Original Article

Using a kayak paddle power-meter in the sport of whitewater slalom

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ABSTRACT

The purpose of this paper was to demonstrate the use of a kayak-paddle power-meter to enhance scientific understanding, quantification of athlete assessment and training prescription in slalom kayaking. Data was collected from a continental-championship race, in addition to the author's work, which included testing and prescribing training for elite athletes preparing for national and international competition. Results indicate that work rate varies considerably over a competition run (CV=74.4-80.5 %). Intra-athlete performance between two competition runs of one of the leading competitors differed by 1.1% or 0.94 s, while power output decreased by 9.0 % for the fastest run due to an increase in number of steering strokes (11 vs 3). Turning strokes had greater impulse (208 vs 94 N·s), peak force (362 vs 321 N), and a lower rate of peak force development (810 vs 1925 N·s^{-1}). Methods to identify biomechanical/technical issues via analysis of force profiles per stroke exhibit bilateral comparisons of strength, while quantification of physical and physiological capability is determined through power output. Training zones are categorised into seven zones (Easy, Threshold, Critical Power, Speed Endurance, Speed and Strength) enabling coaches and athletes to implement specific training programmes targeting key facets of performance. The importance of testing venue is established where river technicality grade (I, II and IV) showed power output at the onset of blood lactate to be 120, 90, and 84 W, respectively. This paper thus supports the efficacy of using a paddle power-meter to enhance scientific understanding of slalom kayak racing through real-world competition analysis capability along with enabling the quantification of training prescription and monitoring based around work rate capability during sport specific testing, in conjunction with technical, physical and physiological qualities.
Keywords: Power meter; Kayaking; Slalom; Technology.

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INTRODUCTION

International Canoe Slalom requires athletes to race over a predetermined course lasting 90 s (range 75-95 s) over a section of river involving natural and artificial obstacles. Courses consist of 18-25 gates (two suspended poles separated by a width of 1.2-4.0 m), where six-eight predetermined gates, must be negotiated in an upstream direction. Competitors receive time penalties for hitting (2 s) and missing (50 s) a gate, where the fastest overall time wins. As such performance is determined through an athlete's ability to interact with the flow(s) of water in combination with the timing and application of force development (at the footrests, seat, knee braces and paddle shaft), fused together to determine kayak positioning.

Interestingly, several authors (Aitken & Neal, 1992; Baker, 1998; Sperlich & Klauck, 1992) advocated the efficacy of recording forces at the shaft during paddling for diagnostic and prescriptive purposes many years ago. Specifically, in slalom *Sperlich & Klauck, 1992* identified the need to obtain objective data combining kinematics with video in order to assess technique. However, such devices were not commercially available, would likely detract from competitive performance due to weight, and involved time-consuming or largely unavailable equipment for analysis. Even so, high performance support teams were capable of collecting data and metrics of force used to determine athlete capability. However, only data taken from flat-water kayakers is available in peer review articles. In these papers, peak force signified on-water strength with values ranging from 525-425 N for 1000m males and 375-280 N for 500m females (Baker, 1998), while impulse combined with a knowledge of stroke rate was used to denote work done by the paddler. Additionally, Australian 500m flatwater paddlers' data averaged per stoke over race distance (Baker, 1998; Sperlich & Baker, 2002) showed that typical propulsive strokes for elite men and women last 0.47 and 0.44 s, have peak forces of 375 and 290 N and an impulse of 109 and 80 N·s, respectively.

The scarcity of peer reviewed work in slalom has been identified as a limiting factor regarding the capability of coaches, athletes and trainers (Messias, Dos Reis, Ferrari, & De Barros Manchado-Gobatto, 2014). The same group of authors have since tried to address the aforementioned requirements to enhance canoe slalom's development by use of a tethered system, attaching a strain gauge to the bank and slalom boat while performing straight-line efforts for tests of anaerobic and aerobic performance (Ferrari et al., 2017; Messias et al., 2015). More recently, the same group have identified the need to assess stroke-by-stroke force data during straight-line sprinting. While this work is a step forwards in terms of specificity of athlete assessment (use of athlete's own boats and paddles on the water), the test are continuous in nature and do not involve aspects of turning identified as an important factor in slalom performance (Green, 2012; Hunter, 2009). As such a system enabling paddlers to train and race using a device that records stroke-by-stroke high-speed data, or 1-s real-time averaging of data, using the methods first investigated during the 1990's (Baker, 1998; Sperlich & Baker, 2002; Sperlich & Klauck, 1992) and now commercially available and validated for slalom (Macdermid & Fink, 2017) would be more beneficial. Such a system would allow slalom support staff to introduce testing that overcomes the problem of testing protocols needing to consider changes in direction, fluctuations in work rate and the addition of water technicality. With a paddle power-meter not only is it possible to collect data during world-class events but also important isolated aspects of the sport. Strength traditionally estimated using repetition maximums of specific exercises in a gym (Dohoney, Chromiak, Lemire, Abadie, & Kovacs, 2002) could be assessed using specific strokes on the water. Adapting tests involving repetitive accelerations in other sports (Draper & Whyte, 1997) to enable assessment of anaerobic qualities during intermittent exercise can be performed on slalom courses and quantified via work rate. Standardised laboratory protocols for assessment of endurance through use of blood lactate values in relation to work rate (Faude, Kindermann, & Meyer, 2009) are also possible. Additionally, simpler and less time-consuming protocols related to work rate, can now be performed anywhere, with non-invasive methods and no need for support staff. A commonly used protocol requiring athletes to exercise maximally for 2-3 mins is the critical power test (Jones, Vanhatalo, Burnley, Morton, & Poole, 2010). This test enables athletes or coaches to quantify work rates associated with anaerobic and high intensity aerobic respiration.

