Profiling the Sport of Stand Up Paddle Boarding

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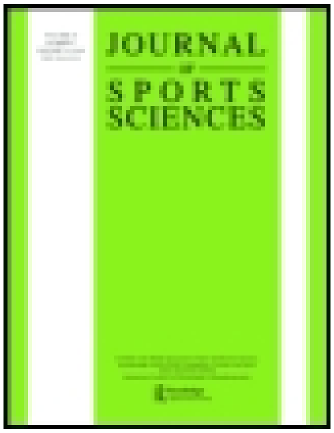

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ABSTRACT

Stand-up paddle boarding (SUP) is a rapidly growing activity where only anecdotal evidence exists for its proposed health and fitness benefits. The purpose of this study was to profile elite and recreational SUP with respect to anthropometric, physiological and musculoskeletal measurements. A total of 30 SUP participants (15 recreational, 15 elite) and 15 sedentary controls participated in this study. Elite and recreational (rec) SUP participants had significantly lower body fat than sedentary (sed) individuals, elite had significantly higher HDL and significantly lower triglycerides than other groups during lipid profiling (P > 0.05). There were significant differences (P > 0.05) between all groups in maximal oxygen uptake (elite 43.7, s = 5.89 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. rec 31.9, s = 7.7 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. sed 20.4, s = 3.7 $ml \cdot kg^{-1} \cdot min^{-1}$) and anaerobic 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 displayed significantly longer endurance than the recreational and sedentary group in the prone bridge (elite 253.4, s = 67.6 s vs. rec 165.6, s = 42.2 s vs. sed 69.7, s = 31.2 s), right-sided bridge (elite 107.9, s = 34.0 s vs. recreational 68.2, s = 24.1 s vs. sed 34.6, s = 15.5 s), left-sided bridge (elite 99.8, s = 24.9 s vs. rec 68.2, s = 27.2 s vs. sed 32.5, s = 15.2 s) and Biering Sorensen test (elite 148.8, s = 35.4 s vs. rec 127.2, s = 43.2 s vs. sed 71.1, s = 32.9 s). Elite SUP had significantly better static and dynamic postural control when compared to the other groups. This study demonstrates the anthropometric, physiological and musculoskeletal values representative of elite and recreational SUP. SUP appears to be associated with increased levels of aerobic and anaerobic fitness, increased static and dynamic balance and a high level of isometric trunk endurance.

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Profiling; water sports; aquatic; paddle boarding

Introduction

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

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

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

As SUP can be performed in a competitive environment, it is assumed that participants would require both aerobic and anaerobic fitness to be successful in distance competition. With a number of competitive SUP endurance events lasting in excess of 5 h (Molokai to Oahu Paddle Board Race, 2012), a high level of aerobic fitness appears to be required from its elite participants. Anaerobic fitness is essential for short speed bursts and to catch waves.

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

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

The rationale for comparison of elite and recreational SUP participants is to identify the physiological and musculoskeletal attributes which differentiate the two groups. An indication of the fitness attributes of elite SUP participants provides a guideline for an individual wanting to succeed in competitive SUP. The profiling of SUP participants has yet to be quantified, leaving a gap in the scientific literature. Therefore, the purpose of this study was to provide original data regarding the physiological and musculoskeletal profiles of SUP athletes and compare it to sedentary individuals with no previous exposure to the activity.

Methods

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

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

Participants attended the human performance laboratory where they were assessed for stature (to the nearest 0.1 cm) and mass (to the nearest 0.1 kg) on a standard medical balance scale (Seca, 700, Hamburg, Deutschland). Body composition and basal metabolic rate was assessed using bio-electrical impedance (BIA) with Tanita Body Composition Analyzer MC-980MA, Illinois, USA) as this has been shown to successfully determine body composition (Lukaski, Bolonchuk, Hall, & Siders, 1986). Participants were advised to be rested from exercise for a minimum of 24 h, be euhydrated and bladder and bowels emptied prior to the BIA assessment. Blood lipids were analysed prior to exercise using a portable analyser (Cardiochek, PA, Indiana, USA) to ascertain total cholesterol (TC), high-density lipoproteins (HDL), low-density lipoproteins (LDL) and triglycerides (Trigs).

