The effect of stroke rate on performance in flat-water sprint kayaking

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by

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Candidate contributions to co-authored papers

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My contribution and the contributions of co-authors for the chapters presented in this thesis are indicated in the following table. Patria Hume contributed the ideas for chapter 2 to be a stand-alone chapter and to perform a study on the ergometer (chapter 7). Patria provided input on study design/structure and manuscript revision for chapters 2-9. Volker Nolte contributed input for the observational model development, some time towards analysing stroke rate profiles to help with study design issues during data analysis of chapter 4, and also provided feedback on study design for chapters 4-6. Volker assisted with manuscript revision for chapters 2-9. Joe McQuillan developed and ran the incremental ergometer test for chapter 7, as he was the kayak squad's physiologist at the time of data collection. Joe also assisted with manuscript revision for chapter 7. All co-authors have approved the inclusion of these papers in Lisa McDonnell's doctoral thesis.

Co-author contribution	Thesis Chapter							
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Study idea	L, P	L	L	L	L	L, P	L	L
Study design	L, P, V	L, P	L, P, V	L, P, V	L, P, V	L, P, J	L, P	L, P
Data collection	L	L	L	L	L	L, J	L	L
Data analysis	L	L	L, V	L	L	L	L	L
Manuscript writing	L	L	L	L	L	L	L	L
Manuscript revision	L, P, V	L, P, V	L, P, V	L, P, V	L, P, V	L, P, V, J	L, P, V	L, P, V

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Ethical approval

Ethical approval for this thesis research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC references were:

Chapters 5 and 6:

- 09/275. **Reliability and validity of video, Garmin, and Digitrainer on-water training systems: Measuring performance variables**. Approved on 29th January 2010.

Chapter 7:

- 10/57. **Power profiles and performance predictors in elite sprint kayakers**. Approved with the video analysis addition on 3rd September 2010.

Chapters 8 and 9:

- 11/102. **Optimising stroke rate in developing paddlers**. Approved on 3rd June 2011.

Abstract

Stroke rate has been implicated as an important determinant of sprint kayaking performance via correlation analysis. This thesis determined the effect of stroke rate on sprint kayaking performance including: (1) What stroke rates are required to achieve medal winning times?; (2) What are typical self-selected stroke rates of New Zealand paddlers?; (3) Do paddlers respond well to stroke rate feedback?; and (4) What is the effect of increasing stroke rate on performance and technique? Two literature reviews, one quantitative descriptive performance analysis, two quantitative experimental reliability studies, two quantitative experimental biomechanical studies, and one quantitative experimental intervention study were completed. Elite K1 200-m world championship medallists' average stroke rates ranged 144-168 spm for men and 131-147 spm for women in competition. New Zealand elite paddlers (males and females) typically rated 98-101 spm, but tests were limited to 300-m sprint training at "race pace" and during the last stage of an incremental ergometer test. It was best to assess stroke rates using time-trials. The typical self-selected stroke rates of New Zealand male sub-elite paddlers were 122 ±11 spm during K1 200-m time-trials. While metronome feedback targets were not fully achieved when increasing stroke rate by 5-10 spm, the metronome was effective for increasing stroke rate by 4-5 spm (2.9-4.2%). The stroke rate increase led to a 200-m performance time enhancement of 0.9-1.0% for sub-elite paddlers, where a general trend existed that faster paddlers responded better to the stroke rate increase. Other key variables that indicated better performances were shorter water phase times, aerial phase times, entry sub-phase times and exit sub-phase times. Overall, absolute phase and sub-phase times reported in seconds were more associated with performance than relative phase and sub-phase times. Increasing stroke rate using metronome feedback also caused reductions in water and aerial phase times. Water phase times were reduced primarily by reductions in pull sub-phase times. Pull sub-phase times were not significantly associated with performance, possibly indicating variability in the efficiency of the pull phase between skill levels on-water. Key segmental sequencing variables important for inducing a stroke rate increase between intensities were shorter durations of the pull arm, trunk, and leg actions. Decreasing forward reach was inevitable and decreasing pull arm time was the most important variable for increasing stroke rate, so paddlers should focus on reaching as far forward as possible without hindering their ability to quickly direct the paddle backward. Trunk rotation and leg extension movements increased with intensity and are considered important for performance theoretically for achieving greater paddle tip velocity when the blade enters the water by utilising a greater leg pedalling motion. In conclusion, New Zealand paddlers typically rated well below the recommended stroke rates required to achieve medal winning times in the K1 200-m event. Metronome feedback was effective for eliciting an acute stroke rate increase of 4-5 spm (2.9-4.2%), which led to performance enhancements of 0.9-1.0% in K1 200-m time-trials. Further research is needed to determine the ideal training strategies for making larger increases in stroke rate without losing efficiency in the pull sub-phase.

Chapter 1: Introduction and rationale

Background

Flat-water sprint kayaking is a variant of canoeing in which the athlete is seated in boats (K1, K2, or K4) using a two-bladed paddle for means of propulsion. Sprint-distance kayaking competition occurs on a straight course of calm water with nine lanes across for 200-m, 500-m, and 1000-m race distances at most regattas. The ultimate performance criterion of sprint kayaking is race time. Inversely proportional to race time, average boat velocity is used for performance analysis and setting pacing strategies in training and competition. Therefore average boat velocity can be equally used as a performance criterion.

Boat velocity fluctuates within a stroke (Kendal & Sanders, 1992), as a result of propulsive forces and drag forces (Mann & Kearney, 1980; Jackson, 1995; Baudouin & Hawkins, 2002; Michael, Smith, & Rooney, 2009), therefore research has focused on these parameters of performance. Specifically, paddle blade forces have been the primary focus in kayaking biomechanics research. While paddle blade forces are important (Baudouin & Hawkins, 2002), a rowing biomechanics study could not predict performance based on a linear model incorporating total propulsive power created by blade force, synchrony (real-time comparison of propulsive force magnitudes) and total drag contribution (Baudouin & Hawkins, 2004). Among rowing and kayaking, the entire propulsive system includes three elements: the boat, the athlete, and the oar or paddle (Smith & Loschner, 2002; Michael et al., 2009). The sum of all propulsive and resistive forces acting about the system contributes to the net propulsive force. Michael, Smith, and Rooney (2009) provided a comprehensive review of the forces that may contribute toward kayak motion, and suggested a more comprehensive force system measuring blade forces, seat forces, and foot-bar forces should be developed for kayaking as this system may better reflect net propulsive forces compared to blade force alone. Although a comprehensive force analysis system in rowing, that measured pin forces and foot-board forces showed similarities with the boat acceleration curve throughout the entire stroke, the force measures did not completely account for the acceleration curve given the absence of water resistance and air resistance measures (Smith & Loschner, 2002). Therefore assessing kinetic determinants of boat speed are proving to be difficult, even with comprehensive force measurement systems. At present, there are no devices that can measure all of the propulsive forces and drag forces that may influence boat velocity.

One solution for thoroughly assessing factors that affect performance is to shift the focus of kayaking research to kinematics (the branch of biomechanics concerned with describing motion), and back to the performance criterion: race time or boat velocity. The velocity equation (1) was adapted toward solving for average boat velocity of one stroke (2) to show that boat velocity is entirely dependent on the displacement of the kayak and stroke time. Kinetic variables (propulsive forces and drag forces) refer to the variables that cause motion, and influence velocity via their effect on kinematic variables (kayak displacement per stroke and

stroke time). Therefore when studying changes in motion (kinematic variables), the causes of motion (kinetic variables) are already considered. Measuring average stroke displacement throughout a race distance to acquire sufficient strokes for analysis was not feasible. Therefore this thesis focused on stroke time and influencing factors of stroke time.

Equation (1) Velocity = change of position / change of time
Equation (2) Average boat velocity one stroke = kayak displacement per stroke / stroke time

Questions addressed in this thesis

Personal communication with coaches and high performance staff of Canoe Racing New Zealand (CRNZ), New Zealand's national sport organization for flat-water sprint kayaking, revealed the need for greater stroke rates and "arm speed" to be as successful as the frequently medalling German squad. Further changes to the Olympic events such as excluding all men's 500-m kayak events and replacing them with 200-m events in which stroke rates are expected to be higher, placed increased importance on this topic. Therefore the overarching question of this thesis was: "What is the effect of stroke rate on performance among flat-water sprint kayakers?"

When investigating the effect of stroke rate on performance times, four main questions emerged:

- What stroke rates are required to achieve medal winning times?
- What are the typical self-selected stroke rates of New Zealand paddlers?
- Do paddlers respond well to stroke rate feedback?
- What is the effect of increasing stroke rate on performance and technique?

Adding to the limited research in kayaking, and supporting the needs of CRNZ, this thesis aimed to:

- Define positions and phases of the kayak stroke.
- Develop a deterministic model for sprint kayaking performance.
- Establish medal winning performance times and stroke rate and displacement combinations required for success.
- Evaluate the validity and reliability of feedback and data collection equipment for measuring biomechanical performance variables of New Zealand sprint kayakers.
- Determine how kinematic variables change during routine physiological testing protocols and offer implications for monitoring performance.
- Determine the effect of an acute stroke rate increase in developing paddlers for the K1 200-m event.

Thesis methodology and theoretical framework

The overarching research question relates to specific quantitative measures of performance and identifying effect magnitudes, therefore a quantitative experimental

methodology was used for this thesis. As outlined in the background, this thesis focuses on kinematics, the branch of biomechanics concerned with motion. As such, Newtonian mechanics (also termed classical mechanics) is the theoretical framework most appropriate for dealing with the study of motion of humans, given the typical size of the body and speed at which we move.

Structure of the PhD thesis

The thesis comprises 10 chapters (see Figure 1.1). Each of the study Chapters 2-9 are written as stand-alone papers embedded between Chapters 1 and 10 which introduce and summarise the work as a whole. Chapter 1 illustrates the thesis flow, discusses overall themes, and lists the delimitations imposed during the development of the thesis. The first thesis theme is on determinants of kayak velocity. This theme was originally going to comprise only a literature review, however inconsistencies within the descriptions of the kayak stroke phases among the literature caused non-comparable temporal data (time-dependent variables such as time in a given phase), and inspired the inclusion of Chapter 2 as an important precursor to the literature review. Positions and phases of the kayak stroke were defined to defend the use of terminology used in the literature review and remaining studies. A two-tiered observational model for assessing the kayak stroke via videographic techniques, that was determined suitable for qualitative and quantitative analysis, was created to encourage consistency in the use of sprint kayaking stroke phases among the biomechanics research community. Chapter 3 highlights the lack of investigation of basic determinants of boat velocity as a review of literature. Average boat velocity is a product of stroke displacement and stroke rate. Measuring average stroke displacement throughout a race to acquire sufficient strokes for analysis was not feasible, and because the literature review identified that a low stroke sampling rate may be responsible for the lack of findings among previous research, stroke rate and its contribution toward performance was chosen as the main focus throughout this thesis.