Documenting the experiences of using such technological advances with athletes in real-world situations would increase understanding of the sport and facilitate duplication or advancement of the process.

Therefore, the aim of this paper is to demonstrate the use of a kayak paddle power-meter through the authors experiences of working with high performance athletes in order to enhance scientific understanding, quantify athlete capability, prescribe training and monitor subsequent development within the sport of whitewater slalom kayaking.

METHODS

The information presented within this paper centres on the authors knowledge regarding the sport, coaching, and scientific principles. Experientially, the authors have worked as coaches and/or scientific support staff within the sport for a 30-year period and all have been/are world-class paddlers.

Data presented within the paper originated for the sole purpose of assessing or monitoring performance(s) within the athlete’s yearly competition cycle(s). Permission to use data was obtained.

Themes and Data

The paper is organised around themes pertinent to the acquisition of knowledge perceived as crucial to athlete development in regard to the use of a paddle power-meter. These include:

1. *Sporting Knowledge:* relates specifically to movement demands or patterns, physical requirements and the subsequent physiological response(s). Kinetic variables obtained during the heats of the 2018 Oceania Championships (Vector Wero, Whitewater Park, Auckland, NZ) are presented in relation to time or progressive stroke number, in order to show specific work demands of the sport in relation to performance test data.

Strokes were characterised as propulsive or turning/steering. Propulsive strokes move the boat forwards or backwards with a duration ≤0.6 s while turning/steering strokes change or hold the trajectory of the boat, have durations >0.6 s, and include forwards sweep strokes, reverse sweep strokes, and draw strokes. For a visual demonstration see The Bilateral Stroke Strength Test Video (https://doi.org/10.6084/m9.figshare.7440866.v1, (Macdermid P.W. & Macdermid N.J.P., 2018a))

2. *Athlete Assessment:* quantifies the efficacy of developmental processes utilised in the context of working with a specific athlete(s) and is based upon sporting knowledge. Tests specific to the sport demands were employed while corresponding with traditional concepts of performance and physiological assessment. These included:

a. Bilateral Strength: where kinetic stroke capability for key strokes used during slalom (forwards, reverse, turning strokes including left and right forwards sweep strokes, reverse sweep strokes, and draw strokes) is determined through multiple repetitions at maximum effort on flatwater, using the athletes own kayak and paddle (https://doi.org/10.6084/m9.figshare.7440866.v1, (Macdermid P.W. & Macdermid N.J.P., 2018a)). Following a warm-up, six repetitions performed at maximum effort (6-RM) enabled mean stroke length, impulse, peak force, time to peak force and rate of peak force development to be determined.

b. Anaerobic performance: based upon tests used for intermittent team sports (Draper & Whyte, 1997) but within the context of canoe slalom. Two slalom gates separated by 17m, are negotiated in a figure of eight sequence and performed at an all-out intensity (Figure 3A, https://doi.org/10.6084/m9.figshare.7433966.v4 *(Macdermid P.W. & Macdermid N.J.P., 2018b).* The kayaker starts parallel to the inside pole of one of the gates, sprints to negotiate the 1st upstream gate and repeats the pattern for six upstream gates whereupon they sprint to the finish line (inside pole of the opposite upstream gate). Data collected enables metrics of anaerobic capacity to be determined. These include the kayaker's peak power or acceleration (calculated as the highest power-output average between the two inside poles of the upstream gates), mean power or repeat acceleration endurance (the mean power output of the 7 efforts between upstream inside poles), and fatigue index (the percentage difference between the peak power and minimum power recorded per effort).

c. Endurance: determined through identification of work rates at key physiological markers. Blood lactate profile testing (Faude et al., 2009) involves athletes kayaking a set course lasting approximately 3-mins, at an initial intensity of 60 W (dependent on ability) with an incremental increase of 20 W thereafter, for a total of 7-stages. At the cessation of each stage a capillary blood sample was taken to ascertain blood lactate response to exercise using a Lactate Pro2 (COSMED, Rome, It.). The results were used to quantify submaximal endurance capability along with the facilitation of prescribed training intensities.

To show the importance of specificity of training venue and river technical difficulty grade, this test was performed at three different training sites of technical difficulty grade I (Centennial Lagoon, Palmerston North, NZ), II (Kaituna, Rotorua, NZ) and IV (Vector Wero Whitewater Park, Auckland, NZ).

d. Critical Power: the concept of critical power surmises all-out exercise lasting between 90-180 s while recording athlete work rate (Jones et al., 2010). The resultant power-profile produces a two-parameter model where the power output plateau reflects maximal aerobic capacity (critical power), whilst the work performed above this level is deemed anaerobic and is referred to as W-prime (W'). For this test, participants used a world-class training venue (grade III-IV river, Vector Wero Whitewater Park, Auckland, NZ) and completed a slalom course lasting at least 120 s in length, where they were instructed to perform all-out (maximal effort) from the start.

3. *Training Prescription:* encompasses sporting knowledge, athlete capability, projected developmental pathway(s), and an understanding of training principles appropriate to the demands. Data obtained from the test protocols provided is categorized into training intensities/categories.

