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Laboratory and field based assessment of maximal aerobic power of elite SUP athletes

Original Investigation

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35 **ABSTRACT**

36 **Purpose:** Stand up paddle boarding (SUP) is a rapidly growing sport and recreational activity
37 where only anecdotal evidence exists for its proposed health, fitness and injury rehabilitation
38 benefits.

39 **Methods:** A total of 10 internationally and nationally ranked elite SUP athletes volunteered to
40 participate in this study. Elite SUP athletes were assessed for their maximal aerobic power on an
41 ergometer in a laboratory and compared to other water based athletes. Field based assessments
42 were subsequently performed utilising a portable gas analysis system and a correlation between
43 the two measures was performed.

44 **Results:** The mean VO_2max (relative) was significantly higher ($P=0.037$) when measured in the
45 field with a portable gas analysis system ($45.48\pm 6.96\text{ml/kg/min}$) when compared to laboratory
46 based metabolic cart measurements ($43.20\pm 6.67\text{ml/kg/min}$). There was a strong, positive
47 correlation ($r=0.907$) between laboratory and field maximal aerobic power results. Significantly
48 higher ($P=0.000$) measures of SUP paddling speed (m/s) were found in the field when compared
49 to the laboratory ergometer (+42.39%). There were no significant differences in maximal heart
50 rate between the laboratory and field settings ($P=0.576$).

51 **Conclusion:** The results demonstrates the maximal aerobic power representative of
52 internationally and nationally ranked SUP athletes and shows that SUP athletes can be assessed
53 for maximal aerobic power in the laboratory with high correlation to field based measures. The
54 field based portable gas analysis unit has a tendency to consistently measure higher oxygen
55 consumption. Elite SUP athletes display aerobic power outputs similar to other upper limb
56 dominant elite water based athletes (surfing, dragon boat racing and canoeing).

57 **Key words:** profiling, water, sports, aquatic, paddle boarding, SUP

58 INTRODUCTION

59 Stand up paddle boarding (SUP) is a new sport and recreational activity, which is increasing in
60 popularity around the world due to its proposed health and fitness benefits and enjoyment ¹.

61 Stand up paddle boarding is a hybrid of surfing and paddling in which participants can either
62 distance paddle and/or surf waves ². Many websites anecdotally advocate the use of SUP to
63 increase strength, fitness, core stability, balance and decrease back pain. However, our recent
64 review of the literature utilising the search terms “SUP”, “Stand Up Paddle Boarding” and “Stand
65 Up Paddle” of CINAHL, SPORTDiscus, EMBASE & Medline found no scientific evidence to
66 substantiate these proposed benefits.

67
68 An ideal physiological test is one which accurately and reliably assesses the specific energy
69 systems of the musculature involved in that particular sport ³. To adhere to the principle of
70 specificity, in addition to laboratory testing, field testing for aerobic power on a stand up paddle
71 board is highly desirable. This allows comparison between testing in a laboratory under tightly
72 controlled conditions and actual SUP performance on water.

73
74 Recent advances in technology have allowed for more compact, light-weight and ambulatory
75 pulmonary gas analysis system (Cosmed K4b2, Rome, Italy). The development of such systems
76 has allowed field testing to gain a greater understanding of the metabolic demands during various
77 modes and intensities of exercise in the environment in which they are normally performed ⁴.

78
79 An indication of the aerobic capacity of elite SUP athletes provides a guideline for an individual
80 wanting to succeed in competitive SUP. The measurement of aerobic fitness of internationally

81 and nationally ranked SUP athletes has yet to be quantified, leaving a gap in the scientific
82 literature. Therefore, the purpose of this study was to assess internationally and nationally ranked
83 SUP athletes in the laboratory under tightly controlled conditions, then compare the result to a
84 field based assessment with a portable gas analysis system.

