & Breucq, 2011) in which six postural
142 conditions were tested. Static posture was tested for 50 seconds and dynamic posture was tested
143 on a seesaw for 25 seconds. These conditions were tested with eyes open (EO) and then repeated
144 with eyes closed (EC). The testing order was from most stable to least stable.

145

146 Center of Pressure (COP) signals were smoothed using a Butterworth filter with a 10Hz low pass
147 cut off frequency. The 100% square (a square in which all the samples lie) was calculated post
148 collection via the range of both the x and y deviations. The COP sway path length (the total
149 distance travelled by the COP over the course of the trial duration) was calculated via the
150 distance between each sampling point. From the COP excursion, the COP velocity was
151 calculated (velocity=distance/time).

152

153 Trunk muscle endurance was measured as per methodologies previously described by McGill
154 (McGill, Belore, Crosby, & Russell, 2010). The endurance of the flexors of the spine was
155 assessed with a prone bridge, lateral flexors with a side bridge and the extensors with a Biering
156 Sorensen. The tests were terminated when the participant could no longer maintain the required
157 position as determined by the tester and that time was recorded.

158

159

160 **Statistical Analysis**

161 A one-way analysis of variance was used to compare differences between the groups. Post hoc
162 Tukey analysis was utilised to assess differences between the groups. Alpha was set at $P < 0.05$ *a*
163 *priori*. All statistical analyses were completed using the IBM Statistical Package for the Social
164 Sciences (SPSS, Version 20.0) software program.

165

166 **Results**

167 All three groups ($n=45$) were equally composed of 10 males and 5 females. Of the elite
168 competitors, six were rated amongst the top ten in the world while other competitors were
169 currently competing in the national competition of SUP in Australia. As seen in Table 1, there
170 were no significant differences between the groups with regards to age, stature or mass. Elite
171 SUP participants were on average, younger than both the recreational (-4.9%) and sedentary
172 groups (-13.8%). The sedentary group possessed the smallest stature with recreational SUP
173 being the tallest compared to both the sedentary (+1.3%) and the elite group (+0.5%). The elite
174 group was also the lightest with less total mass than both the recreational (-0.4%) and sedentary
175 groups (-13.3%). Both elite and recreational groups had significantly lower BMI ($F_{2,42} = 5.367$,
176 $P = 0.008$, $\eta^2 = 0.204$) than the sedentary group (-14.6%, -3.68kg/m², 95% CI [-6.94, -0.42],
177 $P < 0.01$, $d = 0.42$ and -15.7%, -3.92kg/m², 95% CI [-7.18, -0.66], $P > 0.05$, $d = 0.43$ respectively).
178 There were significant differences in body fat ($F_{2,42} = 13.098$, $P = 0.001$, $\eta^2 = 0.384$) with the elite

179 group the leanest with 31.2% (relative) less fat than the recreational group and 77.4% (relative)
 180 significantly less than the sedentary group (7.14% body fat, 95% CI [-17.68, -6.25], $P < 0.001$,
 181 $d = 0.69$). There were significant differences between the elite and recreational group when
 182 compared to the sedentary group with respect to BMI and percentage body fat ($P < 0.05$).

183

184 Table 1: Participant demographics (mean \pm SD) * = significant difference from sedentary ($P < 0.05$).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
Age (years)	38.2 \pm 9.37	40.07 \pm 7.44	43.47 \pm 12.59
Height (cm)	174.3 \pm 8.0	175.1 \pm 11.3	173.2 \pm 9.9
Mass (kg)	76.5 \pm 10.6	76.8 \pm 13.1	86.7 \pm 17.3
BMI (kg/m ²)	25.18 \pm 2.56*	24.94 \pm 2.84*	28.86 \pm 5.09
Body fat (%)	15.45 \pm 6.76*	20.27 \pm 6.86*	27.41 \pm 5.64