Equipment

Athletes used their own kayaks and their preferred paddle blades were inserted into a kayak power-meter paddle shaft (One Giant Leap, Gisborne, NZ).

The kayak power-meter can be used alongside a variety of sports watches that enable Bluetooth or ANT+ external power-meter devices. Watches used by participants included Garmin 910XT, Garmin 930XT, AND Garmin 735. In its simplest form, power data is logged and averaged at a rate of 1Hz for real-time display and downloadable with a multitude of training applications available across the different platforms.

A more advanced alternative enables force and power data logging for both left and right shafts at 50 Hz, which is transferred to a standard personal computer as a .csv file and processed as required. The data presented in this paper was processed by MATLAB R2016a for the purpose of identifying: stroke length (s), defined as the time taken from data onset (when the drive side blade triggers a force threshold > 2 N and is a > 10 number points from the end of the previous stroke) to data offset (when the drive side blade triggers a force threshold < 2 N); impulse (N·m^{-1}), the area under the force curve per stroke; peak force (N), the maximum force reached during each stroke; time (s) to peak force, the time from stroke onset to the time of maximum force (Macdermid & Fink, 2017).

RESULTS

Part 1. Sporting Knowledge

Analysis of two world-class competition runs on the same course by the same athlete (Figure 1A-D) emphasises considerable variation in work rate (Co-efficient of variation for Run 1 = 74.4 and Run 2 = 80.5 %). The two runs analysed only differed in performance by 1.1 % or 0.94 s, for which the quickest run (Run 2) had a lower mean power output and mean stroke kinetics (Figure 1A-D).

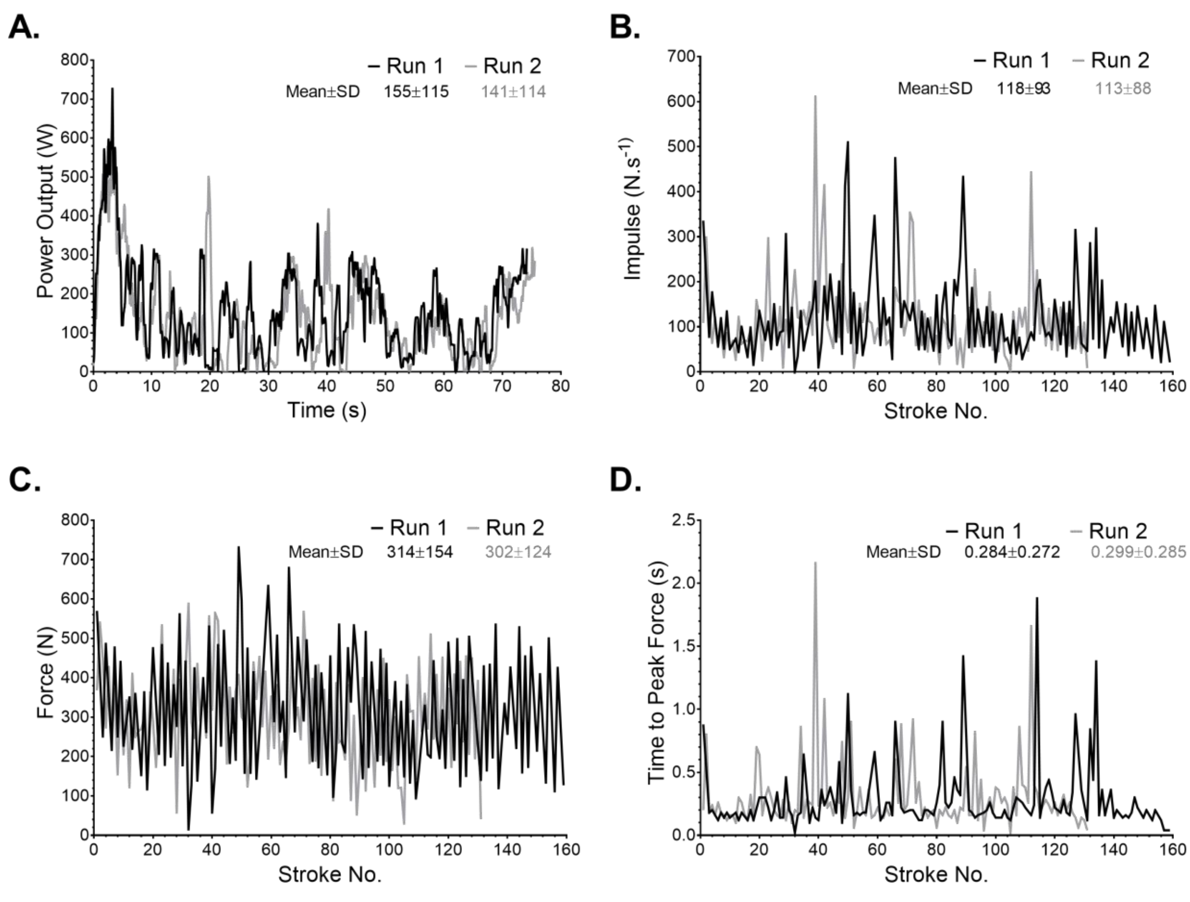
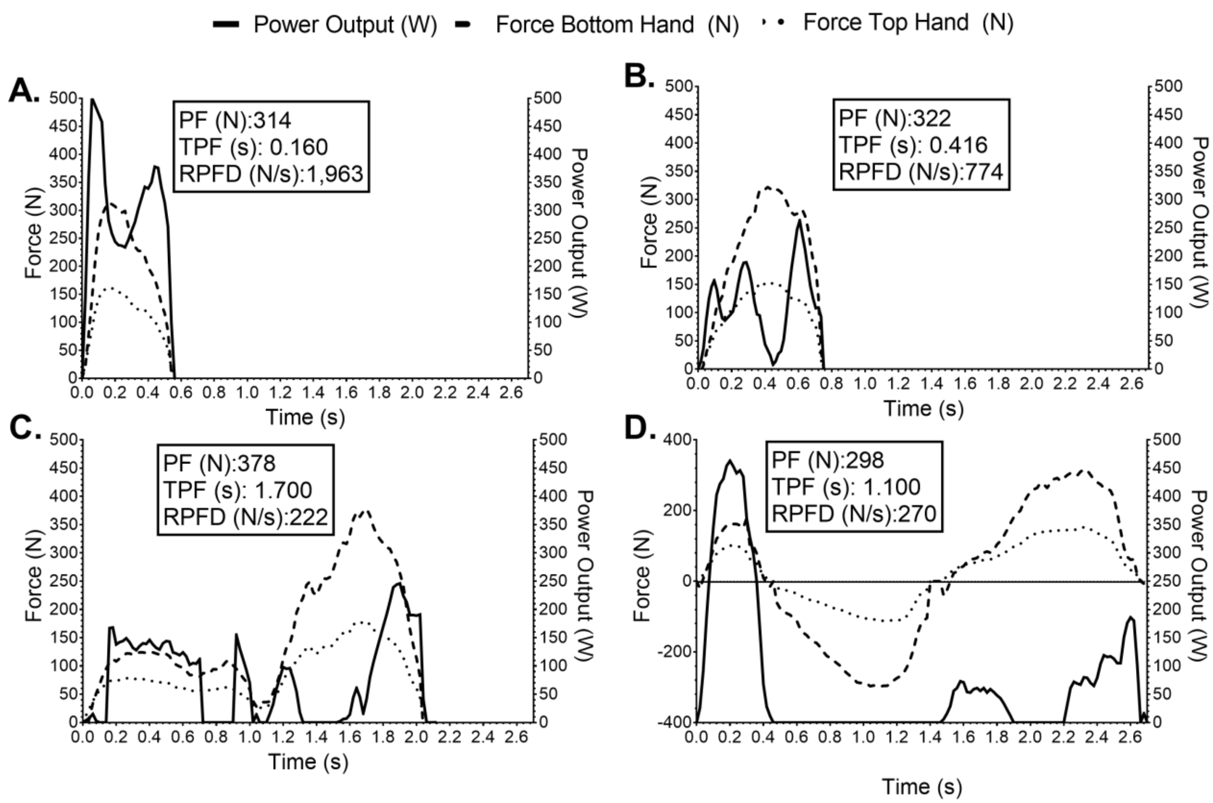


