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A Proposed Field Assessment Method for Stand-up Paddle Board Technology

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Abstract: There is limited information regarding the performance of Stand-Up Paddleboard (SUP) technology and the means to evaluate its performance. The aim of this study was to assess the intra-test reliability of a proposed outdoor field assessment methodology and three different levels of SUP technology. These included changes made to the board, the paddle or the fin and to assess their performance and statistical reliability. A participant completed a series of randomised runs at 2.5 m/sec over a 230 m distance on three separate test events all held at a flat water test venue. The stroke index was used to evaluate each technological change made to the paddler's equipment. All three test events yielded a good level of reliability (Coefficient of Variation = <2.4%). The proposed assessment method was also able to detect seven out of eight prescribed technological changes with statistical significance (p = 0.05). As a result, the proposed assessment method is recommended as a specific, geographically accessible and cost effective means of SUP technological assessment.

Key words: Stand-up paddleboard, hydrodynamics, paddler, drag, racing, technological assessment

INTRODUCTION

Stand-Up Paddle boarding (SUP) is a relatively new sport and a recreational water sports activity that has been increasing in popularity (Schram *et al.*, 2016a). Whilst it has contentious origins, it comprises elements and skills similar to those from traditional surfing, outrigger canoeing and inland canoeing (West, 2012). SUP requires a paddler who is stood up on a board to then provide forward motion through use of a long, single bladed paddle. To ensure a straight course, a SUP board typically has a single fin positioned at its tail and also sees the paddler periodically switch sides with their paddle. The paddling action is typically aligned to minimise any yawing moments whereas the paddler will be subjected to rolling and pitching changes due to wake, waves or the resultant reaction to any applied paddling forces. These factors are counteracted by the balance and technique of the paddler and the characteristics of the board design itself. Such athletes are shown in Fig. 1.

As the sport has increased in popularity, the competitive side of the sport has also developed and has seen a formalised World Championships held, since, 2012. SUP has several competitive disciplines and these are typically long distance races, technical races (that involve negotiating around a series of buoys) and surfing contests (whereby points are awarded to athletes for performing techniques and manoeuvres whilst surfing a wave). Both distance and technical races can take place on either calm flatwater locations (such as rivers or lakes) or open water (such as the sea or ocean). As these

Fig. 1: Competitive SUP paddlers

disciplines have developed so has the equipment that is used to best facilitate them. However, there has been extremely scant peer reviewed research conducted with respect to SUP. To date, the few studies that exists have mostly centred on both the positive health benefits (Ruess *et al.*, 2013a, b; Schram *et al.*, 2016a-c) and the physiological muscle activity of stand up paddle surfing as well as a performance analysis of distance SUP racing and the physiological profiling of SUP athletes. No attention to date has been focused on the development or the evaluation of its technology.

During 2016, it was announced that surfing will make its debut at the 2020 Olympic Games. With the governing body for surfing being the same as that of SUP, it is not inconceivable that SUP could also be included in the Olympic Games at some point in the future. With that in mind, possessing the ability to assess its technology would be an essential component of any athlete's success.

Like canoeing or kayaks, a SUP board exhibits a degree of fluid displacement and as such its forward motion is subjected to three forms of hydrodynamic drag. These include the friction drag between the craft and the water, the pressure drag created when the water is separated to allow the craft to move through it and wave drag, which is the result of accelerating the water away from the craft (Michael *et al*., 2009). There is also the aerodynamic drag created by the frontal area of both the craft and its paddler that is exposed above the waterline when attempting to move through the air (Michael *et al*., 2009). This effect has been stated as being of bluff-body type drag (Jackson, 1995) and of relatively minimal impact in kayaking (Michael *et al*., 2009). However, this could be more prevalent in SUP as the paddler is stood up with their entire body's frontal area exposed. However, the current paucity of information regarding SUP technology means that this aspect can only be speculated upon. Ultimately though, the forward motion of the SUP paddler and their resultant performance is due to their ability to produce the maximum amount of propulsive power to overcome the sum of the drag forces acting upon them. The paddleJune 9, 2018r can utilise their training to maximise their propulsive power whereas effective technological choices will attempt to minimise the resistant forces that act against the paddler and their watercraft.