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

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

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

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

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

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

Statistical analysis

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

Results

All three groups (n = 45) were equally composed of 10 males and 5 females. Of the elite competitors, six were rated amongst the top ten in the world while other competitors were currently competing in the national competition of SUP in Australia. As seen in Table 1, there were no significant differences between the groups with regard to age, stature or mass. Elite SUP participants were on average, younger than both the recreational (–4.9%) and sedentary groups (–13.8%). The sedentary group possessed the smallest stature with recreational SUP being the tallest compared to both the sedentary (+1.3%) and the elite group (+0.5%). The elite group was also the lightest with less total mass than both the recreational (–0.4%) and sedentary groups (–13.3%). Both elite and recreational groups had significantly lower BMI ($F_{2,42}$ = 5.367, P = 0.008, η^2 = 0.204) than the sedentary group (–14.6%, –3.68 kg · m^{-2}, 95% CI [–6.94, –0.42], P < 0.01, d = –0.91 and –15.7%, –3.92 kg · m^{-2}, 95% CI [–7.18, –0.66], P < 0.05, d = –0.97, respectively). There were significant differences in body fat ($F_{2,42}$ = 13.098, P = 0.001, η^2 = 0.384) with the elite group, the leanest with 31.2% (relative) less fat than the recreational group and 77.4% (relative) significantly less than the sedentary group (–7.14% body fat, 95% CI [–17.68, –6.25], P < 0.001, d = –1.91). There were significant differences between the elite and recreational group when compared to the sedentary group with respect to BMI and percentage body fat (P < 0.05).

Table 1. Participant demographics (mean ± SD).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n = 15)
Age (years)	38.2 (9.4)	40.1 (7.4)	43.5 (12.6)
Height (cm)	174.3 (8.0)	175.1 (11.3)	173.2 (9.9)
Weight (kg)	76.5 (10.6)	76.8 (13.1)	86.7 (17.3)
BMI (kg · m^{-2})	25.2 (2.6)*	24.9 (2.8)*	28.9 (5.1)
Body fat (%)	15.5 (6.7)*	20.3 (6.9)*	27.4 (5.6)

Note: * Significant difference from sedentary (P < 0.05).

Table 2. Blood lipid profiles, values are mean (±SD).

	Elite (n = 15)	Recreational (n = 15)	Sedentary (n = 15)
Total cholesterol (mmol · L^{-1})	4.02 (0.79)	4.63 (1.11)	4.63 (0.67)
HDL (mmol · L^{-1})	2.10 (0.47)*	1.64 (0.61)	1.33 (0.55)
Triglycerides (mmol · L^{-1})	0.82 (0.19)*†	1.37 (0.68)	1.40 (0.49)
LDL (mmol · L^{-1})	1.70 (0.85)*	2.27 (0.93)	2.69 (0.67)

Note: † Significant difference from recreational; * significant difference from sedentary (P < 0.05).

Blood lipid profiling demonstrated no significant differences between groups in total cholesterol, although elites had lower TC than both the recreational (+15.2%) and the sedentary (+15.2%), which is indicative of lower cardiovascular risk. The elite SUP had a significantly higher HDL ($F_{2,42}$ = 7.407, P = 0.002, η^2 = 0.26) than sedentary controls (+57.9%, +0.76 mmol · L^{-1}, 95% CI [0.28, 1.25], P < 0.05, d = 1.45). Elite SUP also demonstrated a significantly ($F_{2,42}$ = 5.396, P = 0.008, η^2 = 0.20) lower LDL as compared to controls (–58.2%, –0.99 mmol · L^{-1}, 95% CI [–1.72, –0.25], P < 0.01, d = –1.24). The elite group displayed significantly lower triglyceride ($F_{2,42}$ = 6.483, P = 0.004, η^2 = 0.24) levels than the recreational group (–0.55 mmol · L^{-1}, 95% CI [–0.99, –0.11], P < 0.05, d = –1.17) and the control group (–0.58 mmol · L^{-1}, 95% CI [–1.01, –0.14], P < 0.01, d = –1.58). There were no significant differences between the recreational and sedentary groups with respect to triglycerides (Table 2).