Figure 1. Intra-athlete comparison of two competition (2018 Oceania Championships) runs for: A. Absolute Power Output (W) sampled at 50Hz; and stroke-by-stroke data for B. Impulse (N·s-1); C. Peak Force (N) and; D. Time to peak force (s).

Frequency analysis of combined run data for stroke length, indicates that 90.8 ± 2.3 % were less than 0.6 s in duration while the remaining 9.2 ± 2.3 % were greater than 0.6 s. Mean data for the two runs combined, displays comparatively low impulse (94.2 vs 208.1 N·s), lower peak force (321 vs 362 N), shorter time to reach peak force (0.185 vs 0.618 s) and a considerably greater rate of peak force development (1925 vs 810 N·s^{-1}) for propulsive strokes (<0.6 s) compared to turning strokes (>0.6s), respectively.

Isolation of four specific strokes (https://doi.org/10.6084/m9.figshare.7440866.v1, (Macdermid P.W. & N.J.P., 2018a)), shows basic profiles of power and force exerted by the top hand and bottom hand, in relation to time-series per stroke (Figure 2A-D) and supports the aforementioned data taken from competition runs.



Note: PF refers to peak force per stroke; TPF refers to Time to Peak Force per stroke; and RPFD refers to Rate of Peak Force Development per stroke.

Figure 2. Key variables (power output and force for each hand) during four different strokes used by slalom kayak paddlers during training and racing. A. Forwards stroke; B. Sweep stroke; C. Draw stroke upstream; D. Reverse stroke upstream.

Combined frequency analysis of power data for the two runs reported in relation to performance tests indicates that 29.8 ± 4.3, 29.2 ± 1.1, 31.5 ± 4.0, and 9.6 ± 0.7 % of run time was spent below critical power, at critical power, at W^2, and W^1, respectively. Comparison between race runs confirms greater time spent at/or below critical power (61.3 vs 56.6 %), less time at W^2 (28.6 vs 34.3), and greater time at W^1 (10.1 vs 9.1 %) during run 2 compared to run 1. Comparison of strokes used indicated that the same number of strokes (130) were used over both runs but run 2 (the quickest run) had marginally fewer forwards propulsive strokes (107 vs 111) and more strokes in the length range of 1-1.2 s (11 vs 3).

Part 2. Athlete Assessment

Understanding the work demand of a sport enables informed choice regarding athlete testing requirements while technological advancements that enable such processes means more specific field data can be measured. In identifying specific strokes (Figure 2) for slalom kayak paddlers, the paddle power-meter enables assessment of individual stroke capability on the water and using their own equipment.