Other forms of competitive watercraft have utilised a variety of techniques to assess their hydrodynamic properties or performance. These have included the use of towing tanks, computer aided design simulations and field tests (Robinson *et al*., 2013; Gomes *et al*., 2012). These methods will provide the ability to isolate the impact of technological changes from the dynamic paddling behaviour of the paddler (Gomes *et al*., 2012). However, it has been recommended to match paddle sport equipment choices to the specific mass and paddling style of a particular athlete (Robinson *et al*., 2013). In addition, if SUP does follow similar behaviour to kayaks, an increase in the paddler/craft total mass will also increase the wetted surface area and therefore increase the level of surface drag (Gomes *et al*., 2015). As a result, the assessment and selection of paddle sport technology based on test methods that do not utilise a specific paddler may produce different results (Robinson *et al*., 2010) and may not be specific to the athletes particular needs (Bugalski, 2008). Therefore, if the performance of a paddler is sought to maximised, it would seem prudent to test the entire locomotive system of paddler and their equipment together. Ultimately, the assessment of fluid dynamics using larger installations such as towing tanks or wind tunnels can be prohibitively expensive, difficult to locate or geographically difficult to access (Dyer, 2015). With this in mind, the development of a reliable field assessment protocol for such technology could offer a viable alternative to such practices. Whilst not evident specifically for SUP, the uses of field assessments have been undertaken successfully for use with other types of racing watercraft. These have included an assessment of racing kayaks (Gomes *et al*., 2012) and involved towing such craft by a motor boat (Gomes *et al*., 2012) or using a land-mounted cable (Gomes *et al*., 2015). The changes in hydrodynamic drag of craft to craft were measured by assessing changes recorded by a load cell. However, this study did not allow the participant to paddle therefore did not consider the symbiotic effect that the stroke or users biomechanical behaviour could have upon the overall locomotive performance. Alternatively, field assessments have also been applied to C1 competitive racing canoes (Robinson *et al*., 2013). In this study, the overall performance was assessed by using a group of elite paddlers performing a series of timed runs over 350m and performed using an 'all out' exercise intensity. Likewise, field assessment tests were performed on both flat water kayakers and canoeists have also been successfully validated to assess the changes in physiological adaptations by monitoring the watercrafts velocity and the paddlers resulting heart rate (Place and Billat, 2012). In all of these cases, the outdoor setting produced statistically reliable test methodologies.

In most previous hydrodynamic assessment studies, the canoeing or kayaking hull has been the main source of focus. However, SUP boards provide considerable levels of technological customisation. This can include the size and forward/aft position of a fin mounted to the board's underside, the length of shaft and blade size of a SUP paddle and the design of the board itself. These choices may influence the effectiveness of the paddling locomotive stroke and therefore the overall forward velocity. However, no test has been validated to date to investigation has been made to date with how this could be investigated.

MATERIALS AND METHODS

A series of experiments were undertaken to evaluate the proposed method of technological assessment. Each experiment involved a fundamental change to the type and scale of SUP equipment being tested. These included:

- Experiment 1: The evaluation of two different boards
- Experiment 2: The evaluation of three different paddles
- Experiment 3: The evaluation of three different fins

For the purposes of this study, each piece of technology is primarily referred to by the first letter of its equipment type. These are Boards (B), Paddles (P) and Fins (F). In addition, a second number attached to this prefix designates which of the types of technology were being tested.

Due to their countries of manufacturing or design origin, all of the equipment was specified by their manufacturers in imperial units. The SUP boards utilised in this study were from the same manufacturer (Starboard, Thailand) and were a 2014 'Allstar' that was specified by the manufacturer as 14ft long and with a 26.5 inch width (B1) and a 2014 'Sprint' that was specified by the manufacturer as 14ft long with a 26 inch width (B2). The three test paddles used for experiment 2 were all manufactured by the same supplier (Quickblade, Costa Mesa, CA) and were the 'Trifecta' design with a 86sq inch paddle blade (P1), a 'V Drive' design with a 91sq inch paddle blade (P2) and 'Big Mama Kalama' with a 120sq inch paddle blade (P3). Finally, three fin designs were tested in experiment 3. These were a 'Race 24' fin (Starboard, Thailand) (F1), a 'JB Runner' fin (Futures, CA) (F2) and a 'Maliko' fin (Black Project, Maui, Hawaii) (F3).