With regard to maximal aerobic power, the VO_{2max} of the elite group was significantly higher in both relative ($F_{2,42}$ = 83.53, P = 0.001, η^2 = 0.73) and absolute terms ($F_{2,42}$ = 24.71, P = 0.001, η^2 = 0.79) as compared to the recreational group (relative = + 37.1%,+11.83 ml · kg^{-1} · min^{-1}, 95% CI [6.53, 17.13], P < 0.001, d = 1.72, absolute = + 51.3%, +2.23 L · min^{-1}, 95% CI [1.79, 2.66], P < 0.05, d = 1.41) and the sedentary group (relative +114.9%, +23.37 ml · kg^{-1} · min^{-1}, 95% CI [18.07, 28.67], P < 0.001, d = 4.73, absolute = + 85.2%, +1.56 L · min^{-1}, 95% CI [1.12, 1.99], P < 0.001, d = 2.67, Table 3). There was also a significant difference between the recreational and sedentary groups with these two parameters (VO_{2max} relative, +56.8%, +11.55 ml · kg^{-1} · min^{-1}, 95% CI [6.24, 16.85], P < 0.001, d = 1.90, absolute, +33.3%, +0.67 L · min^{-1}, 95% CI [0.23, 1.11], P < 0.005, d = 0.85). With regard to gender differences, elite males recorded a mean 46.8, s = 3.7 ml · kg^{-1} · min^{-1} and elite female's 37.5, s = 4.2 ml · kg^{-1} · min^{-1}. Recreational participants were lower with a mean score for the males 35.3, s = 6.6 ml · kg^{-1} · min^{-1} and recreational females 25.2, s = 4.9 ml · kg^{-1} · min^{-1} while the sedentary males achieved a mean VO_{2max} of 21.9, s = 3.1 ml · kg^{-1} · min^{-1} and females 17.4, s = 3.0 ml · kg^{-1} · min^{-1}.

There were no significant differences between groups in regard to respiratory exchange ratio, peak heart rate or peak lactate. The elite group reached 102.7% of their age predicted maximum heart rate (220 – age), whilst recreational participant's attained 103.9% and sedentary participants 98.0% of their age predicted maximum heart rate. The peak aerobic power ($F_{2,42}$ = 41.48, P = 0.001, η^2 = 0.66) achieved was significantly higher in the elite group as compared to the recreational group (+43.7%, +9.27 W, 95% CI [3.95, 14.59], P < 0.001, d = 1.32) and the sedentary group (+188.8%, +19.94 W, 95% CI [14.61, 25.26], P < 0.001, d = 4.14) and also

Table 3. Physiological characteristics of elite and recreational SUP. Results are expressed as mean (±SD).

Parameter	Elite (n = 15)	Recreational (n = 15)	Sedentary (n = 15)
Aerobic performance			
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	3.39 (0.63)†*	2.44 (0.77)*	1.83 (0.57)
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	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 ($mmol \cdot L^{-1}$)	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 ($strokes \cdot min^{-1}$)	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 ($m \cdot s^{-1}$)	2.18 (0.16)†*	1.93 (0.24)*	1.50 (0.15)
Anaerobic performance			
Anaerobic power (W)	35.67 (11.08)†*	25.04 (11.69)*	13.44 (7.05)
Relative anaerobic power ($W \cdot kg^{-1}$)	0.46 (0.12)†*	0.32 (0.13)*	0.15 (0.06)
Peak speed ($m \cdot s^{-1}$)	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)

Note: † Significant difference from recreational; * significant difference from sedentary ($P < 0.05$).