185

186 Blood lipid profiling demonstrated no significant differences between groups in total cholesterol,
 187 although elites had lower TC than both the recreational (+15.2%) and the sedentary (+15.2%),
 188 which is indicative of lower cardiovascular risk. The elite SUP had a significantly ($F_{2,42} = 7.407$,
 189 $P = 0.002$, $\eta^2 = 0.26$) higher HDL as compared to both recreational (+28%) and sedentary
 190 controls (+57.9%). Elite SUP also demonstrated a significantly ($F_{2,42} = 5.396$, $P = 0.008$, $\eta^2 =$
 191 0.20) lower LDL as compared to both recreational (-25.1%) and controls (-58.2%). The elite
 192 group displayed significantly lower triglyceride ($F_{2,42} = 6.483$, $P = 0.004$, $\eta^2 = 0.24$) levels than the
 193 recreational group ($P < 0.05$) and the control group ($P < 0.01$). There were no significant
 194 differences between the recreational and sedentary groups with respect to triglycerides (Table 2).

195

196 Table 2: Blood lipid profiles † = significant difference from recreational * = significant difference from sedentary
 197 ($P < 0.05$).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
Total cholesterol (mmol/L)	4.02 ± 0.79	4.63 ± 1.11	4.63 ± 0.67
HDL (mmol/L)	2.10 ± 0.47*	1.64 ± 0.61	1.33 ± 0.55
Triglycerides (mmol/L)	0.82 ± 0.19*†	1.37 ± 0.68	1.40 ± 0.49
LDL (mmol/L)	1.70 ± 0.85*	2.27 ± 0.93	2.69 ± 0.67

198

199

200 With regard to maximal aerobic power, the VO_{2max} of the elite group was significantly higher
201 $F_{2,42} = 83.53$, $P=0.000$, $\eta^2=0.73$) in both relative (+37.1%,+11.83ml/kg/min, 95% CI [6.53,
202 17.13], $P<0.001$, $d= 0.65$) and absolute terms ($F_{2,42} = 24.71$, $P=0.000$, $\eta^2= 0.79$) (+51.3%,
203 +2.23L/min , 95% CI [1.79, 2.66], $P<0.05$, $d=0.58$) as compared to the recreational group and
204 the sedentary group (+114.9%, +23.37ml/kg/min, 95% CI [18.07, 28.67], +85.2%, +1.56L/min,
205 95% CI [1.12, 1.99] respectively) (Table 3). There was also a significant difference ($P<0.01$)
206 between the recreational and sedentary groups with these two parameters (VO_{2max} relative,
207 +56.8%, +11.55ml/kg/min, 95%CI [6.24, 16.85] VO_{2max} absolute, +33.3%, +0.67L/min, 95%
208 CI [0.23, 1.11]). With regard to gender differences, elite males recorded a mean 46.8, $s = 3.7$
209 ml/kg/min and elite female's 37.5, $s = 4.2$ ml/kg/min. Recreational participants were lower with
210 a mean score for the males 35.3, $s = 6.6$ ml/kg/min and recreational females 25.2, $s = 4.9$
211 ml/kg/min while the sedentary males achieved a mean VO_{2max} of 21.9, $s = 3.1$ ml/kg/min and
212 females 17.4, $s = 3.0$ ml/kg/min.

213

214 There were no significant differences between groups in regards to respiratory exchange ratio,
215 peak heart rate or peak lactate. The elite group reached 102.7% of their age predicted maximum
216 heart rate (220-age), whilst recreational participant's attained 103.9% and sedentary participants
217 98.0% of their age predicted maximum heart rate. The peak aerobic power achieved was

218 significantly higher in the elite group (30.5, $s = 6.0$ W) as compared to the recreational group
219 ($P < 0.01$, +43.7%) and the sedentary group ($P < 0.01$, +188.8%) and also when comparing the
220 recreational to sedentary groups ($P < 0.01$, +101.0%). A significantly greater peak stroke rate
221 ($P < 0.01$, +25.5%), distance covered during the test ($P < 0.01$, +48.5%) and peak aerobic speed
222 ($P < 0.01$, +13.0%) was recorded from the elite group when compared to the recreational group
223 and the sedentary group ($P < 0.01$, +64.7%; $P < 0.01$, 102.7%; $P < 0.01$, +45.3). Significant
224 differences were also observed in peak stroke rate ($P < 0.01$, +31.2%), distance covered ($P < 0.05$,
225 +36.5%) and peak speed achieved during the test ($P < 0.01$, +28.7%) between the recreational and
226 sedentary groups.