The test runs were all undertaken by a single participant and was the same used for all three experiments. The participant was male and an experienced SUP paddler. The subject was provided with details of the testing beforehand and provided informed consent. To minimise learning effects, the participant paddled with all of the various equipment immediately prior to the experiments taking place for familiarisation purposes. No experiment or runs took place until an adequate comfort level with any equipment change was established and then confirmed by the participant. To minimise the impact of the unknown importance of aerodynamic drag when SUP locomotion is undertaken, the participants clothing was kept identical for all three experiments. The paddler's feet position on both B1 and B2 was defined with marking tape for each foot to ensure that the boards pitch, trim and stability was the same for all of the test runs. For experiments 2 and 3, B1 was used to test P1-3 and F1-3.

For each experiment, a series of test runs were undertaken. The order of the test runs were randomised to control for learning, fatigue and any environmental effects. The test run procedure consisted of performing six randomised runs with each form of technological change. To minimise run to run physiological fatigue, each experiment took place on a different day and would therefore each comprise upto 18 test runs. Each run took place over the same 230 m straight line course and was marked by buoys positioned at the start and at the finish. This distance is shorter than the 350 m utilised by Robinson *et al.* (2013). However, due to the slower relative velocity of SUP paddling, the actual test duration would be of a similar amount and was circa 90 sec in length. This short duration is advocated as it minimise the impact of paddler fatigue (Robinson *et al.*, 2013). All test runs were performed individually and from a dead start. The test runs were all performed at a targeted velocity of 2.5 m/sec (9 km/h). This target was typical of the participants racing average velocity. The level of hydrodynamic drag of paddled watercraft is dependent on velocity is non-linear in nature (Pendergast *et al.*, 2005) and it is recommended that equipment should be matched to the specific paddler (Robinson *et al.*, 2013). As a result, it was considered important to ensure the test velocity was matched to any paddler's competitive expectations to ensure that the watercraft is being exposed to a similar velocity of fluid flow.

The average velocity (m/sec), time (secs), cadence (stroke per minute) and distance per stroke (m) were all captured and recorded using a Speedcoach GPS Model 2 computer (Nielsen-Kellerman, Boothwyn, PA) and the data was analysed after all of the testing had been completed. The means and standard deviations were calculated. To evaluate the proposed tests reliability, the variability of the test run data of all of the captured metrics were compared and the Coefficient of Variation (CV) was calculated for all of these. The CV is defined as the absolute reliability of a data set (Atkinson and Nevill, 1998) and was calculated as the standard deviation divided by the mean and then multiplied by 100 to express this as a percentage. When using GPS equipment, a CV of <5% has been defined as 'good' (Coutts and Duffield, 2010).

A single test event for each experiment was used. Other outdoor watercraft field assessments have also only focused on single event testing (Robinson *et al.*, 2013; Gomes *et al.*, 2012). A test-retest analysis of the same experiment held on multiple occasions would generally prove challenging due to the variability of outdoor weather conditions.

To account for the individual nature of paddling and to provide a measure that would account for this, the Stroke Index (SI) was calculated. The SI accounts for the characteristic that as velocity increases, so does the distance per stroke (Costill *et al.*, 1985). It can be considered a measure of an athlete's own personal efficiency (Costill *et al*., 1985) and is calculated as:

$$SI = Average\ velocity \times Distance\ per\ stroke$$

Given that the proposed assessment method is a relative assessment of SUP technology, this makes its use suitable as it considers the dynamic characteristics of a paddler and their ability to use a piece of equipment. This method of assessment has been utilised in other propulsive water sports such as swimming (Sanchez and Arellano, 2002) and in outrigger canoe paddling (Sealey).

Finally, to ascertain whether the proposed test method would be suitable to assess different scales of possible technological changes, student t-tests were calculated from the obtained SI scores for experiment 1. For experiments 2 and 3, ANOVA was used to compare the different fins and paddles. Post-hoc student t-tests were then calculated for experiments 2 and 3. A p level of <0.05 was set for determining the level of statistical significance for both the ANOVA and the t-tests.