when comparing the recreational to sedentary groups (+101.0%, +10.67 W, 95% CI [5.34, 15.99], $P < 0.001$, $d = 1.76$). A significantly greater peak stroke rate ($F_{2,42} = 32.66$, $P = 0.001$, $\eta^2 = 0.61$), distance covered during the test ($F_{2,42} = 34.41$, $P = 0.001$, $\eta^2 = 0.63$) and peak aerobic speed ($F_{2,42} = 49.59$, $P = 0.001$, $\eta^2 = 0.70$) was recorded from the elite group when compared to the recreational group (+25.5%, +14.13 strokes $\cdot$ min^{-1}, 95% CI [5.92, 22.35], $P < 0.001$, $d = 1.50$; +48.5%, +244.07 m, 95% CI [133.24, 354.91], $P < 0.001$, $d = 1.68$; +13.0%, +0.25 m $\cdot$ s^{-1} 95% CI [0.08, 0.42], $P < 0.005$, $d = 1.23$) and the sedentary group (+64.7%, +27.33 strokes $\cdot$ min^{-1}, 95% CI [19.12, 35.55] $P < 0.001$, $d = 2.78$; 102.7%, +378.69 m, 95% CI [267.86, 489.52], $P < 0.001$, $d = 3.67$; +45.3, +0.68 m $\cdot$ s^{-1}, 95% CI [0.51, 0.85], $P < 0.001$, $d = 4.38$). Significant differences were also observed in peak stroke rate (+31.2%, +13.20 strokes $\cdot$ min^{-1}, 95% CI [4.98, 21.42], $P < 0.005$, $d = 1.55$), distance covered (+36.5%, +134.61 m, 95% CI [23.78, 245.45], $P < 0.05$, $d = 1.09$) and peak speed achieved during the test (+28.7%, +0.43 m $\cdot$ s^{-1}, 95% CI [0.26, 0.60], $P < 0.001$, $d = 2.15$) between the recreational and sedentary groups.

The anaerobic test displayed significant differences between all of the groups in all measurements (Table 3). The peak power output ($F_{2,42} = 17.97$, $P = 0.001$, $\eta^2 = 0.46$) of the elite group was significantly higher than the recreational group (+42.5%, +10.63 W, 95% CI [1.62, 19.63], $P < 0.05$, $d = 0.94$) and the sedentary group (+165.4%, +22.22 W, 95% CI [13.21, 31.23], $P < 0.001$, $d = 2.39$). There was also a significant difference between the recreational and sedentary group (+86.3%, +11.59 W, 95% CI [2.58, 20.59], $P < 0.01$, $d = 1.20$). The peak speed of the elite group was significantly higher than the recreational (+18.1%, +0.37 m $\cdot$ s^{-1}, 95% CI [0.06, 0.67], $P < 0.05$, $d = 1.13$) and the sedentary groups (+45.1%, +0.73 m $\cdot$ s^{-1}, 95% CI [0.43, 1.04], $P < 0.001$, $d = 2.67$) and the recreational group was significantly higher than the sedentary (+28.7%, +0.36 m $\cdot$ s^{-1}, 95% CI [0.06, 0.67], $P < 0.05$,

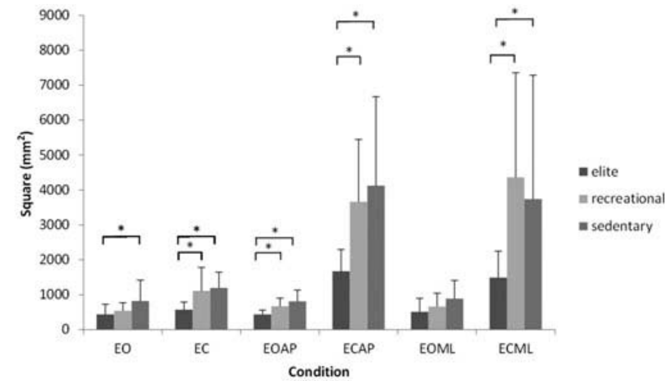

Figure 1. Balance results of participants. Results are expressed as mean ± SD. * $P < 0.05$; EO, eyes open; EC, eyes closed; AP, anterior posterior instability; ML, medial lateral instability.

$d = 1.13$). The elite group covered significantly more distance during the test than the recreational (+19.1%, +3.3 m, 95% CI [0.46, 6.14], $P < 0.05$, $d = 0.98$) and the sedentary group (+46.4%, +6.52 m, 95% CI [3.68, 9.36], $P < 0.001$, $d = 2.17$). Once again, significant differences were also evident between the recreational and sedentary groups in the distance covered (+22.9%, +3.22 m, 95% CI [0.38, 6.06], $P < 0.05$, $d = 0.98$).