The second thesis theme on developing performance targets comprises Chapter 4, which determines the performance times and boat velocity required to achieve medals in the men's and women's K1 200-m event in the world cup and world championship regattas by assessing the consistency of place times in the A finals. Though desired performance enhancements are typically determined by assessing individual paddler consistency (Bonetti & Hopkins, 2010), understanding the consistency of place times helps set performance targets for those who are not currently achieving medals. Since no descriptive data of key performance determinants were available at the highest level of elite performance in the previous chapters, a matrix of required stroke displacements and stroke rates to achieve medal winning performances of the K1 200-m events was created based on race times and a review of World Championship video.

The third thesis theme on measuring performance, focuses on reliability and validity, and comprises Chapters 5 and 6. The reliability studies discuss consistency (repeatability or reliability of a measure), variability (the spread of a measure), and when applicable, validity (precision of a measure) to gain a better understanding of what equipment should be used in the experimental approaches, to confirm methods (e.g. an application of a filter) and establish

the smallest worthwhile changes for a given variable and the study design chosen. In Chapter 4, the quality of video and video editing prevented consecutive stroke to stroke data from being plotted over race time, so gaps existed throughout the profiles. Equipment and methodology suitable for assessing stroke rate for each stroke were addressed within this theme. Chapter 5 focused on the differences in equipment for measuring stroke rate on a stroke-to-stroke basis using one method of analysis, while Chapter 6 focused on comparing results from different analyses methods and discussed when each method may be appropriate in research and the practical environment. Chapter 6 also contributed descriptive reliability data for stroke phase durations in sprint kayaking.

The fourth thesis theme on kayaking biomechanics comprises Chapters 7 and 8 which consist of quantitative experimental studies that aided in identifying self-selected stroke rates at different training intensities and throughout race simulations in addition to other influencing factors of self selected stroke rates. Chapter 7 involved a biomechanical analysis of a common incremental test on the kayak ergometer. The use of a kayak ergometer was justified due to on-water limitations of collecting sufficient strokes for a kinematic analysis. At this point in the thesis it was known that in the event of low sample sizes, paddlers' biomechanical data could be reliably measured over 40 continuous strokes. Differences in power output, stroke rate, and kinematics between trials of different intensities was determined, and important variables were identified for future on-water analysis. Two problems occurred at this stage of the thesis that required immediate action regarding the direction of the thesis: (1) Elite paddlers were no longer available for testing due to Olympic preparations; (2) It was suspected that paddlers would not achieve their true selected stroke rates when asked to achieve "race pace" for a 40-stroke period given the lower than expected stroke rates measured in the thesis. Full time-trials were expected to provide a higher ecological validity of performance. Therefore assessments of 40 continuous strokes were replaced with full time-trial analyses. Chapter 8 was an on-water analysis to determine on-water self selected stroke rates, as well as performance time reliability in male competitive club paddlers during K1 200-m time trials. The highest level of club paddlers available were chosen for the intervention study due to the elites' preparation for the Olympic games in 2012. This chapter was also required to choose the self-selected stroke rates and smallest worthwhile effects prior to the intervention in Chapter 9 which used the same participants.

The fifth thesis theme on interventions to improve performance consists of a quantitative experimental study, Chapter 9, to investigate the effect of metronome feedback for controlling stroke rate, and the effect of a change in stroke rate on timing characteristics, and race time.

The culminating Chapter 10 forms the discussion and overall conclusions of the thesis as a whole. It summarizes the key findings that were pertinent to the effects of increasing stroke rates on timing characteristics, technique, and performance, under routine physiological testing protocols on the ergometer and during time trials on-water. Chapter 10 narrowed the variables that were found important for performance. The Chapter also addresses the thesis limitations and areas for future research.

Abstracts of the oral conference presentations resulting from the work of this thesis are provided in Appendix 1. As the PhD thesis work was originally initiated with Rowing New Zealand before changing to work with Canoe Racing New Zealand, the initial literature review conducted for Rowing New Zealand that led to improved writing skills, and gave transferable information relevant to CRNZ, is included in Appendix 2. All studies were approved by the Auckland University of Technology Ethics Committee, and ethics information documents for Chapters 5, 6, 7, 8, and 9 are provided in Appendices 3-5.

Statistical analysis approach

This thesis followed a more progressive statistics approach using magnitude-based inferences than the traditional approach of assessing for statistical significance when attempting to determine effects. The magnitude-based inferences approach allows researchers to communicate the likelihood that the true value of an effect is of sufficient magnitude to be practically meaningful. Using this method requires: (1) Knowledge of what is practically important in the sport of sprint kayaking; (2) A confidence interval; and (3) A sufficient sample size in order to declare clear effects. While the magnitude-based inferences method is described in detail in published sources (Batterham & Hopkins, 2006; Hopkins, Marshall, Batterham, & Hanin, 2009) the key benefits over a p-value approach are:

- There is less likelihood of having a type I error (0.5% when effects are clear using a 90% confidence interval; traditionally, type I error is 5% when sample size is based on an 80% likelihood of statistical significance at the 5% or $p = 0.05$ level, also known as a power of 80%).
- There is a slightly greater likelihood of making a type II error (25%; traditionally type II error is 20%).
- One-third the traditional sample size for the default type I and type II errors (i.e. 5% and 20% respectively) are needed when using magnitude-based inferences using a 90% confidence interval; approximately half the traditional sample size is needed when using a 95% confidence interval.
- Likelihoods of benefit and harm, or positive and negative changes, derived from the likelihood of the true value (uncertainty represented by the confidence interval) being larger than the smallest worthwhile change yields more practioner friendly outcomes which is better for the participants.

Achieving adequate sample size for research in elite sprint kayaking is difficult, especially for the small population of paddlers available in New Zealand. Therefore the default 90% confidence interval was chosen for analysis, as effects would be more clearly seen with fewer participants. Previous rowing research used an averaged individual approach where as many elite rowers as possible (six rowers) were studied using an adequate sample size of 40 strokes (Coker, 2010). This design was chosen for the initial reliability and experimental studies (Chapters 5, 6, and 7) for this thesis on the basis that rowers and kayakers exhibited similar

performance reliability (Bonetti & Hopkins, 2010). The ergometer analysis in Chapter 7 was only 19 double-strokes, and analysis was limited to the sagittal plane. However, the smallest worthwhile changes were amplified in Chapter 7 to the typical error for a more conservative approach when identifying change. This approach only required a sample size of at least 10 strokes for analysis using the sample size estimation worksheet developed by Hopkins (available at www.sportsci.org, last accessed November, 2013). Within these studies the maximum number of participants available (i.e. 6-7 paddlers) were sought to provide a representative sample of elite paddlers in New Zealand. It was later realized that a full time-trial would be more appropriate, and the smallest worthwhile change values did not need to be amplified if averageing the values of all strokes in a time-trial. However, sample size needed to be larger, so sample size was performed 'on the fly' (also called a group-sequential design) where a number of participants were recruited and data collection was repeated until effects were detected (Batterham & Hopkins, 2005). The minimum number of paddlers needed for the pre-post single group design was 10 paddlers (Batterham & Hopkins, 2005). The maximum number of paddlers available in the area who achieved the performance criteria (average 200-m time-trial time less than 50 s) was 12 paddlers. Their pre- and post-intervention tests were performed twice to achieve a sample of 24 paddlers, and expected effects were detected with this sample size.

Delimitations

In the process of designing the completed research studies, the following delimitations were imposed:

1. Participants must have been competitive New Zealand sprint paddlers and currently training.
2. Participants must have been free from injury that would affect performance.
3. Paddlers must have been available for testing in Auckland.
4. On-water analysis was limited to the K1 boat class only.

The Effect of Stroke Rate on Performance in Flat-water Sprint Kayaking

Chapter 1: Preface/Introduction

Determinants of kayak velocity

Chapter 2: An observational model for biomechanical assessment of sprint kayaking technique. *Literature review and qualitative model. (Sports Biomechanics, 11, 507-523)*

Chapter 3: A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Literature review. (Sports Biomechanics, 12, 205-220)*

Developing performance targets

Chapter 4: Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition. *Quantitative descriptive. (International Journal of Performance Analysis in Sports, 13, 38-50)*

Measuring performance: Reliability and validity

Chapter 5: Sprint kayaking stroke rate reliablity, variability and validity of the Digitrainer accelerometer compared to GoPro video measurement. *Quantitative experimental. (ISBS 2012)*

Chapter 6: A comparison of analysis methods for determining the reliability of stroke rate and stroke phase temporal variables in sprint kayaking. *(Submitted to Sports Biomechanics)*

Kayaking biomechanics

Chapter 7: The effect of intensity on kayak ergometer paddling technique. *Quantitative Experimental. (Submitted to Journal of Sports Sciences)*

Chapter 8: Measuring on-water kinematic performance determinants and symmetry for K1 200-m sprint kayaking time-trials.. *Quantitative Experimental. (To be submitted to Journal of Science and Medicine in Sport)*

Interventions to improve performance

Chapter 9: The effect of metronome feedback on stroke rate in sprint kayaking. *Quantitative Experimental. (To be submitted to Research Quarterly for Exercise and Sport)*

Chapter 10: Discussion/Conclusion

Appendix 1: Abstracts of conference presentations

Appendix 2: Abstract of publication in Sports Medicine

Appendices 3-5: Ethics information for chapters 5, 6, 7, 8, and 9.

Figure 1.1. Overview of the structure of the thesis.