227

228 The anaerobic test displayed significant differences between all of the groups in all
229 measurements (Table 3). The peak power output of the elite group was significantly higher than
230 the recreational group ($P < 0.05$, +42.5%, +10.63W, 95% CI [1.62, 19.63], $\eta^2 = 0.461$) and the
231 sedentary group ($P < 0.01$, +165.4%, +22.22W, 95% CI [13.21, 31.23]). There was also a
232 significant difference between the recreational and sedentary group ($P < 0.01$, +86.3%, +11.59W,
233 95% CI [2.58, 20.59]). The peak speed of the elite group was significantly higher than the
234 recreational ($P < 0.05$, +18.1%) and the sedentary groups ($P < 0.01$, +45.1%) and the recreational
235 group was significantly higher than the sedentary ($P < 0.05$, +28.7%). The elite group covered
236 significantly more distance during the test than the recreational ($P < 0.05$, +19.1%) and the
237 sedentary group ($P < 0.01$, +46.4%). Once again, significant differences were also evident
238 between the recreational and sedentary groups in the distance covered ($P < 0.05$, +22.9%).

239

240

241

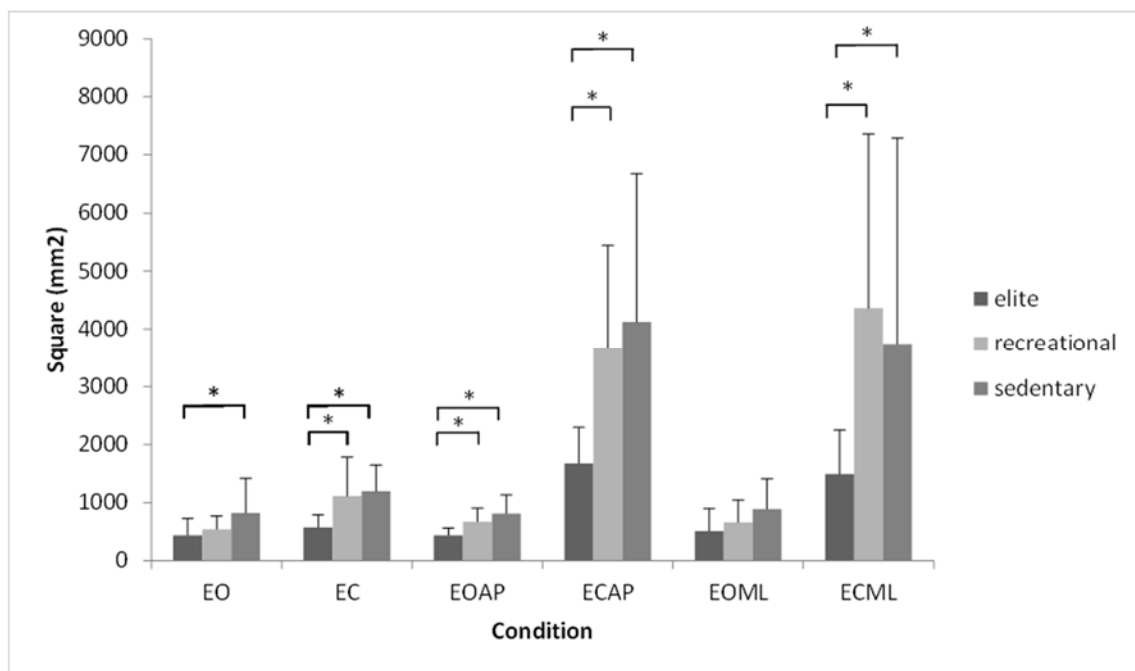
242 Table 3: Maximal aerobic and anaerobic test results of elite, recreational SUP. Results expressed as
 243 mean±SD. †=significant difference from recreational * =significant difference from sedentary ($P<0.05$).