Figure 1 shows that the elite group had significantly smaller 100% squares than the sedentary group in all but the "eyes open – medial to lateral" condition and significantly smaller than the recreational group in all but the eyes open and "eyes open – medial to lateral" condition. There were no significant differences between the recreational and sedentary groups with respect to the 100% square. Overall the eyes open condition displayed the best postural control as indicated by the lowest velocity of sway and smallest 100% square of the static tests for all groups. Under the dynamic conditions, the "eyes open – anterior to posterior" demonstrated the lowest velocity of sway for all groups and the "eyes open – anterior to posterior" had the smallest 100% square amongst the elite and sedentary group while it was smallest in the "eyes open – medial to lateral" condition for the recreational group.

Figure 2 shows that elite group had significantly lower velocity of sway compared to the recreational group in all conditions, and significantly lower velocity than the sedentary group in both dynamic tests with eyes closed (eyes closed – anterior to posterior and eyes closed – medial to lateral). There

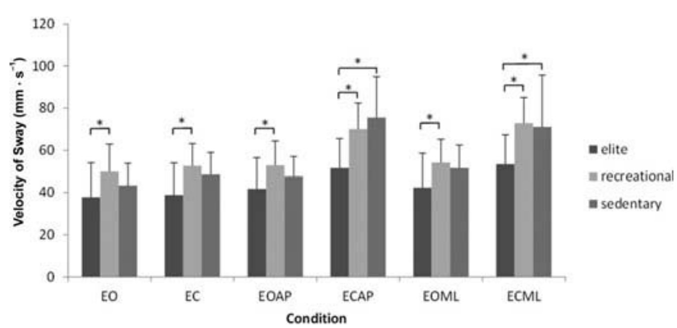

Figure 2. Balance results. EO, eyes open; EC, eyes closed; AP, anterior posterior instability; ML, medial lateral instability. Results are expressed as mean ± SD. * Significant difference ($P < 0.05$).

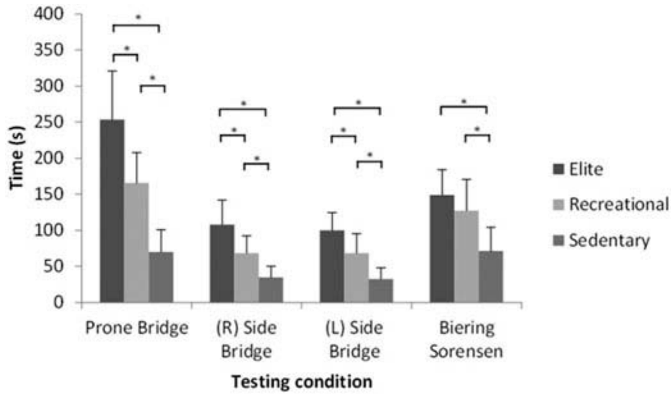

Figure 3. Results of isometric endurance tests.
* Significant difference ($P < 0.05$).

were no significant differences between the recreational and sedentary groups with respect to velocity. The highest velocities were recorded in the "eyes closed – medial to lateral" condition for all groups and the greatest 100% square was in the "eyes closed – anterior to posterior" condition for the elite group and "eyes closed – medial to lateral" for the recreational and sedentary group. There was a significant increase ($P < 0.05$) in velocity and 100% square for each condition when the participant's eyes were closed as opposed to when they had visual feedback to rely on.

Results for the isometric tests (Figure 3) show many significant differences between the three groups. The elite group had significantly longer hold times in the prone bridge ($F_{2,42} = 51.88$, $P = 0.001$, $\eta^2 = 0.71$) than both the recreational (+53.1%, +87.83 s, 95% CI [44.01, 131.65], $P < 0.001$ $d = 1.56$) and sedentary group (+263.4%, +183.67 s, 95% CI [139.85, 227.49], $P < 0.001$, $d = 3.49$). The recreational group also displayed significantly longer hold times than the sedentary group (+137.5%, +95.83 s, 95% CI [52.01, 139.65], $P < 0.001$, $d = 2.58$). The right-sided bridge was significantly greater $F_{2,42} = 30.74$, $P = 0.001$, $\eta^2 = 0.59$) in the elite group than the recreational (+58.3%, +39.73 s, 95% CI [16.97, 62.48], $P < 0.001$, $d = 1.35$) and sedentary groups (+212.2%, +73.36 s, 95% CI [50.60, 96.12], $P < 0.001$, $d = 2.78$). The recreational group showed a significantly longer right-sided bridge than the sedentary group (+97.3%, +33.63 s, 95% CI [10.88, 56.39], $P < 0.005$, $d = 1.66$). The left-side bridge was significantly ($F_{2,42} = 32.10$, $P = 0.001$, $\eta^2 = 0.61$) greater in the elite than the recreational (+46.4%,+31.62 s, 95% CI [11.20, 52.03], $P < 0.005$, $d = 1.21$) and the sedentary (+207.2%, +67.28 s, 95% CI [46.87, 87.70], $P < 0.001$, $d = 3.26$) while the recreational was significantly greater than the sedentary (+109.8%, +35.67 s, 95% CI [15.26, 56.08], $P < 0.001$, $d = 1.62$).