Chapter 2: An observational model for biomechanical assessment of sprint kayaking technique

This chapter has been published as:

Overview

Sprint kayaking stroke phase descriptions for biomechanical analysis of technique vary among kayaking literature, with inconsistencies not conducive for the advancement of biomechanics applied service or research. We aimed to provide a consistent basis for the categorisation and analysis of sprint kayak technique by proposing a clear observational model. Electronic databases were searched using key words kayak, sprint, technique, and biomechanics, with 20 sources reviewed. Nine phase-defining positions were identified within the kayak literature, and were divided into three distinct types based on how positions were defined: water-contact defined positions, paddle-shaft defined positions, and body defined positions. Video of elite paddlers from multiple camera views were reviewed to determine visibility of positions used to define phases. The water-contact defined positions of catch, immersion, extraction and release were visible from multiple camera views, therefore were suitable for practical use by coaches and researchers. Using these positions, phases and sub-phases were created for a new observational model. We recommend that kayaking data should be reported using single strokes and described using two phases: water and aerial. For more detailed analysis without disrupting the basic two phase model, a four sub-phase model consisting of entry, pull, exit, and aerial sub-phases should be used.

Introduction

Sprint kayaking is a variant of canoeing in which the athlete, termed paddler, is seated in a kayak (K1, K2, or K4 where the number represents the number of paddlers in the kayak) using a two-bladed paddle for propulsion. Competition occurs on a straight course of calm water for 200-m, 500-m, and 1000-m race distances. The objective is to finish the race in the least amount of time.

Sprint kayaking technique is related to ability and performance outcomes. In a notational analysis of elite, national and club paddlers during competition, differences in technique across ability levels were seen in trunk rotation, stroke width, forward reach, leg motion, overall motion of the kayak, blade-water contact time, and stroke rate (Brown, Lauder, & Dyson, 2011). More successful paddlers entered their blade in the water well forward and closer to the longitudinal axis of the kayak, and moved their paddle a greater distance laterally, and a smaller distance backward during the stroke when using the wing paddle (Kendal & Sanders, 1992).

Video analysis (2D or 3D), force analysis, electromyography, and accelerometry have been used by researchers to assess the motion of the paddler, paddle and kayak (Michael et al., 2009). However, most of these methods are high cost, time-intensive, and technically challenging. Qualitative 2D video analysis is the quickest, least expensive and likely the most widely used biomechanical service available to paddlers. Unfortunately, limited access to equipment may provide a limitation to the type of analysis that can be performed depending on how the stroke is divided and observed.

When analysing technique, the kayak stroke is usually broken down into two to four phases (Mann & Kearney, 1983; Logan & Holt, 1985; Cox, 1992; Szanto, 2004; Michael et al., 2009). Given limited pre-existing research in sprint kayaking in the late 1970's, Plagenhoef (1979) admittedly used "arbitrary" phases for his analysis of Olympic sprint paddlers as a starting point for kayak technique analysis. However, in more recent literature, the kayak stroke phases (entry, pull, exit, and recovery) were described as "questionably discernible" given clear start and end positions were not described for each phase. Elite paddlers have reported being confused when receiving technique feedback from differences in terminology and/or definitions of stroke phases used by coaches. To communicate effectively, biomechanists, coaches, and paddlers need to have a clear understanding and consistent use of stroke phase categorisation.

Developing a clear observational model may help improve communication and the application of research to practice. Important components of an observational model include defining a mechanical objective, determining the number of movement phases, defining movement phases, and knowing what factors influence the ability to observe performance (Knudson & Morrison, 2002). Kayaking research has not developed one generally accepted observational model with consistent terminology or clear definitions. Therefore a critical review of observational models used among kayak research was warranted. The aim of this review was to provide a consistent basis for the categorisation and analysis of sprint kayak technique by proposing a clear observational model.

Methods

SportsDiscus, Google Scholar, and International Society of Biomechanics in Sports (ISBS) conference databases from 1975 to May 2012 were searched using key words kayak, sprint, technique, and biomechanics. Additional manual searches through article reference lists were performed. Inclusion criteria for all articles were: (1) the article must have provided a description of phase-defining positions used in kayaking, and (2) must have been accessible in English. Three relevant books, 10 peer-reviewed journal articles, six conference communications, and one unpublished report were retained.

Definitions of the kayak stroke, kayak stroke positions, and kayak stroke phases used in the literature were summarised. Overall quality of the observational model presented for each paper was indicated in Table 2.1 with capital letters A-G, judged on the following corresponding criteria: (A) Positions used for start and end points of phases were defined in the paper; (B) All phases were defined with start and end points, and occurred over a span of time; (C) The term

stroke or stroke cycle was defined with a start and end point or implied with the use of defined phases or implied with the use of a single right-sided or left-sided stroke; (D) Pictures of phase-defining positions were provided; (E) Pictures reflected the definition (i.e. showed blade water contact if the position was defined by blade water contact) and did not contradict the definitions presented in the text; (F) All terms were defined in the methodology section, or stroke description section in a review; (G) The observational model presented in the manuscript could be accurately repeated by a coach for qualitative analysis (without making any assumptions). More letters in the "quality" column of Table 2.1, indicated higher quality descriptions of the stroke cycle within the literature, but ultimately achieving repeatability without further assumptions (G) was considered most important.

Phase-defining positions were categorized into three different types of positions depending on their definitions; four water-contact defined positions, four paddle-shaft defined positions, and one body defined position. Videos of two elite New Zealand paddlers (of different body types) during an aerobic training session on-water taken by the authors of this paper, were reviewed from multiple camera views (front, right side, left side, back, and oblique angles) to critique visibility of phase-defining positions presented in the literature. Two models in the literature presented a phase division for kayak ergometer technique analysis (Trevithick, Ginn, Halaki, & Balnave, 2007; Michael et al., 2009), so ergometer videos from the side view were also reviewed to assess the kayak ergometer observational models.

To compare and contrast observational models used between studies, all observational models were normalised to our single stroke definition, beginning from the right (blade) catch (0%) and ending at the catch of the opposite side (100%).

Table 2.1. Terminology presented in the literature in chronological order for dividing the kayak stroke into phases for observation.

Reference	Stroke terminology and definition[a]	Position terminology and definitions[a]	Phase terminology and definitions[a]	Location of definitions within the paper	Quality[b]	Our interpretation summary[c]
(Plagenhoef, 1979)	Stroke: paddle entry of one side until the same position occurs again (implied from definition of stroke time). Total stroke: implied as only containing four parts (eight parts accounted for the stroke time as defined above, thus the term *stroke* contains a double meaning).	(1) Position 1: paddle entry. (2) Position 2: the point when the paddle is in the vertical plane. (3) Position 3: when the top arm completes its forward motion. (4) Position 4: when the paddle clears the water at exit.	(1) Part one: from position 1 to position 2. (2) Part two: from position 2 to position 3. (3) Part three: from position 3 to position 4. (4) Part four: out of water phase until the paddle again touches at entry (implied position 4 to position 1 on opposite side).	Results section.	A, B, D.	(1) Stroke defined: double stroke. (2) Positions: catch, vertical, greatest forward reach, release. (3) Model limitations: L1, L2, L4, L5, L6, L7. (4) Model benefits: B1, B4.
(Mann & Kearney, 1983)	Kayak stroke: not defined (implied as a single-sided stroke with the use of phases).	(1) Entry: paddle entry. (2) Vertical: shaft vertical position. (3) Exit: water-paddle disassociation/paddle exit.	(1) Phase clearly implied though not stated: from position 1 to position 2. (2) Phase clearly implied though not stated: from position 2 to position 3. (3) Paddle air phase: from exit toward entry on opposite side.	*The kayak stroke* section.	A, B, C, D, F, G.	(1) Stroke defined: single stroke. (2) Positions: catch, vertical, release. (3) Model limitations: L4, L5, L7. (4) Model benefits: B2, B3, B4.
(Logan & Holt, 1985)	Kayak stroke: not defined (implied as a single-sided stroke with the use of phases).	(1) Horizontal blade position. (2) When the blade of the paddle is completely submerged in the water. (3) When the removal action of the blade in the water is initiated.	(1) Catch phase: from a horizontal blade position to when the blade of the paddle is completely submerged in the water. (2) Pull phase: from when the blade is fully buried at the beginning of the in-water portion of the stroke, to when the removal action of the blade from the water is initiated. (3) Exit phase: from a submerged blade position to a horizontal in-air position. (4) Recovery phase: the recovery position represented by the horizontal paddle position.	*Stroke phase analysis* section.	C, D, E, F, G.	(1) Stroke defined: single stroke. (2) Positions: horizontal, immersion, extraction, horizontal. (3) Model limitations: L3, L5, L7. (4) Model benefits: B3, B5, B7.

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Reference	Stroke terminology and definition[a]	Position terminology and definitions[a]	Phase terminology and definitions[a]	Location of definitions within the paper	Quality[b]	Our interpretation summary[c]
(Baker, Rath, Sanders, & Kelly, 1999)	Two full stroke cycles: paddle entry to same paddle entry.	Not defined (implied water in point and water out point based on phase definitions).	(1) Pull phase: when the blade was in the water. (2) Run phase: when both blades were out of the water.	Stroke defined in methods section; phases defined in results section.	C, G.	(1) Stroke defined: single stroke. (2) Positions: catch, release. (3) Model limitation: L7. (4) Model benefits: B3, B4, B5, B6.
(Cox, 1992)	Stroke: not defined, though clearly implied as the sum of four phases beginning from the horizontal position of one side to the horizontal position of the opposite side.	Not defined.	(1) Entry phase: from a horizontal paddle position that ends when the blade of the paddle is completely submerged in the water. (2) Pull phase: no start and end points defined, but characterised as occurring after the blade has entered the water. (3) Exit phase: no start and end point s defined, but occurs once the body has passed the paddle and includes the blade being lifted from the water. (4) Recovery: no specific start point was defined, but the phase was described as the completion of the exiting action to the horizontal paddle position.	Kayak technique section.	C, F.	(1) Stroke defined: single stroke. (2) Positions: horizontal, immersion, two unknown positions. (3) Model limitations: L1, L2, L5, L7. (4) Model benefit: B3.
(Kendal & Sanders, 1992)	Two consecutive strokes: one right-side stroke followed by a left-side stroke. Stroke time: composed of pull time and glide time.	(1) Blade entry: not defined. (2) Blade exit: not defined.	(1) Pull time: time from blade entry to blade exit on the same side. (2) Glide time: time from blade exit to opposite side blade entry.	Methods section.	B, C, D, F.	(1) Stroke defined: single stroke. (2) Positions: catch, release. (3) Model limitation: L7. (4) Model benefits: B1, B3, B4, B6.
(Hay & Yanai, 1996)	Stroke cycle: Consisted of pull and run phases.	(1) Instant at which the tip of the blade entered the water. (2) Instant at which the tip of the blade exited the water.	(1) Pull phase: from position 1 to position 2. (2) Run phase: from position 2 to position 1 of the opposite side.	Methods subsection termed "Critical Instants".	A, B, C, D, E, F, G.	(1) Stroke defined: single stroke. (2) Positions: catch, release. (3) Model limitations: L7. (4) Model benefits) B1, B3, B4, B5, B6.