Parameter	Elite (n = 15)	Recreational (n = 15)	Sedentary (n=15)
<i>Aerobic Performance</i>			
VO _{2max} (L/min)	3.39 ± 0.63†*	2.44 ± 0.77*	1.83 ± 0.57
VO _{2max} (ml/kg/min)	43.73 ± 5.87†*	31.90 ± 7.68*	20.35 ± 3.69
Respiratory exchange ratio	1.13 ± 0.05	1.16 ± 0.11	1.18 ± 0.07
HR _{peak} (bpm)	186.60 ± 15.00	187.6 ± 13.71	173.93 ± 17.21
Peak lactate (mmol/L)	13.70 ± 3.59	12.43 ± 3.56	-
Aerobic power (W)	30.50 ± 5.98†*	21.23 ± 7.86*	10.56 ± 3.21
Peak stroke rate (strokes/min)	69.60 ± 10.59†*	55.47 ± 7.99*	42.27 ± 9.02
Average stroke length (m)	2.19 ± 0.28	2.24 ± 0.27	2.34 ± 0.48
Distance covered (m)	747.59 ± 128.66†*	503.51 ± 159.97*	368.90 ± 68.42
Peak speed (m/s)	2.18 ± 0.16†*	1.93 ± 0.24*	1.50 ± 0.15
<i>Anaerobic Performance</i>			
Anaerobic power (W)	35.67 ± 11.08†*	25.04 ± 11.69*	13.44 ± 7.05
Relative anaerobic power (W/kg)	0.46 ± 0.12†*	0.32 ± 0.13*	0.15 ± 0.06
Peak speed (m/s)	2.35 ± 0.32†*	1.99 ± 0.40*	1.62 ± 0.31
Distance covered (m)	20.60 ± 3.08†*	17.29 ± 3.60*	14.07 ± 2.88

244

245 Figure 1 shows the elite group had significantly smaller 100% squares than the sedentary group
 246 in all but the EOML condition and significantly smaller than the recreational group in all but the
 247 EO and EOML condition. There were no significant differences between the recreational and
 248 sedentary groups with respect to the 100% square. Overall the EO condition displayed the best
 249 postural control as indicated by the lowest velocity of sway and smallest 100% square of the
 250 static tests for all groups. Under the dynamic conditions the EOAP demonstrated the lowest
 251 velocity of sway for all groups and the EOAP had the smallest 100% square amongst the elite
 252 and sedentary group while it was smallest in the EOML condition for the recreational group.

253



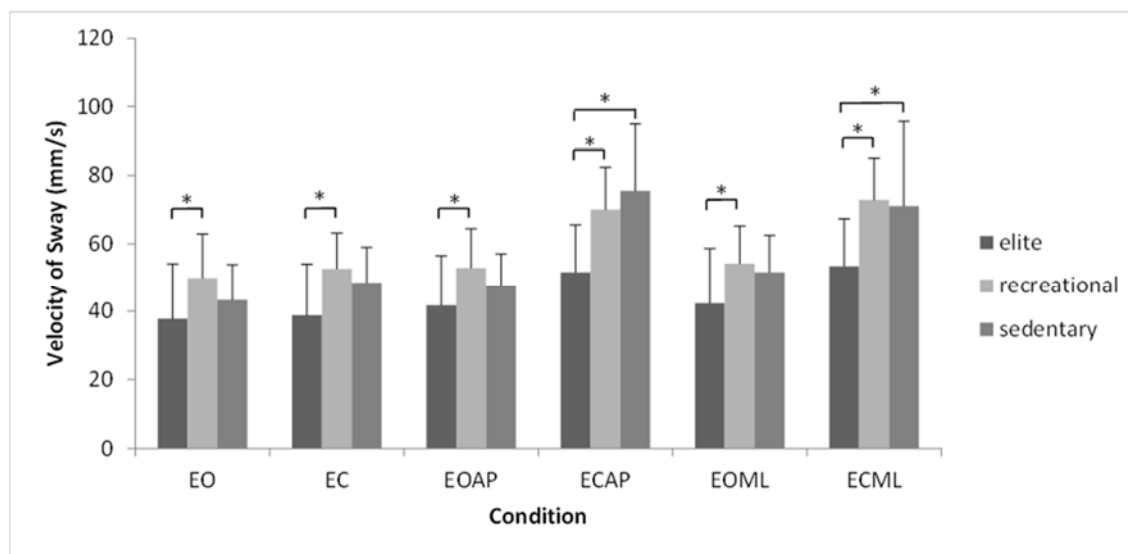
254

255 Figure 1: Balance results of participants. Results expressed as mean±SD. Where * = $P < 0.05$; EO = eyes open, EC =
 256 eyes closed, AP = Anterior Posterior Instability, ML = Medial Lateral Instability.