Table 1. Athlete bilateral capability for isolated strokes imperative to slalom kayaking using a 6-RM protocol

Stroke	Stroke Length (s)	Impulse (N·s)	Peak Force (N)	Time to Peak Force (s)	Rate of Peak Force Development ($N·s^{-1}$)
Forwards	0.557	140	333	0.270	1280
Reverse	0.676	125	297	0.520	582
Left Sweep	0.814	219	394	0.374	1074
Right Sweep	0.793	132	240	0.397	615
Left Reverse Sweep	0.852	198	319	0.468	742
Right Reverse Sweep	0.812	213	344	0.460	772
Left Draw	1.594	143	146	0.629	253
Right Draw	1.640	186	228	1.080	211

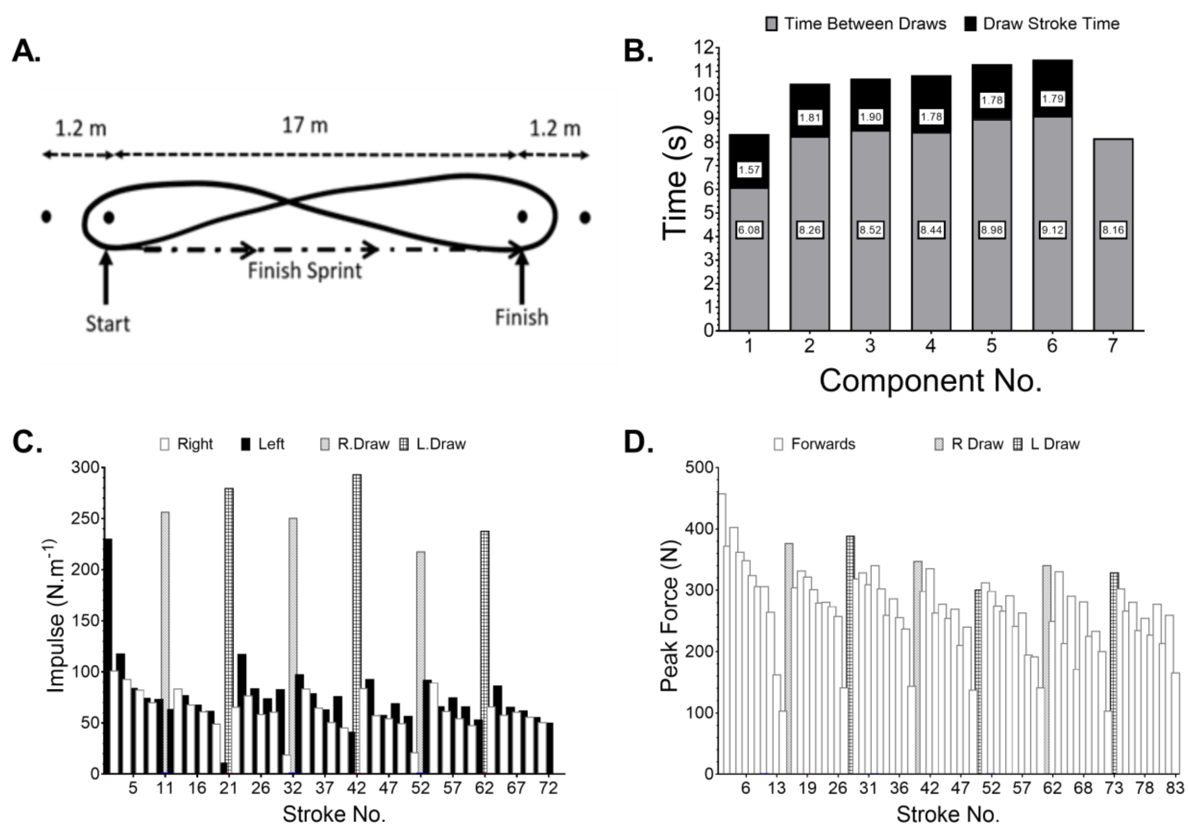


Figure 3. A. Pictorial representation of the slalom anaerobic test (SAT); B. Performance times for the total, sections between gates and times spent turning; with stroke-by-stroke data for C. Impulse, and D. Peak force.

Table 1 shows 6-RM stroke capacity for an athlete under isolated conditions, where capability is 112 % greater for forwards compared to reverse paddling for both impulse and peak force while rate of peak force development is 220 % greater. Bilateral comparisons for turning strokes indicates imbalances, where the right sweep is only 61, 61, and 57 % for impulse, peak force and rate of peak force development of the left sweep stroke; the right reverse sweep stroke is 107, 108, and 104 % for impulse, peak force and rate of peak force development of the left reverse sweep stroke; and the right draw stroke is 130, 156, and 84 % for impulse, peak force and rate of peak force development of the left draw stroke.

Data presented from the slalom anaerobic test (Figure 3) enables overall analysis in relation to performance time (Figure 3B), for time spent between gates and during gates turning. Physical capability reflected through impulse (Figure 3C) permits overall data analysis where peak effort was 103 N·s, the overall mean for the test was 70.3 N·s and the fatigue index was 40.5 %, while greatest stroke impulse was 230 N·s with a fatigue index of 62.4 % over the whole test. Likewise, analysis of peak force (Figure 3D) for peak effort was 311 N, the overall mean was 264 N, and the fatigue index was 25.8 %, with a highest stroke peak force of 458 N and a fatigue index of 33.8 % over the whole test.