Reference	Stroke terminology and definition[a]	Position terminology and definitions[a]	Phase terminology and definitions[a]	Location of definitions within the paper	Quality[b]	Our interpretation summary[c]
(Szanto, 2004)	Kayak stroke: not defined, though clearly implied as the sum of the entry phase time, draw phase time, exit phase time, relaxation phase time, and firming phase time.	Not defined.	(1) Aquatic phase or Power transmission phase: includes catch and draw sub-phases. (1.1) Water catch or entry phase: from introduction of the blade into the water to when the blade is totally submerged. (1.2) Draw phase: from end of 'water catch' to when the blade begins to exit the water. (2) Recovery phase: includes exit, relaxation, and firming sub-phases. (2.1) Exit phase: from end of 'draw phase' to when the blade last touches the water. (2.2) Relaxation phase: most of the muscles are in relaxation. (2.3) Firming phase: the muscles are firm.	Kayak technique section	A, C, D, F.	(1) Stroke defined: single stroke. (2) Positions: catch, immersion, extraction, release, one unknown position. (3) Model limitations: L1, L3, L5, L7. (4) Model benefits: B3, B5, B7.
(Espinosa-Sanchez, 2005)	One stroke: not defined. Paddling cycle: one stroke on the right side of the boat followed by one stroke on the left side of the boat.	Not defined.	(1) Entry of the blade into the water: not defined. (2) Pull of the paddle: not defined. (3) Exit of the blade from the water: not defined. (4) Recovery: not defined.	Introduction section.	C.	(1) Stroke defined: single stroke. (2) Positions: unknown. (3) Model limitations: L1, L7. (4) Model benefit: B3.
(Qiu, Wei, Liu, & Cao, 2005)	Paddling period: divided into four space marking points and four phases.	(1) Position 1: the level point. (2) Position 2: the water-in point. (3) Position 3: the vertical point. (4) Position 4: the water-out point.	(1) Preparation phase: from the level point to water-in point. (2) Catch phase: from the water-in point to the vertical point. (3) Power phase: from the vertical point to the water-out point. (4) Recovery phase: from the water-out point to the level point. (A) Pull phase: includes catch and power phases. (B) Air-work phase: includes preparation and recovery phases.	Methods section.	A, B, C, F, G.	(1) Stroke defined: single stroke. (2) Positions: horizontal, catch, vertical, release. (3) Model limitations: L4, L5, L7. (4) Model benefits: B1, B3, B4.

Continued next page

Reference	Stroke terminology and definition[a]	Position terminology and definitions[a]	Phase terminology and definitions[a]	Location of definitions within the paper	Quality[b]	Our interpretation summary[c]
(Trevithick et al., 2007)	Kayak stroke (one stroke cycle): comprised three phases.	(1) Most forward paddle position: most forward position of a marker placed at the quarter shaft distance. (2) Horizontal: position of the paddle shaft. (3) Most backward paddle position: most backward position of a marker placed at the quarter shaft distance.	(1) Pull-through phase: from the most forward paddle position of the testing arm to the most backward position. (2) Exit phase: from the most backward paddle position until it reached a horizontal position. (3) Recovery phase: from the horizontal position to the most forward excursion of the paddle.	Methods section.	B, C, F.	(1) Stroke defined: single stroke. (2) Positions: most forward quarter shaft, most backward quarter shaft, horizontal. (3) Model limitation(s): L2, L3, L6. (4) Model benefit(s): B3, B6.
(Begon, Lacouture, & Colloud, 2008)	One full stroke/stroke: starting with the initial blade-water contact and continuing until blade-water contact was made on the opposite side.	(1) Entry: not defined (implied as initial blade-water contact). (2) Verticality: vertical position of the paddle. (3) Exit: not defined (implied as exit position of the paddle).	The stroke was broken down into three parts according to: paddle immersion, shaft verticality and water exit. (1) Water phase: divided into two parts (entry to verticality; verticality to exit) (2) Aerial phase: not defined (implied as the time when both blades were out of the water, given by the results)	Stroke defined in methods section; phases and position terminology used to define phases were first introduced in the results section.	C, D, G.	(1) Stroke defined: single stroke. (2) Positions: catch, vertical, release. (3) Model limitations: L4, L5, L7. (4) Model benefits: B2, B3, B4.
(Michael et al., 2009)	Single stroke: from the start of the catch when the paddler enters the water to the start of the catch on the opposite side. In between strokes: when the water resistance slows the kayak down – implies that the recovery is not part of a stroke – contradicts single stroke definition.	Not defined.	(1) Catch phase: when the paddle enters the water. (2) Pull phase: the paddle is submerged and drawn through the water. (3) Exit phase: no definition. (4) Recovery phase: when no paddle forces are being applied.	Unclear and potentially contradictory definitions presented in the kinetic data analysis section compared with kinematic data analysis section of the review.	None.	(1) Stroke defined: single stroke. (2) Positions: Unknown. (3) Model limitations: L1, L7. (4) Model benefit: B3.

Reference	Stroke terminology and definition[a]	Position terminology and definitions[a]	Phase terminology and definitions[a]	Location of definitions within the paper	Quality[b]	Our interpretation summary[c]
(Brown et al., 2011)	Stroke cycle: not defined.	Not defined.	(1) Pull phase: not defined (implied use of Kendal and Sanders' [1992] model). (2) Glide phase: not defined (implied use of Kendal and Sander's [1992] model).	No definitions were presented in the paper; the use of pull and glide phases were introduced in the results and implied the use of Kendal and Sander's (1992) model in the discussion.	None.	(1) Stroke defined: double stroke – via results (unknown). (2) Positions: catch, release. (3) Model limitation: L7. (4) Model benefits: B1, B4, B6.
(Michael, Rooney, & Smith, 2012)	Stroke: not defined, but implied as a single sided stroke by differentiating right and left sides.	(1) Catch: maximum point of the paddle position in the positive anterior-posterior direction with reference to the centre of the testing frame. (2) Finish: maximum point of the paddle position in the negative anterior-posterior direction with reference to the centre of the testing frame.	(1) Drive phase: begins with the catch and ends at the finish. (2) Glide time: not defined, but presumed to be from the finish to opposite side catch.	Data analysis section of the methodology.	A, B, C, F.	(1) Stroke defined: single stroke. (2) Positions: catch, release. (3) Model limitation: L1, L6. (4) Model benefits: B1, B3, B4, B6.

[a] Stroke, position and phase terminology and definitions were presented as described and defined by the authors of the respective reference; [b] Quality of definitions used to describe the stroke cycle and its phases were assessed on the following criteria: (A) Positions used for start and end points of phases were explicitly defined in the paper; (B) All phases were defined with start and end points, and occurred over a span of time; (C) The term stroke or stroke cycle was clearly defined with a start and end point or implied with the use of clearly defined phases or implied with the use of a single right-sided or left-sided stroke; (D) Pictures of phase-defining positions were provided; (E) Pictures reflected the definition (i.e. showed blade water contact if the position was defined by blade water contact) and did not contradict the definitions presented in the text; (F) All terms were defined in the methodology section, or stroke description section in a review; (G) The observational model presented in the manuscript could be accurately repeated by a coach for qualitative analysis (without making any assumptions); More letters indicated higher quality descriptions of the stroke cycle within the literature, but ultimately achieving repeatability without further assumptions (G) was considered most important; [c] Our interpretation summary shows our interpretation of the stroke and position terminology used in the literature as defined within this paper in order to compare and contrast models used between studies. Model limitation(s) included: (L1) One or more positions were difficult to discern; (L2) Order of positions may have changed with technique; (L3) Inappropriate phase categorization (propulsive and non-propulsive components occurred in the same phase); (L4) Inappropriate movement categorization (phases did not adequately divide the stroke into primary movement actions); (L5) May have required more than one camera view to distinguish timing of positions for both sides; (L6) Marking was required; (L7) Limited to on-water analysis only. Model benefit(s) included: (B1) Helped distinguish successful performances; (B2) Eliminated confusing aspects of a previous model; (B3) Single stroke analysis may have been useful for symmetry assessment; (B4) Separating movement analysis into propulsive and non-propulsive actions may help align kinematic and kinetic analysis in the future; (B5) Primary movement in each phase of the stroke was distinguishable from all other phases; (B6) All positions were visible in one camera view; (B7) Separating movement by the amount of blade surface area in contact with the water allowed kinetic principles to be qualitatively applied to kinematic analysis.

Terminology

Stroke terminology, position terminology, phase terminology, their definitions, and where the definitions were clearly expressed varied between the papers reviewed. The observational model explanations as described and defined by the authors of the literature reviewed, quality of descriptions in the literature, our own interpretation using terminology defined later in this paper, model limitations and model benefits were summarised in Table 2.1. Less than 50% of the literature reviewed provided clear descriptions of observational models (i.e. clear descriptions were determined if the phase-defining positions were clearly stated or implied by the use of phase definitions or results). In terms of clarity, Hay and Yanai (1996) presented the highest quality model description by meeting all criteria (Table 2.1). Unfortunately, their paper was a report to the US Olympic Committee and not widely accessible.

There were two definitions used for a kayak stroke which we interpreted as a single stroke and double stroke (Table 2.1). A single stroke encompasses the time from a given position to the same position on the opposite paddle side (analogous to a step in walking gait), while a double stroke continues until the same position on the same side is achieved (analogous to a stride in walking gait). Therefore the double stroke consists of both right and left single strokes, though not necessarily in that order. We use these definitions throughout this paper.