257

258 Figure 2 shows that elite group had significantly lower velocity of sway compared to the
 259 recreational group in all conditions, and significantly lower velocity than the sedentary group in
 260 both dynamic tests with eyes closed (ECAP, ECML). There were no significant differences
 261 between the recreational and sedentary groups with respect to velocity. The highest velocities
 262 were recorded in the ECML condition for all groups and the greatest 100% square was in the
 263 ECAP condition for the elite group and ECML for the recreational and sedentary group. There
 264 was a significant increase ($P < 0.05$) in velocity and 100% square for each condition when the
 265 subject's eyes were closed as opposed to when they had visual feedback to rely on.

266



267

268 Figure 2: Balance results EO = eyes open, EC = eyes closed, AP = Anterior Posterior Instability, ML = Medial Lateral
 269 Instability. Results are expressed as mean±SD. * = Significant difference ($P < 0.05$).

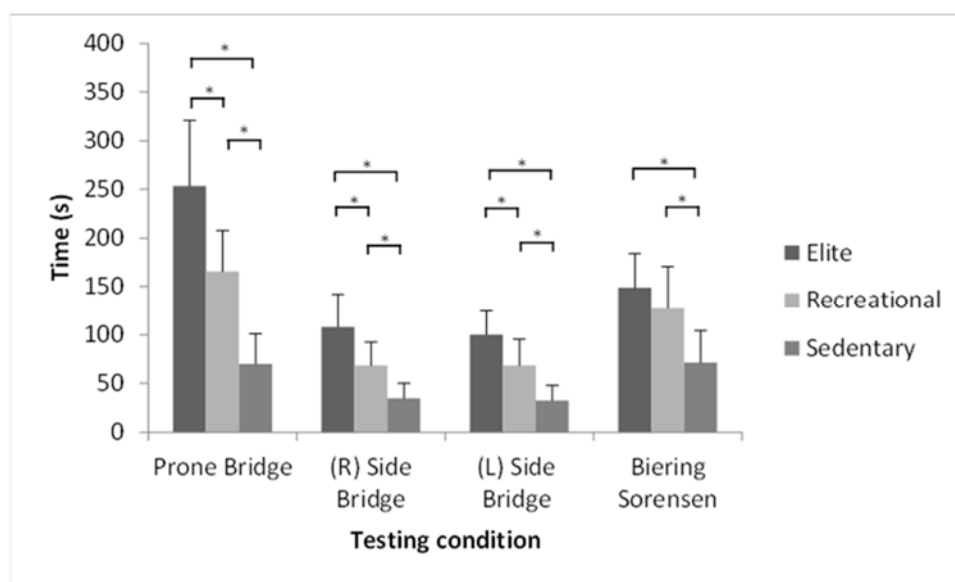
270

271 Results for the isometric tests (Figure 3) show many significant differences between the three
 272 groups. The elite group had significantly ($P < 0.05$, $\eta^2 = 0.71$) longer hold times in the prone
 273 bridge than both the recreational (+53.1%, +87.83sec, 95% CI [44.01,131.65]) and sedentary
 274 group (+263.4%, +183.67sec, 95% CI [139.85, 227.49]). The recreational group also displayed
 275 significantly ($P < 0.05$) longer hold times than the sedentary group (+137.5%, +95.83sec, 95% CI
 276 [52.01, 139.65]). The right sided bridge was significantly greater ($P < 0.05$, $\eta^2 = 0.59$) in the elite
 277 group than the recreational (+58.3%, +39.73sec, 95% CI [16.97, 62.48]) and sedentary groups
 278 (+212.2%, +73.36sec, 95%CI [50.60, 96.12]). The recreational group showed a significantly
 279 longer right sided bridge than the sedentary group (+97.3%, +33.63sec, 95% CI [10.88, 56.39]).
 280 The left side bridge was significantly ($P < 0.05$, $\eta^2 = 0.61$) greater in the elite than the recreational
 281 (+46.4%,+31.62sec, 95% CI [11.20, 52.03]) and the sedentary (+207.2%, +67.28sec, 95% CI
 282 [46.87, 87.70]) while the recreational was significantly ($P < 0.05$) greater than the sedentary
 283 (+109.8%, +35.67sec, 95% CI [15.26,56.08]).