RESULTS AND DISCUSSION

The results of experiment 1 are shown in Table 1. Both boards demonstrated a low level of CV (1-2.6%) on all measures therefore indicating a high level of data repeatability. The range of this CV was 1.6. The CV of the velocity, cadence and SI were all consistently greater on B2 than for B1. There was a fractionally higher level of achieved velocity with B1 than B2 and it took 3 strokes per minute more to achieve this. As a result of this B2 demonstrated a higher SI and therefore a greater level of performance for the paddler. B2 achieved a SI performance that was statistically significant from B1 ($p = 0.0001$).

The results of experiment 2 are shown in Table 2. As per experiment 1, the randomised test runs all achieved a low level of CV thereby demonstrating a high level of data repeatability. The range of this was greater than experiment 1 (1.9) but achieved lower values than experiment 1 for the overall mean velocities.

ANOVA determined that the three fin designs were significantly different from each other ($p = 0.000001$). Post-hoc tests revealed that the SI performance of P1-P2 was determined as significant ($p = 0.02$) and was also significant both P2-P3 ($p = 0.003$) and P1-P3 ($p = 0.00002$). This suggests that changes in paddle designs could be both reliably tested and that their performance was potentially detectable from each other.

The results of experiment 3 are shown in Table 3. As per experiments 2 and 3, the randomised test runs all achieved a low level of CV. Again, this demonstrated a high level of test run to run repeatability. The CV's were from 0.4-1.1% and thereby had a range of 0.7 which was much lower than both experiments 1 and 2.

The calculated ANOVA determined that the three fin designs were significantly different from each other ($p = 0.0001$). Post-hoc tests revealed that the SI was statistically significant between F2-F3 ($p = 0.007$) and between F1-F3 ($p = 0.001$) but was not determined as significant ($p = 0.16$) of F1-F2.

The three experiments set out to determine if a field assessment could be reliably created to assess SUP watercraft. In addition, it was investigated if progressively smaller-scale changes made to SUP technology could be reliably measured and detected. The technological

Table 1: Experiment 1 results

Equipment selection	Mean velocity (m/sec)	Velocity CV (%)	Mean cadence (spm)	Cadence CV (%)	Mean distance per stroke (m)	DPS CV	SI	SI CV (%)
B1	$2.57^{+/-0.03}$	1.0	$52^{+/-0.65}$	1.2	$2.98^{+/-0.03}$	1.0	$7.67^{+/-0.12}$	1.5
B2	$2.56^{+/-0.06}$	2.3	$49^{+/-1.10}$	2.3	$3.13^{+/-0.03}$	1.0	$7.97^{+/-0.21}$	2.6

Table 2: Experiment 2 results

Equipment selection	Mean velocity (m/sec)	Velocity CV (%)	Mean cadence (spm)	Cadence CV (%)	Mean distance per stroke (m)	DPS CV	SI	SI CV (%)
P1	$2.54^{+/-0.01}$	0.5	$45^{+/-1.05}$	2.4	$3.43^{+/-0.07}$	1.9	$8.73^{+/-0.16}$	1.9
P2	$2.52^{+/-0.01}$	0.6	$42^{+/-0.57}$	1.4	$3.58^{+/-0.06}$	1.6	$9.10^{+/-0.05}$	0.5
P3	$2.54^{+/-0.01}$	0.5	$40^{+/-0.72}$	1.8	$3.83^{+/-0.07}$	1.9	$9.80^{+/-0.11}$	1.1