The terminology used in the literature did not effectively differentiate kayak stroke definitions. Full stroke cycle, full stroke, and stroke were defined as a single stroke (Kendal & Sanders, 1992; Baker et al., 1999; Begon et al., 2008). Stroke time (implying the term stroke) in another study was defined as a double stroke (Plagenhoef, 1979). Brown et al. (2011) did not define start and end positions for the stroke, however reported stroke time (mean stroke time of international level male paddlers during 500-m competition: 0.99 ±0.06 s) that was nearly twice the stroke time reported (mean stroke time of international level male paddlers at max speed: 0.49 ±0.03 s) by Kendal and Sanders (1992). Therefore, it was assumed that Brown et al. (2011) used a similar stroke definition to Plagenhoef (1979). Stroke definitions influence normative data of stroke time and therefore will also affect other temporal variables and position data per stroke (e.g. displacement per stroke or stroke rate). The difference in Plagenhoef's results (elite 500-m male paddler's stroke time: 0.77 s) compared to Brown et al. (Brown et al., 2011) and Kendal and Sanders (1992), shows that normative data changes over time. Therefore inconsistency in terminology and unclear definitions make it difficult to determine how much change in performance variables over time was attributed to a real change or to differences between definitions.

We suggest that when a researcher determines that the presentation of data for a double stroke is appropriate (i.e. analysis of the right wrist joint centre over a double stroke), they report these data over two consecutive single strokes (Kendal & Sanders, 1992; Baker et al., 1999). If the term stroke is chosen to be used independently throughout a manuscript or athlete report, without the descriptive single or double term preceding it, then stroke should be defined in the methodology section and should not change meaning throughout the manuscript or report. The

observational model should be defined with clear phase-defining positions and phases within the methodology section following the definition of a stroke.

Kayak stroke positions

A kayak stroke position is a configuration of the paddler or paddle, at an instantaneous moment in time. Nine kayak stroke positions were identified from the literature reviewed to define the beginning and end points of phases in the kayak stroke (Table 2.1). All nine stroke positions were categorized into three different types of positions depending on their definitions; four water-contact defined positions, four paddle-shaft defined positions, and one body defined position. Visibility from multiple camera views, of each position over two consecutive strokes, are summarized in Table 2.2. The ability to observe each position was partially dependent on its position type.

Water-contact defined positions

Four water-contact defined positions (catch, immersion, extraction, and release) were defined based on the amount of surface area of the blade in contact with the water (Figure 2.1). The catch occurred when the tip of the blade made initial contact with the water, immersion occurred when the entire propulsive surface area of the blade was immersed in the water, extraction described the last moment when the entire propulsive surface area of the blade was in contact with the water, and the release was the last moment of contact between the blade tip and water.

Each water-contact defined position had a right side and left side over two consecutive single strokes, depending on which paddle blade was in contact with the water. The kayak obstructed the view of the water-contact positions on the opposite side to the side being videoed (left catch stick Figure 1L in Figure 2.4). All water-contact positions were visible from the front view, however, videoing from a motorized kayak in front of a kayaker creates excessive wash that may hinder performance given sprint kayaks are highly unstable. While videoing from the back view, paddlers' large upper body girths (Ackland, Ong, Kerr, & Ridge, 2003) sometimes obstructed the visibility of the paddle blade at the catch position when the blade entered closer to the midline of the kayak – a desired characteristic of good technique (Kendal & Sanders, 1992). Using a lightweight kayak bow-mounted camera or a land-based camera eliminates any problematic effects on performance and allows for complete visibility.

Assessing stroke phase times on the ergometer is not practical given a water assessment would need to be conducted for each individual first, to obtain matched blade angles of each individual being assessed if using water-contact positions.

Table 2.2. Visibility of kayak stroke positions identified by type and camera view plane.

Position type	Right side (sagittal)	Left side (sagittal)	Front (frontal)	Back (frontal)	Oblique planes[a]
Water-contact defined					
Right catch	yes	-	yes	o	v
Right immersion	yes	-	yes	yes	v
Right extraction	yes	-	yes	yes	v
Right release	yes	-	yes	yes	v
Left catch	-	yes	yes	o	v
Left immersion	-	yes	yes	yes	v
Left extraction	-	yes	yes	yes	v
Left release	-	yes	yes	yes	v
Paddle-shaft defined					
Right horizontal	yes	yes	-	-	-
Right vertical	yes	yes	-	-	-
Right most forward*	yes	m	-	-	-
Right most backward*	yes	o	-	-	-
Left horizontal	yes	yes	-	-	-
Left vertical	yes	yes	-	-	-
Left most forward*	m	yes	-	-	-
Left most backward*	o	yes	-	-	-
Body defined					
Right greatest forward reach*	yes	-	-	-	-
Left greatest forward reach*	-	yes	-	-	-

[a] Oblique planes are any plane not in a sagittal or frontal plane. There are an infinite number of angles from which to position the camera in an oblique plane. Yes = the position is visible from this view; - the position is not visible from this view; o = the position is sometimes obstructed by the paddlers' own body depending on technique; v = this position is visible in numerous oblique plane camera views as long as the water-line and paddle blade are visible; m = most likely visible, but visibility may depend on marker type and rotation of the paddle shaft; * = these positions require markers for identification.
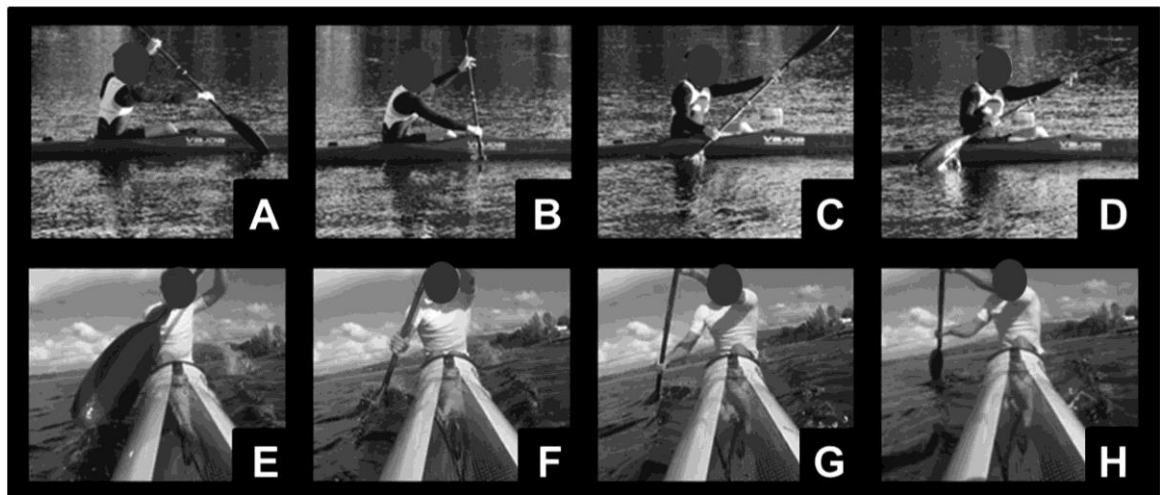
Figure 2.1. Stroke positions for side (A-D) and front views (E-H). From left to right: right catch (A and E); right immersion (B and F); right extraction (C and G); and right release (D and H).

Paddle-shaft defined positions

The four paddle-shaft defined positions (vertical, horizontal, most forward quarter shaft, and most backward quarter shaft) depended on the position of the paddle shaft. The right side or left side positions were differentiated based on the paddle position being on the right or left side of the paddler. The vertical paddle-shaft position was determined based on the vertical alignment of the portion of the paddle shaft between both hands, since the shaft between the blade and water-contact side may bend during the propulsive part of the stroke when the blade is in the water. The horizontal paddle-shaft position occurred when the paddle blade was unloaded and the paddle shaft was level (Figure 2.2). The most forward and backward quarter shaft positions were determined from the most forward and backward location of a marker attached at the quarter shaft; the point halfway between the centre and end of the shaft on a kayak ergometer (Trevithick et al., 2007).

A model using the horizontal position, most forward, and most backward quarter shaft positions was implemented in one study to distinguish three phases among recreational paddlers on the kayak ergometer (Trevithick et al., 2007). However, reviewing these positions among elite paddlers from video sampled at 300 Hz, revealed that the positions could not distinguish three phases because the most backward paddle position occurred, on average, at the same frame as the horizontal position. Therefore only two phases were shown in the summary of models, as phase two became an instantaneous position at horizontal (Figure 2.3). The difference between our observations and the observations of Trevithick et al. (2007) may have been attributed to technique differences between elite sprint paddlers and recreational paddlers, or differences in the total length of the paddle shaft which would alter the location of the marker. Markers toward the end of the shaft would result in an earlier most forward paddle-shaft position compared to markers more toward the shaft centre. A recent ergometer analysis

of elite paddlers also used positions based on the most anterior and posterior positions of the paddle (Michael et al., 2012), however, the marking procedures were unclear for replication.
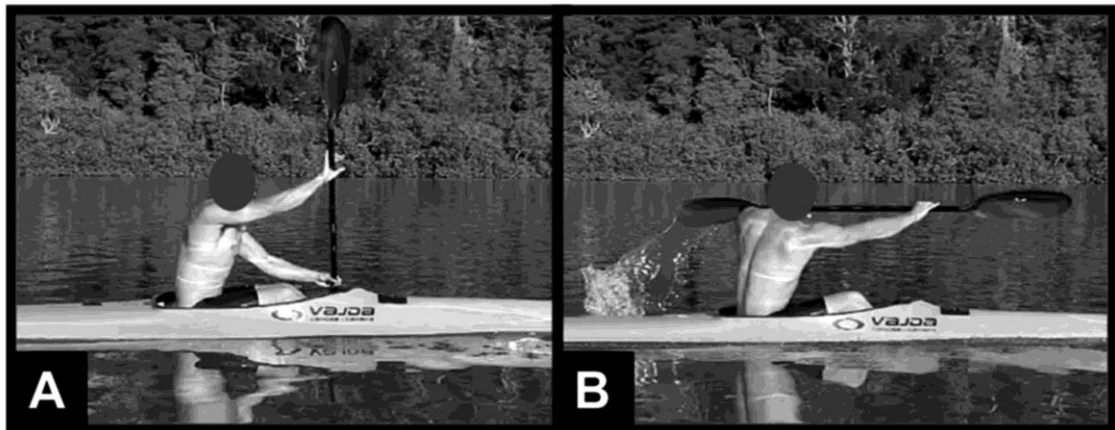
Figure 2.2. Left vertical (A) and left horizontal (B) paddle shaft positions during a left sided stroke are visible from the right side view.

Paddle-shaft defined positions are only visible from the sagittal view. Horizontal and vertical positions are more visible than the most forward and most backward paddle-shaft positions because both right and left sides are clearly visible from the sagittal view of both right and left sides of the paddler, and markers and trajectory tracings are not needed. Depending on technique, size of the paddler, type of marker used, and rotation of the paddle shaft, the opposite side most forward and most backward quarter shaft positions may be obstructed by the paddler or paddle shaft (Table 2.2).