284

285 The elite group demonstrated a non-significant difference in the Biering Sorensen test with the
 286 recreational group (+17.0%) however a significantly higher ($P<0.05$, $\eta^2=0.45$) result in this test
 287 when compared to the sedentary group (+109.3%, +77.68sec, 95% CI [44.45, 110.91]). The
 288 difference between the recreational group and the sedentary group was also significant ($P<0.05$),
 289 +78.9%, +56.08sec, 95% CI [22.85, 89.31]). There were no significant differences between
 290 either group (recreational and sedentary) with regards to right and left bridging.

291



292

293 Figure 3: Results of isometric endurance tests. * = significant difference ($P<0.05$).

294

295 Discussion

296 This was the first study to examine the physiological and musculoskeletal profiles of elite and
 297 recreational SUP participants as compared to a sedentary population. The lean body composition
 298 finding is similar to Ackland's study on the morphological characteristics of the canoe and kayak
 299 athletes attending the 2000 Olympic Games in Sydney (Ackland, Ong, Kerr, & Ridge, 2003).

300 The elite SUP participants also displayed lower cholesterol, LDL and higher HDL when
 301 compared to the recreational and sedentary groups. The elite SUP group demonstrated lipid

302 profiles within the recommended guidelines set by the Australian Heart Foundation; total
303 cholesterol < 5.5mmol/L, HDL > 1.0mmol/L, LDL < 2.0mol/L and triglycerides < 1.5mmol/L
304 (Tonkin et al., 2005). The low BMI, high HDL and low LDL and body fat percentage of the elite
305 groups are possibly associated with the training effect of SUP, beckoning further investigation of
306 the actual health benefits of SUP on cardiovascular risk.

307

308 The elite participants profiled in this study displayed comparable levels of maximal aerobic
309 power as seen in other water sports which are upper limb dominant. Previous research has
310 reported surfer's maximal aerobic fitness ranging from 37.8ml/kg/min to 54.2ml/kg/min
311 (Loveless & Minahan, 2010a; Meir, Lowdon, & Davie, 1991), canoeists from 44.2ml/kg/min to
312 51.9ml/kg/min (Bunc & Heller, 1991; Hahn, Pang, Tumilty, & Telford, 1988) and dragon boat
313 racers from 42.3ml/kg/min to 50.2ml/kg/min. It should be noted this group included males and
314 females. If adjusted for only the males group the average of 46.84ml/kg/min is comparable to the
315 numbers reported previously.

316

317 Caution should be used when comparing an upper limb dominant sport with full body water
318 based sports such as rowing and swimming due to the larger muscle mass utilised. It has
319 previously been reported that decreases of 39.36% in VO₂ max when being tested on a treadmill
320 versus being tested on a swim bench (Lowdon, Bedi, & Horvath, 1989). If a factor of this
321 decrease is added to the figures reported, measures of 65.28ml/kg/min are achieved, which is
322 comparable to other elite athletes of full body water based sports such as rowing
323 (62.88ml/kg/min) (Jurimae, Meaetsu, & Jurimae, 2000) and swimming with 58.4ml/kg/min
324 (Roels et al., 2005). Also, to our knowledge, no studies have compared the power output of these
325 various upper limb dominant sports.

326

327 The necessity to use caution when comparing aerobic power amongst SUP to other sports is
328 indicated by the results from the sedentary group. In this study, average aerobic power outputs of
329 21.85 ml/kg/min from the sedentary males and 17.37 ml/kg/min from the females are much
330 lower than previously reported references. Age stratified measures of 35.6, $s = 7.7$ ml/kg/min
331 have been reported from sedentary males and 27.2, $s = 5.0$ ml/kg/min from sedentary females
332 when utilising cycle ergometers to assess maximal aerobic power (Herdy & Uhlendorf, 2011).