Figure 4A identifies lactate threshold (2mM) and the onset of blood lactate (4mM) and presents the corresponding power outputs (120 and 150 W), and the respective heart rates (144 and 163 bpm) for an individual performing a flat water slalom test. The interaction between the training environment (i.e. the rivers technical difficulty) and physiological responses emphasises the need for specificity regarding training venue (Figure 4B-C). Power output and the corresponding heart rate at lactate threshold (2mM) was 94 W and 124 bpm, and 72 W and 110 bpm, for grade I and II water, respectively, while 60 W was above this physiological marker on the grade IV river. Differences were also seen for the onset of blood lactate (4mM) where power output was 84, 90, and 120 W, while heart rate response was similar (148, 152, and 152 bpm) for grade IV, II, and I rivers, respectively.

Alternatively, a less invasive testing protocol, simply administered and incorporated into everyday training by athletes, is the all-out 2-3 minute critical power test (Figure 5). The results provide quantifiable data for three high intensity aspects of slalom performance including maximal aerobic capacity (CP = 183 W), peak power (W^1 = 550 W) and ability to sustain anaerobic exercise (W^2 = 351 W).

The combination of the test results presented enable comprehensive training prescription across a full range of intensities quantifiable through power output or metrics of force. Each training zone (Table 2) is categorised, labelled and explained regarding its purpose within the training/performance process, how it relates to the data quantification protocol and the critical power value.

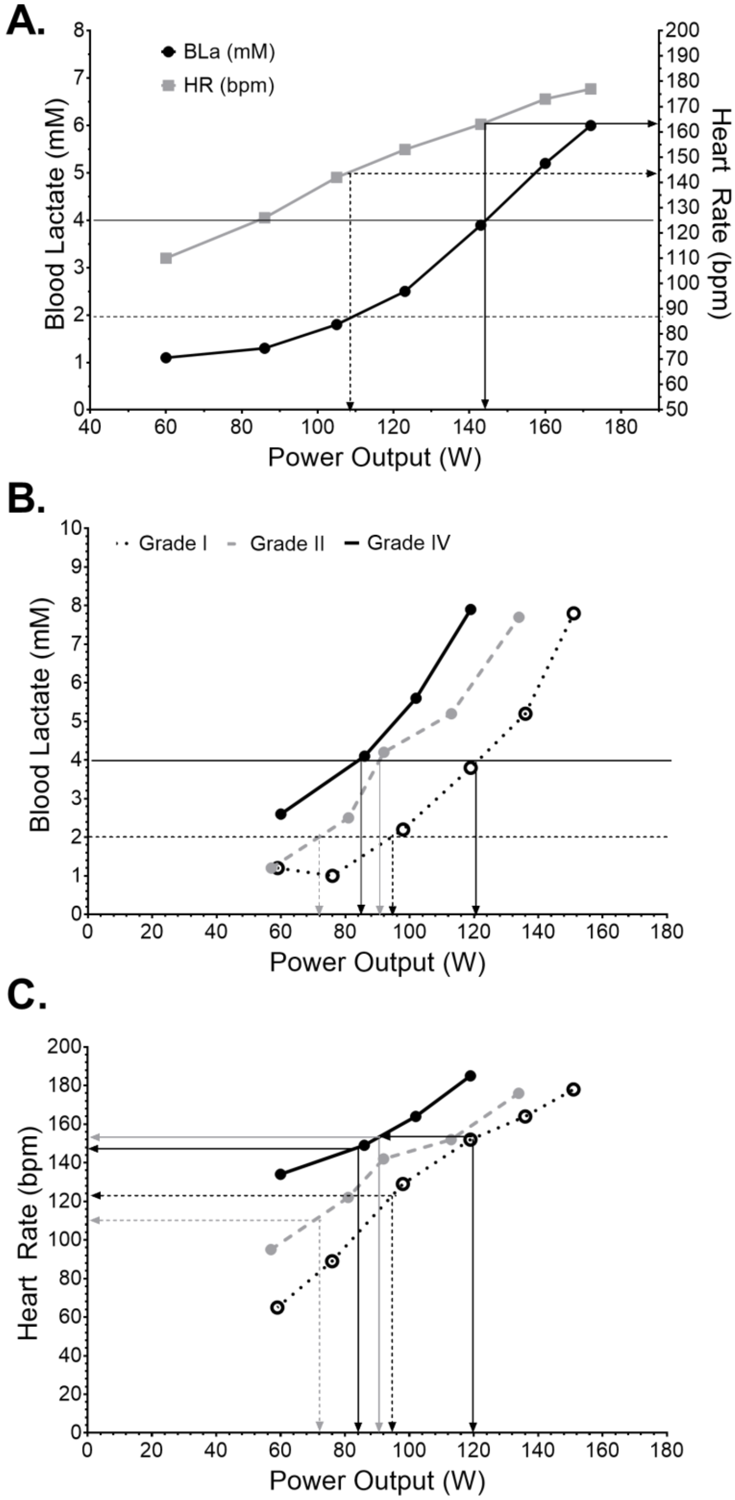


Figure 4. Physiological On-water testing Slalom Kayaking, where: A. Individual blood lactate profile test; B-C. Blood lactate and heart rate response to water grade in a National champion within the space of a two-week period.