85

86 **METHODS**

87 **SUBJECTS**

88 A total of 10 elite competitive (6 males & 4 females) SUP athletes were recruited from the Stand
89 Up Paddle Surfers Association (Gold Coast, QLD, Australia). Of the elite competitors, six were
90 rated amongst the top ten in the world and the remaining athletes were currently competing in the
91 national competition of SUP in Australia. For inclusion, athletes were without a history of back
92 pain and were free from any physical and psychological impairment. The study was approved by
93 the University Human Research Ethics Committee (RO-1550) and each participant formally
94 consented to taking part in the study.

95

96 **DESIGN**

97 This was a comparative study in which athletes were tested for maximal aerobic power in the
98 field with a portable gas analysis system and subsequently in the laboratory under tightly
99 controlled conditions. The primary aims of this study were to assess elite SUP athletes for their
100 maximal aerobic power on an ergometer in a laboratory and compare the results to other water
101 based athletes. The secondary aim was to compare the laboratory result to a field based
102 measurement utilising a portable gas analysis system.

103

104 **METHODOLOGY**

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

114
115 The SUP ergometer VO_{2max} protocol involved the athletes starting at an initial power output of
116 5W with a 5W increase each minute until volitional exhaustion. The athletes were instructed to
117 paddle as per normal, free to alternate paddling on each side ad libitum. Heart rates were
118 monitored throughout the test with a 12 lead ECG via telemetry (figure 1).

119
120 A portable gas analysis system (Cosmed K4b2, Rome Italy) previously validated for field
121 assessment of VO_{2max} in a number of outside activities⁴, was utilized to assess expired
122 concentrations of oxygen and ventilation (figure 1). For comparison to laboratory findings, the
123 athletes then completed a VO_{2max} test whilst on flat water in a creek (tide neutral).

124
125 The protocol for the field based assessment of maximal aerobic power involved starting at 30
126 strokes per minute keeping cadence with a metronome played to the athletes through headphones
127 attached to a portable media player (iPod). The metronome increased cadence by 5 strokes per
128 minute every minute which the participant was to maintain until volitional fatigue. All water

129 based $\text{VO}_{2\text{max}}$ tests were conducted within five days of the laboratory tests to ensure minimal
130 physiological change to maximal aerobic fitness.

131

132 **STATISTICAL ANALYSIS**

133 All statistical analyses were performed using SPSS (Version 20) including mean and standard
134 deviation calculations, while paired *t* tests were used to determine any significant differences
135 between the two groups. Alpha was set at 0.05 *a priori*. A Pearson correlation analysis was
136 performed to compare laboratory results to field results. A Bland Altman plot ⁵ was utilised to
137 provide a graphical representation of the two different measurement techniques, with limits of
138 agreement set at 95%.

139

140 **RESULTS**

141 Table 1 displays that males were younger (-9.42%) but not significantly ($P=0.627$), significantly
142 taller (+8.82%, $P=0.006$) and significantly heavier (+21.37%, $P=0.044$) than the female athletes.
143 The overall group, and female Body Mass Index (BMI) was within the healthy weight category
144 with the males being classified as overweight despite being only slightly more than the females
145 (+2.78%).

146 **<Table 1 here>**

147

148 Field based results of aerobic power for the group, were significantly higher (+5.28%, $P=0.037$)
149 as compared to laboratory based results (Table 2). A significant ($P=0.000$) difference was found
150 in peak speed measured in the field (+42.39%) compared to in the laboratory. There were no
151 significant differences in heart rate measured between the field and laboratory ($P=0.576$). Males
152 had a significantly greater maximal aerobic power as compared to females in both the laboratory

153 (47.59±3.37 vs 36.61±4.24ml/kg/min, $P=0.002$) and in the field (49.68±4.41 vs 39.18±4.96
154 ml/kg/min, $P=0.008$). There were no significant differences between genders with regard to
155 ventilation (VE), Respiratory Exchange Ratio (RER), or heart rate in the laboratory when
156 compared to the field.