333

334 There was a difference in aerobic power outputs reported previously utilising ergometers such as
335 swim bench and rowing ergometers to these SUP results (Farley, Harris, & Kilding, 2012;
336 Loveless & Minahan, 2010a). Aerobic power outputs amongst surfers using a swim bench have
337 reached 199W (Loveless & Minahan, 2010a) and 118W to 158W using modified kayak
338 ergometers (Farley, et al., 2012; Mendez-Villaneuva & Bishop, 2005). Other water sports have
339 also exhibited large aerobic power outputs including 239W from kayakers (Billat, 1996) 371W
340 from rowers (Jurimae, et al., 2000) and 195W from dragon boat racers (Ho, Smith, Chapman,
341 Sinclair, & Funato, 2012). It is assumed that due to the extensive amount of muscle mass used
342 for stabilization, a small percentage of muscle force may actually contribute toward propulsion
343 of the SUP across the water.

344

345 Although there was a greater average stroke length of the sedentary group when compared to the
346 recreational (+4.46%) and the elite group (+6.85%) in the aerobic test, this does not necessarily
347 reflect a better stroke. It can be seen that the stroke rate achieved by the elite group is
348 significantly higher than the recreational group (+25.5%) and sedentary group (+64.7%) and a
349 shorter more powerful stroke is more beneficial to overall performance as indicated by a much
350 greater power output amongst the elites than the recreational group (+43.7%) and the sedentary
351 group (+188.8%). This higher stroke rate with a shorter stroke distance is related to greater

352 power output, and therefore an increased speed across the water. The inversely proportional
353 relationship found between stroke length and rate is also found in swimming, rowing and
354 outriggering and both of these variables are found to be directly proportional to performance
355 (Sealey, Ness, & Leicht, 2011).

356

357 The anaerobic power outputs measured in this study are below those recorded in other water
358 based activities including surfing (205W - 348W,(Loveless & Minahan, 2010b)), swimming
359 (304W, (Hawley & Williams, 1991)), surf lifesaving (326W (Morton & Gaston, 1997)) and
360 kayaking (223W, (Fry & Morton, 1991)). The low numbers could be due to the high amount of
361 muscle activity being used for stabilization on a dynamic surface and consequently minimal
362 muscle activity being used for the overall propulsion. Given our findings, particularly the high
363 levels of maximal aerobic and anaerobic capacity amongst its participants, SUP may be useful
364 for cross-training or athletes wishing to avoid impact after minor injury whilst still developing or
365 maintaining aerobic and anaerobic fitness.

366

367 The potential health benefits of SUP should also be considered. Both elite groups and
368 recreational groups had good to very high maximal oxygen consumptions and favourable lipid
369 profiles. For example, over 83% of SUP participants (elite and recreational combined) had total
370 cholesterol levels at target ($<5.5\text{mmol/L}$) and 93% had HDL levels at target ($>1.0\text{mmol/L}$).
371 However participant's diet and activity levels were not assessed and these parameters would
372 have significant influence on lipid profiles. These lipid profiles combined with favourable BMI
373 and elevated aerobic fitness would afford SUP participants with reduced cardiovascular risk,
374 thereby also providing improved health associated with participation.

375

376 The elite group displaying a greatest 100% square in the ECAP condition is most likely due to
377 the lack of exposure to the AP direction and the familiarity ML instability encountered when
378 standing on a SUP. Due to the length of a board, the greatest postural challenge is in the medial
379 lateral direction, possibly explaining why the sedentary and recreational group had the greatest
380 100% square in the medial – lateral condition. Due to exposure to this condition, their postural
381 control may be increased in this direction amongst the elite.