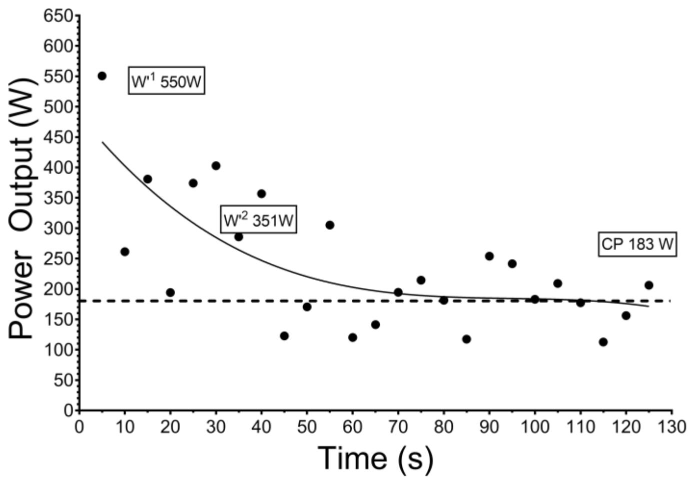


Figure 5. An all-out slalom test (AST) lasting 125s used to identify the power-time relationship in order to determine critical power (CP) and W'. In this instance for training purposes W' has been split into W'1 and W'2 (see Part 4 and Table 2 for explanation).

Table 2. Example of training zones currently used to prescribe training. All intensities are specific to the technical grade of water

Training Zone	Zone label	Description	Tests data obtained from	Estimated Power Output (% CP)
1	Easy (E)	Conversational effort developing the anatomical and physiological structures for more advanced training.	On-water BLA profile test	<60
2	Threshold (T)	Further promotes zone 1 but also involves elements of strength-endurance.	On-water BLA profile test	70-90
3	Interval (I)	Maximal oxygen consumption or CP development.	On-water CP test	80-100
4	Race	Combines training zones 3,5,and 6 and is the current/goal race capability.	Race, race simulation, coach-athlete meeting	Combination of Zone 3, 5 & 6 + 7
5	Speed-Endurance (W'2)	Unsustainable intensity relies on anaerobic glycolytic processes.	CP-Test	150+
6	Speed (W'1)	Acceleration/short sprint or powerful efforts lasting <10s relying heavily on creatine phosphate stores.	CP-Test	300+
7	Strength	High force, low velocity. Emphasis on boat trajectory and turning movements	Stroke 6-RM	N/A

Note: BLA stand for blood lactate; CP critical power test; W' is W-prime component of CP-test.

DISCUSSION

The aim of this paper was to explore how a kayak paddle power-meter could enhance sporting knowledge through competition data analysis and athlete testing in order to provide quantifiable training prescription and monitoring within the sport of whitewater slalom kayaking.

The main findings suggest that elite performances involve power outputs between 140-160 W. Intra-athlete comparison of two competition runs on the same course shows the fastest run had fewer propulsive strokes and more turning strokes (11 vs 3) in the range of 1.0-1.2s. Turning strokes have greater impulse (208 vs 94 N·s), peak force (362 vs 321 N), time to peak force (0.618 Vs 0.185 s), but lower rate of peak force development (810 vs 1925 $N \cdot s^{-1}$). Quantification of athlete capability via work rate for key components (strength, anaerobic variables and markers of endurance) obtained through a multitude of slalom specific on-water tests, have been adapted from traditional laboratory-field test protocols. This enhanced understanding, enabled prescription of training intensities that lend themselves to valuable monitoring of athlete capability. Application of training prescription intensities to sporting demand through frequency analysis, banded for percentage of time over a competition run, indicates 59 % ≤ critical power, 31.5 % at W^2 and 9.6 % at W^1.

In order to understand a sport it is imperative to collect as much data as possible from real-world competition. No current peer reviewed work describes competitive or simulated slalom performance in regard to work rate and metrics of force. The data provided from one of the top performers during the heats of the 2018 Oceania Continental Championships provides useful insight (Figure 1). Further analysis of force profiles (Figure 2) enables categorisation of strokes without timely analysis of video footage. The combined data analysis indicates that ~90 % of strokes used during a slalom competition run are propulsive strokes (<0.6 s in length) yet previous research (Green, 2012; Hunter, 2009) has indicated the importance of athlete/boat trajectory for overall performance. As such, stroke selection and athlete capability for such strokes, combined with prior knowledge of the competition course, could alter the relationship between mean power-output and performance. Interestingly, the 1.1 % difference in performance in our data resulted from a reduction in power output by 9.0 %, but an increase in the number of turning strokes. These strokes require greater impulse and peak force compared to propulsive strokes, which consequently increases time to peak force, and results in a reduced rate of force production (Figure 2, Table 2). As such, prior knowledge of water flow(s) in relation to the sequences of routes afforded by prior practise (i.e. the first competition run of two), or a greater capability to mentally plan and/or practise, could lead to greater efficiency of movement (strokes used and distance travelled) in respect of time taken to complete the sequence(s). This would result in a lower mean power output as per the 2nd run (Figure 1).