157

158 <Table 2 here>

159

160 A high, positive correlation ($r=0.907$) was found between the absolute VO_{2max} recorded in the
161 laboratory and in the field with the portable gas analysis unit (Figure 1). The field measurement
162 was higher in 80% of the subjects tested with only 2 subjects demonstrating higher VO_{2max} values
163 in the laboratory. The mean difference between the two samples was only -2.28 ± 2.95 ml/kg/min.

164 A linear regression of the differences of the mean demonstrated that there was no proportional
165 bias between the two measures ($P=0.785$). There was however, fixed bias ($P=0.037$) as the
166 measurements in the field were consistently higher than the laboratory based measurement.

167

168 <Figure 1 here>

169 <Figure 2 here>

170

171

172

173 **DISCUSSION**

174 The primary aim of this study was to measure the maximal aerobic power of elite SUP
175 athletes with a traditional laboratory based method utilising a metabolic cart and compare the
176 results to other water based athletes. The secondary aim of this study was to compare the

177 laboratory based result to a field based result utilising a portable gas analysis unit. The aerobic
178 power of elite SUP athletes has not previously been reported in the literature and the findings
179 from this study provide some insight into the maximal aerobic fitness levels of elite SUP athletes.

180
181 The elite male athletes profiled in this study displayed high levels of maximal aerobic power as
182 reported in other water sports which are upper limb dominant. For example, previous
183 investigators have reported male surfer's maximal aerobic fitness ranging from 37.8ml/kg/min to
184 54.2ml/kg/min^{6,7}, canoeists from 44.2ml/kg/min to 51.9ml/kg/min^{8,9} and dragon boat racers
185 from 42.3ml/kg/min to 50.2ml/kg/min. Although female surfers have been tested for maximal
186 aerobic fitness whilst running on a treadmill¹⁰ and cycling¹¹ there is currently a minimal amount
187 of normative data for upper limb specific VO₂ max testing for female water based athletes. The
188 maximal aerobic fitness of these female SUP athletes (36.61 ± 4.24 ml/kg/min) is similar to as yet
189 unpublished data for elite female surfers we have tested on a swim bench ergometer of $34.30 \pm$
190 2.71 ml/kg/min¹².

191
192 The pooled data of both male and female values from the field based test demonstrated a high
193 level of correlation between those results obtained from controlled laboratory based test. Given
194 our results, it would appear that laboratory assessment of maximal aerobic power in elite SUP
195 athletes is a valid alternative to field based testing. The tendency of the K4b2 portable unit to
196 record consistently higher oxygen consumption than laboratory based metabolic carts has been
197 found in other research⁴. The differences in the two environments as evident by the fixed bias
198 error may be attributed to athlete comfort and familiarisation when in their natural SUP
199 environment on water. The athletes reported they felt more comfortable completing the maximal

200 aerobic power test whilst on the water, despite wearing the portable gas analysis device which
201 weighed 800 grams and required a utilization of a facemask to collect expired gasses for the
202 duration of the test.

203
204 The differences in speed measures between the two environments are most likely attributed to the
205 different methods for quantification of speed. The laboratory based speed measure is based upon
206 measurement of the moment of inertia of the flywheel on the ergometer whereas the field based
207 measurement was from the K4b2's integrated global positioning system (GPS). The GPS
208 component of the K4b2 was only a 1Hz unit, which is a significantly lower frequency than the
209 more modern, updated 15Hz units which are currently available. Previous research had reported
210 quantification of speed via GPS is associated with measurement errors when sampling rates are
211 low¹³. Field based measurement of speed with lower GPS sampling rates should therefore be
212 interpreted with caution amongst this population. Our current research on field based assessment
213 of speed in SUP utilized 15Hz GPS units, which identified an average speed of 2.72 ± 0.2 m/s
214 during a marathon SUP event (~20km). Further research is therefore required to determine speed
215 measurements across the water whilst SUP.