382

383 It can be seen in this study that expertise decreases both the velocity of sway and area indicated
384 by the 100% square during postural challenges amongst SUP athletes. This increased dynamic
385 postural control could be due to specific adaptation due to the sport or alternatively, as Chapman
386 discussed, possible due to a gravitation toward, and subsequent success in balance related
387 activities from those who have a genetic predisposition toward superior postural control
388 (Chapman, Needham, Allison, Lay, & Edwards, 2008). It could also be that this way of
389 measuring dynamic balance is not specific for this sport and therefore not a true reflection of the
390 postural control of SUP participants.

391

392 It is proposed that instability training stresses the neuromuscular system more than traditional
393 training (Anderson & Behm, 2005) and instability training has been shown to increase knee
394 flexor and extensor strength and also diminish muscle imbalances between dominant and non-
395 dominant sides (Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001). Kidgell
396 demonstrated that six weeks of training on a mini-tramp was as effective as a dura disc for
397 people who have sustained lateral ankle sprains (Kidgell, Horvath, Jackson, & Seymour, 2007).
398 Whether SUP would have a similar effect on muscle strength, balance and rehabilitation due to it
399 having a similar unstable surface, is currently unclear.

400

401 Past studies regarding endurance of the trunk musculature have been centred on back pain with
402 researchers claiming that inadequate trunk endurance is a risk factor in the development and
403 chronicity of low back pain (Arab, Salavati, Ebrahimi, & Ebrahim Mousavi, 2007; Biering-
404 Sorensen, 1984; O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006). The prone bridge has
405 been used to assess trunk flexor endurance previously, and decreased endurance times as low as
406 28.3, $s = 26.8$ seconds have been found amongst symptomatic back pain sufferers (Schellenberg,
407 Lang, Chan, & Burnham, 2007). Ranges of between 92 and 124 seconds have been reported
408 from fit, healthy firefighters, (McGill, et al., 2010) well below the numbers reported amongst
409 these SUP athletes. The endurance hold times of the lateral abdominal wall measured with the
410 side bridges amongst SUP athletes were similar to an athletic population of 87.5, $s = 36.4$
411 seconds on the right and 92, $s = 45.8$ seconds on the left (Evans, et al., 2007).

412

413 The extensor endurance amongst the both SUP groups were similiar to previously published
414 papers including McGill's study which showed an average men's endurance time of 146s,
415 women's 189s amongst young, healthy individuals (McGill, Childs, & Leiebenson, 1999),
416 higher than Adedoyin's of 119, $s = 47$ s for men and 106, $s = 44$ s for women (Adedoyin, Mbada,
417 Farotimi, Johnson, & Emechete, 2011), and much higher than Alaranta, who demonstrated 97s
418 men and 87s women (Alaranta, 1994). Results obtained in this study are also greater than a
419 group of athletes who had back pain with an average hold times of 107.5s (Stewart, Latimer, &
420 Jamieson, 2003).

421

422 It has been demonstrated previously that the endurance of the core muscles can be improved
423 with core training (Aggarwal, Kumar, & Kumar, 2010). Significant improvements in hold times
424 of all the above tests were made with six weeks of core training including multidirectional
425 movements and instability with the use of a swiss ball. As the core muscles seem to be activated

426 by SUP and these athletes demonstrate adequate endurance hold times, perhaps SUP could be
427 used to increase endurance of the core muscles and therefore be used as a prophylactic treatment
428 for back pain.

429

430 The minimal difference amongst the SUP participants in regards to left and right bridge times is
431 most probably due to the paddling motion being performed bilaterally, typically alternating on a
432 regular 10-14 stroke basis. Muscle imbalances are rife amongst competitive canoeists and
433 outriggers who paddle on the one side (Stambolieva, Diafas, Bachev, Christova, & Gatev, 2011)
434 and it is thought that muscle imbalance could be related to injury occurrence (Franettovich,
435 Hides, Mendis, & Littleworth, 2011). The slightly higher, difference right sided bridge score is
436 most likely due to the prevalence of right hand dominance.

437

438 The aim of this investigation was to profile SUP in regards to physiological and musculoskeletal
439 parameters. In summary, there appears to be a high level of aerobic and anaerobic fitness,
440 dynamic postural control and a high level of trunk muscle endurance amongst those who
441 participate in SUP. It would appear as though greater levels of fitness, strength and balance are
442 associated with higher participation.

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