It is noted that researchers may need to use some additional markers to identify each stage of technique if their analyses require it; for example, when performing kinetic analysis and allowing for computer programming issues.

Body defined position

The third grouped position was relative to a body position. The greatest forward reach was defined as when the top hand (left hand during a right sided stroke) stopped moving forward (Plagenhoef, 1979). Plagenhoef (1979) reported this position as the beginning of phase 3, which ended at the release. However, our video analysis of current elite paddlers showed that the top hand continues to move forward until it is no longer technically the top hand, so this position definition was unclear.

For clarity, left greatest forward reach refers to the left hand, while right greatest forward reach refers to the right hand. The left hand during a right sided stroke continues to move forward until just before or sometimes at the left catch. Consequently Plagenhoef's positions were out of order for our elite paddler analysis and phase 3 was eliminated (left greatest forward reach to right release), while phase 2 (right vertical to left greatest forward reach) and phase 4 (right release to left catch) overlapped from right release to left greatest forward reach (Figure 2.3).

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Greatest forward reach was difficult to observe without marker placement, and may also vary, pending the exact location of marker placement or grip width. Theoretically, greatest forward reach should occur at the catch for maximum mechanical efficiency. Although, from our observations when analysing kayak paddling of elite paddlers at a video sampling rate of 300 Hz, posterior displacement of the shoulder initiates just before the catch, then backward displacement of the elbow, and wrist occurs later. The ability of the shoulder, elbow, and wrist to move posteriorly at different times with an outstretched arm may be due to a type of perspective error (parallax), as the elbow and wrist move toward the midline of the body in the transverse plane before moving laterally and posteriorly during the execution of the stroke. The shoulder, elbow and wrist joint centres may also move posteriorly at different times if the arm is not fully extended at the catch. When the blade contacts the water, the hydrodynamic force acting on the blade may cause the arm to extend as the shoulder starts to move posteriorly. The timing of greatest forward reach is expected to vary between individuals given the differences observed between our analysis and Plagenhoef (1979). Although greatest forward reach of any given joint may be important to monitor for mechanical efficiency, it is not an appropriate position to separate phases of the stroke, due to the variation that may occur with the absence of specific marker placement protocols (i.e. use of a hand marker compared to a wrist marker).

Phases

Phases were not always precisely defined in the literature. A phase is the period of time between two positions. One model incorrectly used a single position to define a phase (Logan & Holt, 1985). Applying another model resulted in no differentiation between positions and therefore one phase was limited to a single position (Trevithick et al., 2007). Articles had contradictory images and text (Szanto, 2004), and positions were sometimes described out of order or not defined well enough to interpret (Plagenhoef, 1979), providing confusing descriptions of the stroke. These problems have created unclear observational models with respect to temporal phase division. Our interpretations of these models were illustrated in Figure 2.3. We normalised all models to a single stroke beginning from the right (blade) catch (0%) and ending at the catch of the opposite side (100%). To compare and contrast observational models used between studies, all observational models were normalised to this definition (hence the -20% to 80% range in some models using different stroke start and end points).
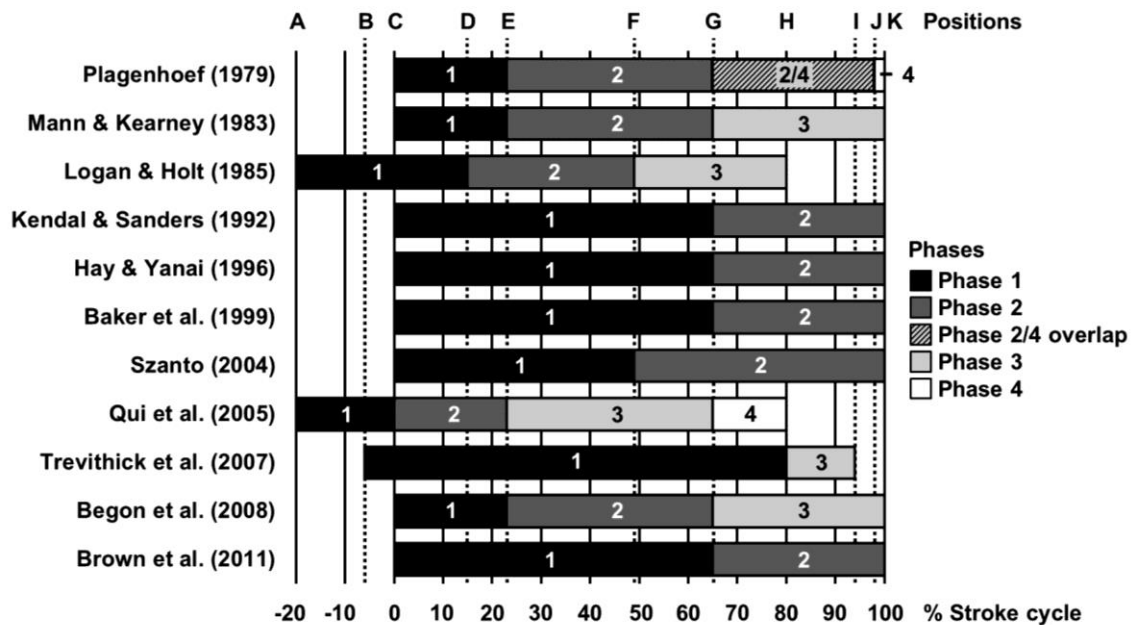
Phase-defining positions: A= left (paddle) horizontal, -20%; B= right most forward (quarter shaft), -6%; C= right (blade) catch, 0%; D= right (blade) immersion, 15%; E= right (paddle) vertical, 23%; F= right (blade) extraction, 49%; G= right (blade) release, 65%; H= right (paddle) horizontal and right most backward (quarter shaft), 80%; I= left most forward (quarter shaft), 94%; J= left (hand) greatest forward reach, 98%; K= left (blade) catch, 100%.

Figure 2.3. Summary of phases defined in the literature and their phase-defining positions, represented as a percentage of single stroke time on the right side, where a single stroke on the right side is defined as beginning from the right (blade) catch (0%) and ending at the catch of the opposite side (100%).

Summary of limitations and benefits of the literature models

Limitations and benefits of the observational models in the literature were summarized in "our interpretation summary" located in Table 2.1. The most important limitations to consider affect the meaningfulness of a technique analysis. Observational models that help with describing the movement patterns in kayaking and align with principles developed from force analysis would be optimal, to allow collaboration between researchers and coaches who may or may not have access to strain gauge technology.

Propulsion of the kayak occurs during the period when the blade is in contact with the water (from catch to release). The majority (70%) of the models differentiate the period of water contact (water phase) from the period when there is no water contact (aerial phase). Among the remaining 30% of the models, both aerial and water phase components were included in at least one of the phases (Logan & Holt, 1985; Szanto, 2004; Trevithick et al., 2007), which can create complex feedback for paddlers based on these models. For example, if interventions require a paddler to shorten the aerial time and lengthen the water time, but a model included

both of these aspects in one phase, the paddler would be asked to shorten one part of the phase while lengthening another.

Among the models separating water and aerial phases, the water phase was often divided into two parts by the vertical paddle-shaft position (Plagenhoef, 1979; Mann & Kearney, 1983; Qiu et al., 2005; Begon et al., 2008). However, there is no clear evidence that the water phase should be divided into two parts by the vertical paddle-shaft position. From a kinetics perspective, it was hypothesized that the most effective stroke force profile would be one where the peak propulsive force was large and quickly achieved, maintained near peak for as long as possible, then reduced to zero as quickly as possible (Michael et al., 2012). From a kinematics perspective, following a primarily downward motion of the pulling hand during blade entry, the main horizontal movement pattern of both right and left hands precedes and follows the vertical paddle-shaft position in the attempt to keep the paddle near vertical for a period of time. Motion of the pulling hand then changes direction to a more upwards motion just before the blade is taken out of the water in an attempt to withdraw the blade as quickly as possible (Mann & Kearney, 1983). Therefore it is unclear why the vertical position should be used to differentiate phases in the stroke.

Within the water phase, propulsive power during a kayak stroke depends on the hydrodynamic force of the paddle blade, which is to a certain degree, dependent on the blade's surface area exposed to the water (Sumner, Sprigings, Bugg, & Heseltine, 2003). This theory supports that increasing the time the paddle blade is completely in contact with the water, and minimizing the time when the paddle blade is partially in contact with the water, may enhance propulsive efficiency by prolonging the duration of the stroke when the hydrodynamic force of the paddle blade is greatest. The model described by Szanto (2004), uses sub-phases to differentiate these water contact positions, however the overall model was unclear given the recovery phase was described as the period of time when no propulsive forces occurred, but included a period of water contact time. The sub-phases were reported in Table 2.1, but not in Figure 2.3 because some sub-phases were defined by muscles relaxing and firming which was not clearly visible.

A clear two-phase model exists, however a clear model for further division that is relevant to performance does not exist. Limitations of visibility may be partially responsible for the variation of models observed among the literature (Figure 2.3). Most studies that assessed technique analysed sagittal plane kinematics, and consequently not all water-contact positions were visible on the opposite side. Designing a model based on equipment or environmental limitations without regard to applications for performance is not appropriate.

Some research was limited to having only one camera, therefore all positions used in that model to define phases for temporal analysis had to be visible in one camera view. The environment poses a limitation for analysing kayak technique. If kayak technique is analysed on the kayak ergometer, water-contact defined positions cannot be used, given there is no paddle blade in the water. Some researchers, however, have been able to estimate water-contact positions on the ergometer based on the paddle shaft positions (Trevithick et al., 2007; Michael et al., 2012). These modelling techniques need to be described in greater detail.

Kayak-mounted cameras are best for assessing temporal characteristics over many strokes. Land-based cameras, require the paddler to paddle straight toward the camera, and are better for analysis of position data over a short duration (two strokes) because the camera is placed further away to reduce perspective error for position measures. Land-based cameras videoing from the frontal plane can supplement sagittal plane video when the view of the blade becomes obstructed by the kayak in quantitative analysis (Kendal & Sanders, 1992). Though ergometer kayaking may be acceptable for mechanically simulating kayaking during inclement weather (Stothart, Reardon, & Thoden, 1986; Sousa, Roriz, & Goncalves, 1996), the similarities between specific ergometers and on-water kayaking have not been clearly stated nor have large populations been investigated.