216
217 A limitation of this study is that two different protocols were used. Unfortunately, we were
218 unable to instrument the SUP paddle to ascertain power outputs for the field assessment therefore
219 a protocol was devised where an incremental increase in stroke rate was used. This was not
220 feasible to replicate in the laboratory as once the subjects stroke rate reached 55 strokes per
221 minute (and higher) athletes were unable to maintain normal strokes and consequently shortened
222 their stroke rate in an attempt to maintain the designated cadence. For example, the average

223 stroke lengths found in this study were in excess of two meters per stroke and therefore a four
224 meter stroke cycle must be completed in approximately one second if that protocol was used in
225 the laboratory assessment, which is physiologically unrealistic.

226
227 Based upon our findings it would appear that elite SUP athletes have high maximal aerobic
228 capacity which compares well to other water based athletes. Laboratory and field based
229 measurements are highly correlated and can be used to assess SUP athletes provided the tendency
230 for the field based measurements using the K4b2 unit to consistently measure higher values is
231 noted.

232

233 **PRACTICAL APPLICATIONS**

234 SUP is a new sport and recreational activity in which little scientific research exists. Our results
235 demonstrate the aerobic capacity representative of elite level SUP athletes which can be used by
236 sport scientists and coaches as targets. Elite level SUP athletes have aerobic capacities similar to
237 other elite water based athletes highlighting that a high level of aerobic fitness is important for
238 competitive SUP. This study demonstrates that SUP athletes can be assessed for maximal aerobic
239 power in the laboratory with high correlation to field based measures.

240

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276 accuracy of 10Hz GPS devices for short distance exercise. *Journal of Sport Science and Medicine*.
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281

282 **FIGURES AND TABLES**

	Group (n=10)	Males (n=6)	Females (n=4)
Age (yrs)	35.8±9.55	34.50±6.03	37.75±14.32
Height (cm)	174.00±0.45	179.83±6.91	165.25±4.27
Weight (kg)	75.59±11.44	81.32±6.41	67.00±12.66
BMI (kg/m ²)	24.87±2.42	25.14±1.36	24.46±3.77
Body Fat (%)	15.87±7.40	11.13±2.79	22.98±6.25

Table 1: Participant demographics. Mean ± SD.

283

	Laboratory	Field
VO ₂ max (ml/kg/min)	43.20±6.67	45.48±6.96*
V _E STPD (L/min)	118.09±24.79	123.63±41.68
Respiratory Exchange Ratio	1.13±0.05	1.16±0.08
Heart Rate (bpm)	180.9±15.58	183±9.89
Peak Speed (m/s)	2.17±0.13	3.09±0.32**

Table 2: Laboratory versus field based results of maximal aerobic power. * = $P=0.037$, ** $P=0.000$. Results expressed as mean±SD.

284



Figure 1: Lab based testing on the SUP ergometer and field based testing with the K4b2 portable unit.