The elite group demonstrated a non-significant difference in the Biering Sorensen test ($F_{2,42} = 17.18$, $P = 0.001$, $\eta^2 = 0.45$) with the recreational group (+17.0%); however, the result obtained in this test is significantly higher when compared to the sedentary group (+109.3%, +77.68 s, 95% CI [44.45, 110.91], $P < 0.001$, $d = 2.27$). The difference between the recreational group and the sedentary group was also significant (+78.9%, +56.08 s, 95% CI [22.85, 89.31], $P < 0.005$, $d = 1.46$). There were no significant differences between either group (recreational and sedentary) with regard to right and left bridging.

Discussion

This was the first study to examine the physiological and musculoskeletal profiles of elite and recreational SUP participants as compared to a sedentary population. The lean body composition finding is similar to Ackland's study on the morphological characteristics of the canoe and kayak athletes attending the 2000 Olympic Games in Sydney (Ackland, Ong, Kerr, & Ridge, 2003). The elite SUP participants also displayed lower cholesterol and LDL and higher HDL when compared to the recreational and sedentary groups. The elite SUP group demonstrated lipid profiles within the recommended guidelines set by the Australian Heart Foundation; total cholesterol < 5.5 mmol · L^{-1}, HDL > 1.0 mmol · L^{-1}, LDL < 2.0 mmol · L^{-1} and triglycerides < 1.5 mmol · L^{-1} (Tonkin et al., 2005). The low BMI, high HDL and low LDL and body fat percentage of the elite groups are possibly associated with the training effect of SUP, beckoning further investigation of the actual health benefits of SUP on cardiovascular risk.

The elite participants profiled in this study displayed comparable levels of maximal aerobic power as seen in other water sports which are upper limb dominant. Previous research has reported surfer's maximal aerobic fitness ranging from 37.8 to 54.2 ml · kg^{-1} · min^{-1} (Loveless & Minahan, 2010a; Meir, Lowdon, & Davie, 1991), canoeists from 44.2 to 51.9 ml · kg^{-1} · min^{-1} (Bunc & Heller, 1991; Hahn, Pang, Tumilty, & Telford, 1988) and dragon boat racers from 42.3 to 50.2 ml · kg^{-1} · min^{-1}. It should be noted this group included males and females. If adjusted for only the males group, the average of 46.84 ml · kg^{-1} · min^{-1} is comparable to the numbers reported previously.

Caution should be used when comparing an upper limb dominant sport with full body water based sports such as rowing and swimming due to the larger muscle mass utilised. It has previously been reported that decreases of 39.36% in VO_{2max} when being tested on a treadmill versus being tested on a swim bench (Lowdon, Bedi, & Horvath, 1989). If a factor of this decrease is added to the figures reported, measures of 65.28 ml · kg^{-1} · min^{-1} are achieved, which is comparable to other elite athletes of full body water based sports such as rowing (62.88 ml · kg^{-1} · min^{-1}) (Jurimae, Meaetsu, & Jurimae, 2000) and swimming with 58.4 ml · kg^{-1} · min^{-1} (Roels et al., 2005). Also, to our knowledge, no studies have compared the power output of these various upper limb dominant sports.

The necessity to use caution when comparing aerobic power amongst SUP to other sports is indicated by the results from the sedentary group. In this study, average aerobic power outputs of 21.85 ml · kg^{-1} · min^{-1} from the sedentary males and 17.37 ml · kg^{-1} · min^{-1} from the females are much lower than previously reported references. Age-stratified measures of 35.6, $s = 7.7$ ml · kg^{-1} · min^{-1} have been reported from sedentary males and 27.2, $s = 5.0$ ml · kg^{-1} · min^{-1} from sedentary females when utilising cycle ergometers to assess maximal aerobic power (Herdy & Uhlendorf, 2011).