We suggest that differences between the definitions of phases used between researchers may have been partially dependent on their equipment limitations (if any) or environmental limitations.

Suggested model

Given the limitations and benefits of models presented in the literature from the review, and confirmation of positions described in the kayak literature being visible from certain camera views (front, right side, left side, back, and oblique angles) via assessment of video of two elite paddlers, we now suggest a well-defined observational model to provide a consistent basis for the categorisation and analysis of sprint kayak technique.

Phases describe a period of time within the stroke cycle, while sub-phases are phases within a larger phase. Phase-defining positions describe the instantaneous moment in time that define the beginning and end points of the phases and sub-phases of the stroke. Phase-defining positions should be clear and easy to determine without the use of markers or expensive motion analysis systems to bring consistency between researchers and coaches.

We suggest a two-tiered model allowing basic or more detailed division of the stroke (Figure 2.4). The basic two-phase model consisting of the water phase (from catch to release) and aerial phase (from release to the opposite side catch) should be used by all researchers and practitioners when describing the stroke. This is consistent with 70% of the observational models presented in the literature to date.

For greater division of the stroke, the water phase should be separated based on water-contact of the blade given the greater visibility of these positions, and because the blade force is presumably greatest during the time the blade is fully buried. Therefore the water phase was divided into the entry, pull and exit phases (Figure 2.4) to provide an optional detailed division of the stroke. Spatial aspects of movement should be described relative to when they occur within the phases or sub-phases.

When biomechanics research has supported that certain kayak stroke positions are critical for kayak performance (e.g. potentially the timing of greatest forward reach), these positions can be added to the model to create a third level to describe key positions. Key positions differ from phase-defining positions in that they do not define the beginning and end

points of a phase or sub-phase, but describe an instantaneous moment in time that may be important to performance. If a period of time is important, then this can be referred to as a time-dependent critical feature and reported as a variable rather than a phase or sub-phase. This will allow normalisation of all biomechanical results toward the same temporal observational model, which is important for the growth of research and effective use of systematic observation strategies for coaches.
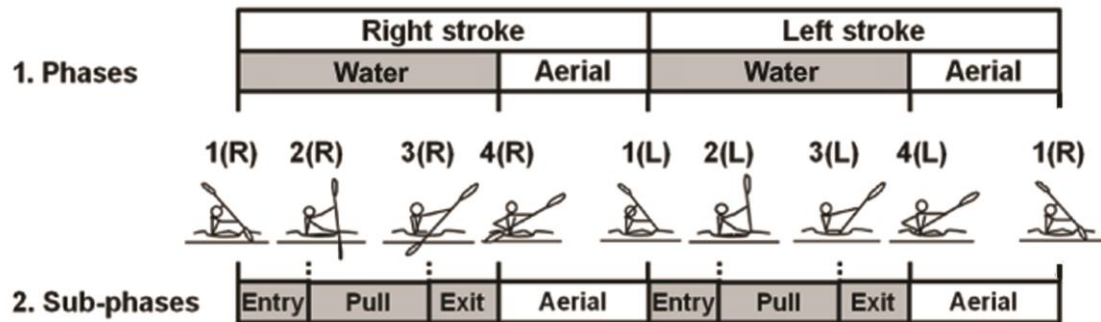
The phase defining positions are: catch (1); immersion (2); extraction (3); and release (4). (R)= right side; (L)= left side.

Figure 2.4. Observational model for kayak analysis including two levels of analysis: Phases and sub-phases.

Conclusions

The mechanical objective of kayaking is to finish the race in the least amount of time (in other words: to have the fastest average boat velocity). Kayaking data should be reported using single strokes and described using two phases (level one): water and aerial. For more detailed analysis without disrupting the basic two phase model, a four part model consisting of entry, pull, and exit sub-phases, and the aerial phase can be used (level two). The phase-defining positions (catch, immersion, extraction and release) in this model were visible from multiple camera views (e.g. oblique, frontal), therefore are suitable for both research and practical use by coaches. All descriptions of paddling should use a level one analysis, with level two used for detailed analyses. The chosen model (level one or level two) should be clearly defined within the methodology section of original research papers or relevant stroke description section of a review. Clear definitions require a stroke definition with a start and end point, followed by clear definitions of phase-defining positions, and phases should be described with a specific start and end point.

The growth of biomechanical research in kayaking depends on the cooperation of researchers using this model. When biomechanics research has determined key kayak stroke positions that describe an instantaneous moment in time important to performance (e.g. potentially the timing of greatest forward reach), these key positions can be added to the model to create a third level.

Chapter 3: A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance

This chapter has been published as:

Overview

The aim of this narrative review was to propose a deterministic model based on a review of previous research documenting the evidence for the associations between average kayak velocity and kinematic variables in sprint kayaking. Literature was reviewed after searching electronic databases using key words 'kayak,' 'biomechanics,' 'velocity,' 'kinematics,' and 'performance.' Our kinematic deterministic model for sprint kayaking performance shows that the average kayak velocity is determined by kayak stroke displacement and stroke time. Stroke time had the strongest correlation with 200-m race time ($r = 0.86$, $p < 0.001$), and stroke rate (inversely proportional to stroke time) was strongly correlated with average horizontal velocity over two consecutive strokes at race pace ($r = -0.83$, $p < 0.05$). Increased stroke rate via decreased absolute water phase time and increased relative water phase time were indicative of more elite performance. There was no significant relationship between stroke displacement and velocity; however, a large decrease in stroke displacement may be detrimental to performance. Individual characteristics may be responsible for a paddlers' ability to achieve and sustain a given stroke rate. Coaches should theoretically focus interventions on increasing stroke rate while maintaining stroke displacement; however this hypothesis should be confirmed with prospective studies.

Introduction

Flat-water kayaking is a variant of canoeing, in which the paddler is seated in a one, two, or four person kayak (K1, K2, or K4), and uses a two-bladed paddle for propulsion through reasonably calm water. Flat-water kayaking was introduced to the Olympic program in 1936 for 1000-m and 10,000-m race distances (Szanto, 2004). Over the years, the introduction of shorter event distances to the Olympic program and equipment advancements has led to reduced performance times. Today, what we now know as 'sprint kayaking' is competed over 200-m, 500-m, and 1000-m distances at the World Cups and World Championships regattas. Olympic men's sprint kayak events are now 200-m and 1000-m, while women compete over 200-m and 500-m event distances. The London Olympic Games in 2012 featured the 200-m event for the first time on the Olympic program for both men and women.

Advancements in kayak hull shapes, materials, and sizes have led to stronger, lighter, and subsequently more efficient equipment with noticeable decreases in Olympic winning 1000-

m race times (Michael et al., 2009). The introduction of the wing blade in the mid-1980s to replace the flat blade has revolutionized the stroke. The foil shaped wing blade allows paddlers to utilize a lift force for propulsion if the paddle blade is guided in a more lateral direction away from the kayak (Kendal & Sanders, 1992). This technique change has required biomechanists to reinvestigate the mechanics of sprint kayaking, as previous research using the flat blade has been rendered obsolete.

Since the introduction of the wing blade, literature reviews of kayaking biomechanics research have been limited to one publication; propulsive power and drag force were identified as the key determinants of average kayak velocity (the performance criterion) in the literature review on biomechanical determinants of sprint kayaking performance (Michael et al., 2009). Performance can be improved by increasing the propulsive power, reducing drag forces by optimising the power to weight ratio of the paddler or by minimizing unnecessary accelerations and rotations along all axes of the kayak (Michael et al., 2009). One major issue for the application of this information to coaches is that there is not enough evidence that commercially available products have an acceptable level of validity for measuring intra-stroke velocity, acceleration, or paddle force measures of elite paddlers.

Four GPS-based accelerometers underreported kayak intra-stroke velocity by 0.14–0.19 m/s, resulting in a 3% reduction in velocity when compared to velocity measurements derived from video (Janssen & Sachlikidis, 2010). Changes greater than 1% race time or average velocity are meaningful changes for elite sprint kayakers (Bonetti & Hopkins, 2010); therefore, these devices are not suitable for valid measurements of kayak velocity or acceleration for elite paddlers, and coaches should be cautious when using these devices (Janssen & Sachlikidis, 2010). More developments and research are needed in the area of GPS-based technology and instrumented paddle systems, as these devices will be useful for coaches and athletes in the future if reliability and validity measures can be improved. While improvements in technology are being achieved, coaches should be provided with information on performance determinants that can be measured easily with video.

From a kinematics perspective, velocity is a product of kayak displacement per stroke and stroke time. To date, no literature reviews have gathered and presented the evidence for correlations between these kinematic variables and velocity or race time to guide future research toward meaningful approaches for improving sprint kayaking performance. The aim of this narrative review was to propose a deterministic model based on a review of previous research documenting the evidence for the associations between average kayak velocity and kinematic variables in sprint kayaking.

Methods

A narrative review approach was undertaken with 165 references reviewed after searching SportsDiscus, ProQuest Direct, and Google Scholar, from 1975 to June 2012 using key words 'kayak,' 'biomechanics,' 'velocity,' 'kinematics,' and 'performance.' Inclusion criteria for all articles were: (1) the article must have provided information towards enhancing

performance in sprint kayaking; (2) the article must include an aspect of biomechanics relevant to the aim of this paper; and (3) the article must be available in English. After meeting the inclusion criteria, some conference communications were excluded if they did not have sufficient information in the methodology section to support their findings, or if general conclusions were made without reporting results. Additional information was sought by manually searching through article reference lists. Two unpublished reports to the U.S. Olympic Committee and U.S. Canoe and Kayak Team were obtained through personal communication with field experts, but one report was excluded given it was a methods paper and did not contribute relevant information toward enhancing performance. One relevant book, 29 journal articles, four conference proceedings, and one unpublished report were retained after determining the relevance to the aim of this paper. Statistically significant correlation coefficients less than 0.7 in magnitude were considered not noteworthy and excluded in the discussion of anthropometry and performance findings.