Table 3: Experiment 3 results

Equipment selection	Mean velocity (m/sec)	Velocity CV (%)	Mean cadence (spm)	Cadence CV (%)	Mean distance per stroke (m)	DPS CV	SI	SI CV (%)
F1	$2.36^{+/-0.01}$	1.1	$40^{+/-0.61}$	1.5	$3.54^{+/-0.02}$	0.6	$8.34^{+/-0.07}$	0.8
F2	$2.38^{+/-0.01}$	0.5	$40^{+/-0.26}$	0.6	$3.57^{+/-0.02}$	0.7	$8.48^{+/-0.04}$	0.5
F3	$2.39^{+/-0.01}$	0.5	$39^{+/-0.17}$	0.4	$3.66^{+/-0.02}$	0.6	$8.75^{+/-0.1}$	1.1

changes utilised for this paper all produced levels of CV that were no greater than 2.6% and for experiments 2 and 3 were never any greater than 2%. This level of intra-test repeatability is high and the level of data variability was superior to those obtained when performing the field assessment of different kayak designs (Robinson *et al*., 2013) and superior to an aspired 'good' level of CV (<5%) when using GPS-based technology (Coutts and Duffield, 2010). The Robinson *et al*. study achieved field assessment CV's that varied from 2.58-5.6%. It is entirely possible that this greater level of CV may be due to the Robinson *et al*. study utilising a larger participant group. However, their study was intended to focus on the specific performance of the kayaks themselves thereby this would have been necessary. In addition, this study did also not disclose the weather conditions when the testing took place. It is entirely plausible that changes or variations in water state, wind or any other prevailing conditions could have increased the variability of the data. The proposed assessment method utilised a test venue that had the advantage of being an enclosed venue (i.e., a lake) and was sheltered from any wind by thick trees. Investigating more exposed and more chaotic conditions may provide more context specific evaluation of SUP equipment that is intended for use in other environments.

Whilst it has already been explained that the relative nature of field assessment in outdoor conditions would make test-retest studies challenging, it should be noted that all three experiments took place on different days and yet, all yielded statistically repeatable performances. This strongly suggests that whilst any such field assessments will always be relative, that this study proposes that this assessment method is viable to evaluate changes in SUP technology.

The level of statistical significance obtained between technological changes was investigated to ascertain whether increasingly small scale changes could be detected using the proposed field assessment method. All of the technological changes made could be detected in the calculated SI. There was one exception when comparing F1-F2. It is possible that any marginal changes made to SUP technology coupled with the proposed assessment method will have a detection limit. However, it should be noted that other watercraft field assessment studies have utilised non-norm levels of statistical significance of $p = 0.1$ (Robinson *et al*., 2013). This deviation from the norm of statistical significance was applied due to sprint canoeing possessing close finishes and placing margins which are as low as 0.01 sec. Whilst SUP generally takes place over much longer durations, it also includes aspects of 'drafting'. This is whereby one craft positions itself behind another in an attempt to lower its hydrodynamic drag which will produce a reduction in the crafts pressure drag (Brisswalter and Hausswirth, 2008). With drafting prevalent in SUP racing, it is entirely possible that sprint finishes will occur and therefore, like the Robinson *et al*. study, it is plausible that the finishing margins could also be low. Therefore, whilst p was set at a typical norm for this study, future evaluations may well assess if these should be altered to reflect the nature of SUP racing when field assessing its technology.

Whilst the assessment method is proposed suitable for use, utilising a larger sample of participants would provide guidance as to whether a specific design of board, paddle or fin generally constitutes a performance advantage. This could prove invaluable as the sport continues to utilise a variety of board length classes and has debated how to consolidate these (http://www.supracer.com/the-board-class-debate-again/). Alternatively it can provide input to manufacturers whether one design of specific watercraft design is more or less advantageous than another (Robinson *et al*., 2013).

Based on the results of this first study, the findings suggest that the proposed field assessment method can be used to evaluate SUP technology within a flat water environment. The method described in this paper could also be applied to other forms of watercraft such as C1 canoes, K1 kayaks and outrigger canoes.

CONCLUSION

A proposed field assessment method for stand up paddleboards was investigated at an outdoor flat water environment. Three degrees of technological changes were made including changes to the board, paddle and fin. In all cases, the results produced a high level of intra-test repeatability and produced a low level of variability in velocity, stroke cadence and stroke index. This assessment method results achieved level of data variability that was lower than other published methods of watercraft field assessment and was superior to a publicised 'good' threshold. The tests were also able to detect statistical significance between all of the types of technology changes made. As a result, the proposed field assessment is recommended when attempting to select the most optimal technology for a competitive athlete to assist in optimising their performance.

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