There was a difference in aerobic power outputs reported previously utilising ergometers such as swim bench and rowing ergometers to these SUP results (Farley, Harris, & Kilding, 2012; Loveless & Minahan, 2010a). Aerobic power outputs amongst surfers using a swim bench have reached 199 W (Loveless & Minahan, 2010a) and 118–158 W using modified kayak ergometers (Farley et al., 2012; Mendez-Villanueva & Bishop, 2005). Other water sports have also exhibited large aerobic power outputs including 239 W from kayakers (Billat et al., 1996), 371 W from rowers (Jurimae et al., 2000) and 195 W from dragon boat racers (Ho, Smith, Chapman, Sinclair, & Funato, 2013). It is assumed that due to the extensive amount of muscle mass used for stabilisation, a small percentage of muscle force may actually contribute towards propulsion of the SUP across the water.

Although there was a greater average stroke length of the sedentary group when compared to the recreational (+4.46%) and the elite group (+6.85%) in the aerobic test, this does not necessarily reflect a better stroke. It can be seen that the stroke rate achieved by the elite group is significantly higher than the recreational group (+25.5%) and sedentary group (+64.7%) and a shorter, more powerful stroke is more beneficial to overall performance as indicated by a much greater power output amongst the elites than the recreational group (+43.7%) and the sedentary group (+188.8%). This higher stroke rate with a shorter stroke distance is related to greater power output, and therefore an increased speed across the water. The inversely proportional relationship found between stroke length and rate is also found in swimming, rowing and outrigging and both of these variables are found to be directly proportional to performance (Sealey, Ness, & Leicht, 2011).

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

The potential health benefits of SUP should also be considered. Both elite groups and recreational groups had good to very high maximal oxygen consumptions and favourable lipid profiles. For example, over 83% of SUP participants (elite and recreational combined) had total cholesterol levels at target (<5.5 mmol $\cdot$ L^{-1}) and 93% had HDL levels at target (>1.0 mmol $\cdot$ L^{-1}). However, participants' diet and activity levels were not assessed and these parameters would have significant influence on lipid profiles. These lipid profiles, combined with favourable BMI and elevated aerobic fitness, would afford SUP participants with reduced cardiovascular risk, thereby also providing improved health associated with participation.

The elite group displaying a greatest 100% square in the "eyes closed – anterior to posterior" condition is most likely due to the lack of exposure to the anterior to posterior direction and the familiarity medial to lateral instability encountered when standing on an SUP. Due to the length of a board, the greatest postural challenge is in the medial lateral direction, possibly explaining why the sedentary and recreational group had the greatest 100% square in the "medial – lateral" condition. Due to exposure to this condition, their postural control may be increased in this direction amongst the elite.

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

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

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

The extensor endurance amongst both SUP groups were similar to results reported in previously published papers including McGill's study, which showed an average men's endurance time of 146 s, women's 189 s amongst young, healthy individuals (McGill, Childs, & Liebenson, 1999), higher than Adedoyin's of 119, s = 47 s for men and 106, s = 44 s for women (Adedoyin, Mbada, Farotimi, Johnson, & Emechete, 2011), and much higher than Alaranta, who demonstrated 97 s for men and 87 s for women (Alaranta, Elmqvist, Held, Pope, & Renstrom, 1994). Results obtained in this study are also greater than those obtained for a group of athletes who had back pain with an average hold time of 107.5 s (Stewart, Latimer, & Jamieson, 2003).

It has been demonstrated previously that the endurance of the core muscles can be improved with core training (Aggarwal, Kumar, & Kumar, 2010). Significant improvements in hold times of all the above tests were made with six weeks of core training including multidirectional movements and instability with the use of a Swiss ball. As the core muscles seem to be activated by SUP and these athletes demonstrate adequate endurance hold times, perhaps SUP could be used to increase endurance of the core muscles and therefore be used as a prophylactic treatment for back pain.

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

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

Disclosure statement

No potential conflict of interest was reported by the authors.

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