Post-competition lactate values of 16.2 ± 1.2 recorded in World Championship performers including the world champion (Baker, 1982) along with oxygen consumption data recorded breath-by-breath over a simulated competition run (Zamparo et al., 2006) indicates that slalom requires a high capacity with regards to facets of speed or power combined with high intensity endurance. The data presented from the kayak paddle power-meter agrees with these findings but also highlights a requirement for sport specific strength, essential for turning or holding boat position. With these facts in mind, combined with the capability to assess kinetics of paddling through the kayak paddle power-meter it was possible to implement traditional laboratory style tests within the field of slalom canoeing in order to assess and quantify physical and physiological performance.

The use of a six-repetition maximum test through use of strain gauge technology within the shaft enables athletes and coaches to understand specific strength aspects not previously available. This is an important tool that can be used to assess bilateral capability with regards to impulse, peak forces and rate of peak force development (Table 1) specific to individual strokes (Figure 2), important not only for performance, but also injury prevention and athlete development. The data presented highlights athlete imbalances for push, pull components when comparing forward-reverse strokes, and thus reflecting different muscle groups utilised. However, incidences of bilateral difference were apparent for sweep strokes where the length of stroke was less and impulse, peak force and rate of peak force development was considerably less indicating that technical and physical aspects could be limiting capability on the right side for this stroke. Interestingly, this was stroke specific as the right draw stroke had a greater capability than the left as did the right reverse sweep. In this instance, video analysis could help with technical aspects along with physiotherapy intervention concerning possible causes and future risk. Additionally, in a sport entailing large amounts of time dedicated to strength training (Sigmund, Rozsypal, Kudláček, Kratochvíl, & Sigmundová, 2016), efficacy of such training methods and the exploration of new methods of training can be assessed.

The slalom anaerobic test (Figure 3) assesses variables of anaerobic capacity in a fashion similar to other running orientated sports that adapted the Wingate anaerobic test (Bar-Or, 1987) to meet the demands of intermittent activity through mode specificity. In this example, slalom canoeists used the kayak power-meter to acquire actual force data per stroke during the forwards propulsive element as well as the turning aspects. This is an improvement over using just time where the equipment, environment or water depth and temperature may complicate the understanding of outcome changes. In this example, it is possible to identify changes from an overall perspective but also detailed changes such as particular strokes in relation to bilateral deficiencies previously mentioned.

Thus far, specificity has been a major objective of the paper with attention to on-water testing and using techniques specific to the sport. Previously, tests of endurance have occurred in a real world environment specific to the sport but lacking understanding regarding work done. More recently, this has been addressed through a tethered system (Ferrari et al., 2017) which lacks the capability to negotiate a slalom course typical of the training used by athletes within the sport. Moreover, with a kayak paddle power-meter it is now possible to ascertain the physiological response to incremental epochs of work while negotiating sequences of gates in order to quantify markers of endurance capability (Figure 4A). By obtaining power outputs associated with physiological markers such as lactate threshold and the onset of blood lactate it is possible to evaluate improvements in the physiological system in relation to work done. Incorporating such methods enhances coach capability for training prescription, athlete ability to perform prescribed training, and thus optimize efficiency of training development programmes.

Importantly in slalom, where athletes change training venues and are often tested in an environment different to normal, the physiological response to work rate changes as shown in Figure 4B-C. The reason for this may be due to a change in the force-time relationship of strokes, and even the types of strokes used, when moving from easy graded to world cup (grade IV) rivers. It is likely that the athletes use more turning or holding strokes that may not decrease overall mean impulse, it will negatively affect work-rate. Further research needs performing to ensure athletes are prescribed optimal training for their environment.

Alternatively, a simpler test that can easily be accommodated within an athlete's training and easily performed when travelling from venue to venue, is the all-out 2-3 minute critical power test (Vanhatalo, Jones, & Burnley, 2011). Based on the power profile presented in Figure 1 and previous physiological research (Baker, 1982; Zamparo et al., 2006) this is an excellent low cost, non-invasive protocol suitable to slalom paddlers of all abilities with access to a power-meter but maybe not the support systems afforded high performance athletes (Figure 5). It provides quantifiable data regarding three high intensity aspects of slalom performance including maximal aerobic capacity, peak power and ability to sustain anaerobic exercise. The athlete capability in these three aspects presented in Figure 5 (CP = 183 W; W^1 = 550 W; W^2 = 351 W) can be used to formulate a basic training plan and utilised to quantifiably monitor stimulus-response to training.

CONCLUSION

The aim of this paper is to provide knowledge regarding the use of a kayak paddle power-meter in furthering the understanding of slalom kayaking during competition, while enhancing current athlete assessment, training prescription, and monitoring within the process of athlete development. The results suggest that a slalom kayak competition involves large variability in relation to metrics of force, movement and time. Top athletes start with a supramaximal effort, followed by a decline to a more sustainable level interceded with intermittent bouts requiring aspects of strength and power therein dependent on course design. This enhanced understanding along with the capability provided by the power-meter paddles enabled the implementation of a series of sport specific test protocols. These generated quantifiable training prescription categories developed from traditional laboratory methods used within sport science, and sports more easily measured. Data highlights the importance of specificity in terms of training venue, technical difficulty grade of river and physiological response to prescribed intensities. Nevertheless, the paddle power-meter provides athletes and coaches with a means of quantifying competition performance and the processes of athlete development involving biomechanical, physical, and physiological capability, integrated with the technical aspects of the sport.

Future research should include building a database regarding athlete capability during races at a variety of levels; validation of testing protocols; the relationship of athlete assessment data to competition performance; efficacy of training methods used within the sport; and the development of a computer application that derives training prescription data from competition data.

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