285

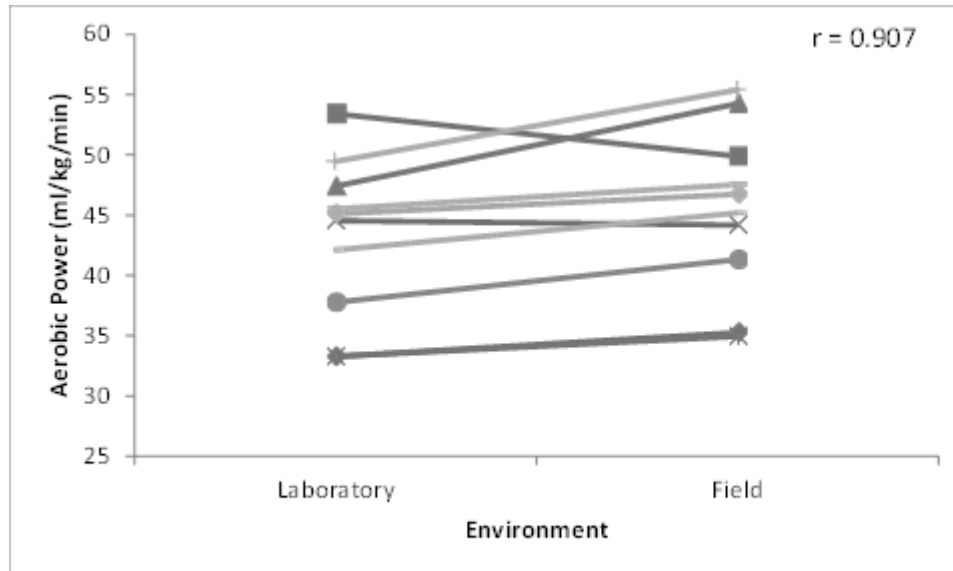


Figure 2: Laboratory and Field based measurements of maximal aerobic power.

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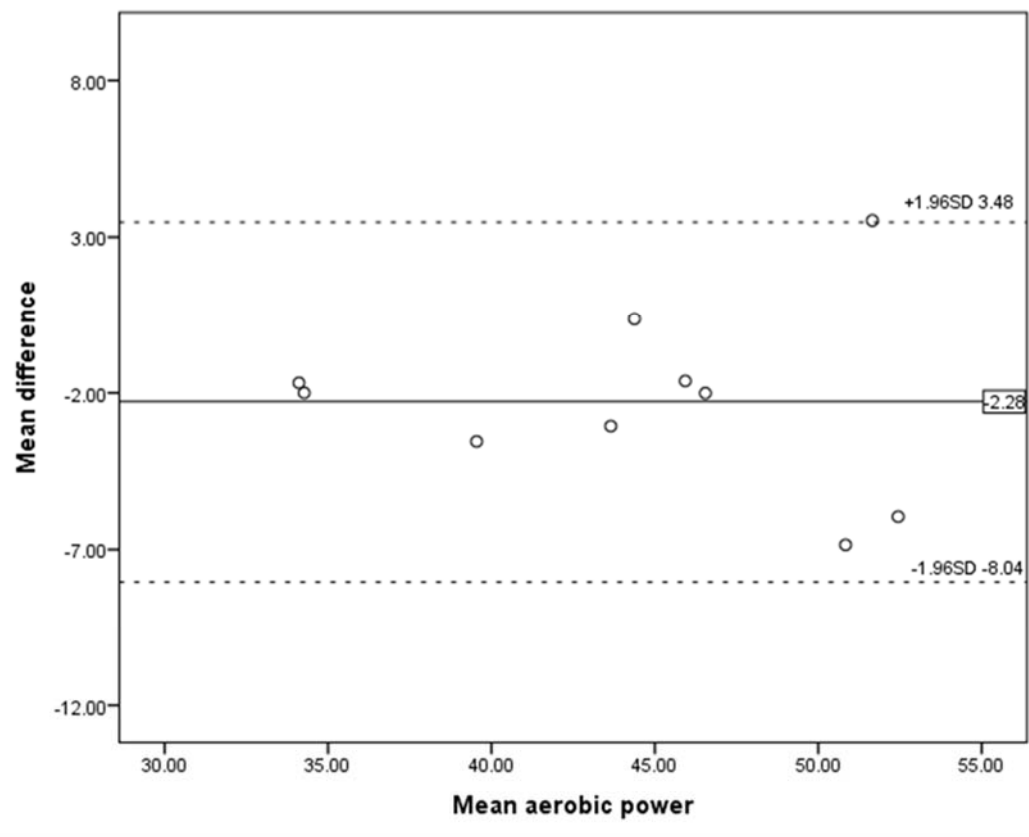


Figure 3: Bland Altman plot displaying mean difference between the two measures and 95% CI.