Deterministic model

Biomechanical deterministic models should be composed of mechanical quantities directly relating to performance, and all factors at one level should completely determine the factors included at the next highest level (Chow & Knudson, 2011). The ultimate performance criterion for sprint kayaking is race time. Race time and average kayak velocity of a given race distance are inversely proportional, so both can be used as criteria of performance. When kayak velocity is used as a performance criterion, it is a linear velocity measure in the direction of the finish line, and all velocities discussed in this paper occur in this direction. We developed our deterministic model based on the velocity equation: velocity = displacement/time. Average kayak velocity of a race is determined by the average kayak velocity of each stroke, which is determined by kayak displacement over time, which can be measured via kayak stroke displacement and stroke time. Spatial aspects of movement should be described relative to when they occur within the phases and subphases (McDonnell, Hume, & Nolte, 2012a); therefore our deterministic model continues to break down the performance variables by phase and subphase (Figure 3.1). Our proposed deterministic model shows the reported relationships from two studies that have found correlations between the performance variable in the lower boxes and average kayak velocity (Mononen & Viitasalo, 1995; Hay & Yanai, 1996).

Average kayak velocity

In the research collated, the average kayak velocity was usually measured by one of the two ways: (1) either over two consecutive strokes on-water at some point during a race-paced or maximal effort sprint, which was termed average kayak velocity (Kendal & Sanders, 1992; Hay & Yanai, 1996; Baker et al., 1999) or (2) calculated from the total race time from a standard race distance, which was termed average race velocity (Mononen & Viitasalo, 1995; Timofeev, Gorodetsky, Sokolov, & Shklyaruk, 1996; Brown et al., 2011). It is important to note that kayak

velocity fluctuates throughout a race, and kayak velocity of any two strokes may or may not reflect the average race velocity.
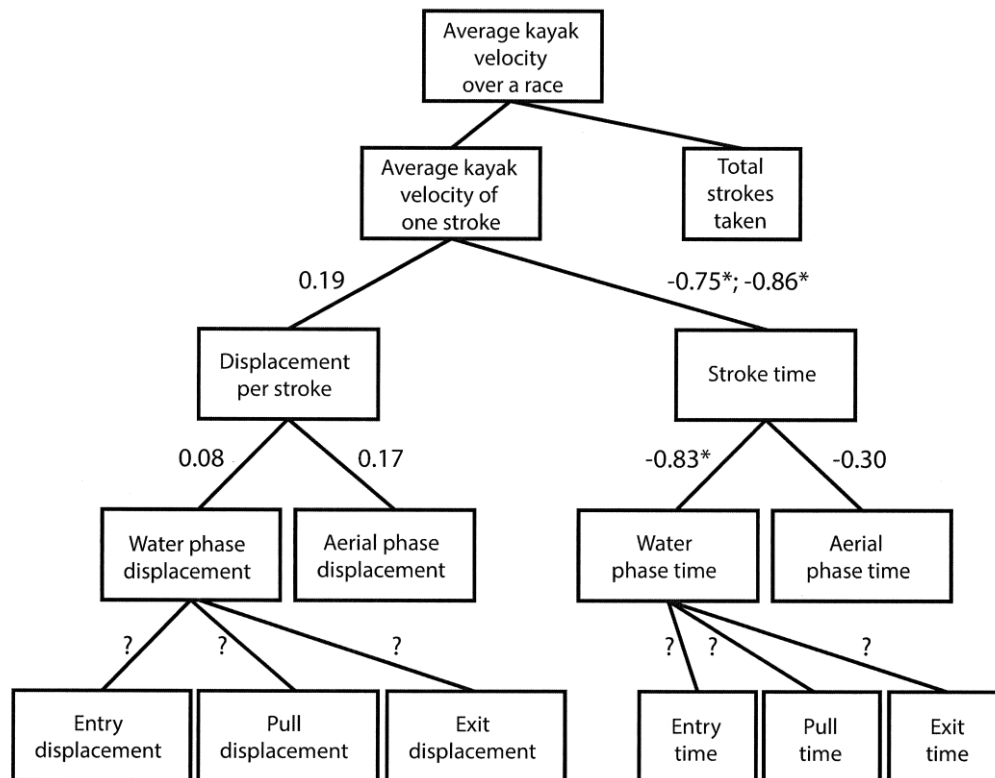
Correlations are shown between the variable in the lower box and average kayak velocity of one stroke (*indicates statistical significance, p < 0.05). The correlation r = -0.86 was from Mononen and Viitasalo (1995), all other correlations were from Hay and Yanai (1996), and all researchers assumed that the stroke analyzed reflected average race pace.

Figure 3.1. A kinematic deterministic model for average boat velocity in sprint kayaking.

Stroke displacement

Stroke displacement (also known as displacement per stroke) is the displacement of the kayak from the catch of one side to the catch of the opposite side. Stroke displacement is composed of water phase displacement and aerial phase displacement (Kendal & Sanders, 1992). Normative stroke displacement values reported among the literature were limited to five studies which displayed data for a variety of testing protocols (Table 3.1). Data from a study reporting stroke length on the ergometer were not included, given the exact methods for measuring stroke length were not clear (Michael et al., 2012). Using mean values from Table 3.1 revealed no significant correlation or tendencies between stroke displacement and kayak velocity ($r = -0.19$, $p = 0.62$). Data were limited to two studies that attempted to determine a relationship between these two variables (Kendal & Sanders, 1992; Hay & Yanai, 1996) and descriptive studies that measured stroke displacement and velocity to compare different field

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tests or gender. Although Hay and Yanai (1996) reported no significant correlation between stroke displacement and velocity for grouped data (n = 10), they reported one case of a male paddler where stroke displacement had a strong negative correlation with velocity (r = -0.77, p < 0.05), indicating that stroke displacement shortened at higher velocities. Another within-paddler investigation showed shorter stroke displacement in testing protocols with higher average kayak velocities (Bourgois, Van Renterghem, Janssens, Vrijens, & De Blieck, 1998), and the higher average kayak velocities were attributed to a higher stroke rate (Hay & Yanai, 1996; Bourgois et al., 1998). In contrast, a between-paddler investigation showed longer displacement in male paddlers who had greater average kayak velocities compared to female paddlers, and stroke rate was not significantly different between genders during the two strokes analysed (Baker et al., 1999). Longer displacement in male paddlers was attributed primarily toward a longer aerial phase displacement and higher kayak velocity, but no direct associations were reported (Baker et al., 1999). The existing evidence is mixed for the strength of the association between stroke displacement and performance.

Water phase displacement

Water phase displacement is the kayak displacement from the catch to release. Hay and Yanai (1996) reported no significant correlation between water phase displacement and average kayak velocity for a grouped analysis (n = 10; r = 0.08, p > 0.05) or for an individual case study (elite male; r = -0.01, p > 0.05). When two studies are compared, water phase displacement appears to be larger in female paddlers with greater kayak velocities (Hay & Yanai, 1996; Baker et al., 1999); however, tendencies are not clear for male paddlers. Data from the study of Timofeev et al. (1996) showed lower average race velocity, despite a large water phase displacement, when compared with data from other studies using male paddlers in Table 3.1. Not enough data exists to determine a relationship or general trend between water phase displacement and velocity or stroke displacement (Table 3.1).

Water phase displacement can be broken down into the displacement of the kayak during each subphase (entry, pull and exit); however, there were no data available for kayak displacement for each subphase. Water phase displacement had been previously broken down into three components: forward reach, backward reach and slip (Kendal & Sanders, 1992).

Forward reach was defined as the horizontal displacement of the blade tip at the catch relative to the middle of the kayak's length (Kendal & Sanders, 1992). Quantitative data for forward reach (1.01 ±0.06 m) was limited to one study (Kendal & Sanders, 1992). Brown et al. (2011) defined forward reach by how far forward the paddle entered the water in reference to the front of the cockpit of the kayak for a qualitative assessment. Although forward reach was not significantly correlated with performance due to low sample size (n = 5), more successful paddlers entered their blade further forward than less successful paddlers (Kendal & Sanders, 1992), and greater forward reach was qualitatively observed to be indicative of higher performance levels (Brown et al., 2011).

Table 3.1. Quantitative measures of stroke displacement in sprint kayaking arranged in order from maximum to minimum mean kayak velocity in the direction of the finish line (Mean ± SD).

Mean kayak velocity (m/s)	Protocol	Gender; boat; sample number; level	TSD (range)[a] (m)	WSD (range)[a] (m)	ASD (range)[a] (m)	Study
5.16	Race pace[b]	Male; K1; 6; Elite	2.62 ±0.09 (2.52-2.75)	1.68 ±0.05 (1.62-1.75)	0.93 ±0.11 (0.77-1.06)	Hay and Yanai (1996)
4.99	Max velocity[c]	Male; K1; 5; Elite	2.43 ±0.09 (2.32-2.55)	1.70 ±0.08 (1.61-1.81)	0.74 ±0.08 (0.67-0.88)	Kendal and Sanders (1992)
4.94	1000-m race pace[c]	Male; K1; 6; Elite & National	2.66 ±0.19	1.62 ±0.16	1.04 ±0.06	Baker et al. (1999)
4.78	30 s trial	Male; K1; 11; Elite & National	2.32 ±0.13	-	-	Bourgois et al. (1998)
4.60	Race pace[b]	Female; K1; 4; Elite	2.50 ±0.18 (2.30-2.71)	1.64 ±0.11 (1.52-1.74)	0.86 ±0.11 (0.72-0.98)	Hay and Yanai (1996)
4.53	60 s trial	Male; K1; 11; Elite & National	2.45 ±0.07	-	-	Bourgois et al. (1998)
4.50	500-m race pace[c]	Female; K1; 4; Elite & National	2.47 ±0.16	1.54 ±0.08	0.93 ±0.09	Baker et al. (1999)
4.19	120 s trial	Male; K1; 11; Elite & National	2.55 ±0.11	-	-	Bourgois et al. (1998)
3.97	1000-m time trial	Male; K1; 13; Elite	2.68[d]	1.70 ±0.29 (1.58-1.77)	-	Timofeev et al. (1996)

TSD = total stroke displacement of the boat per stroke, WSD = water phase stroke displacement, ASD = aerial phase stroke displacement, SD = standard deviation. [a] Range not available in Baker et al. (1999) and Bourgois et al. (1998); [b] Paddlers had >30 m to accelerate to race pace (of an unknown target race distance) before entering a calibrated zone where velocity and stroke displacement data were calculated for two consecutive strokes; [c] Paddlers had 200 m to accelerate to the required pace (max velocity, 1000-m race pace, or 500-m race pace) before entering a calibrated zone where velocity and stroke displacement data were calculated for two consecutive strokes; [d] Stroke displacement was calculated for Timofeev et al. (1996) based on mean stroke rate and race time.

Backward reach is the horizontal displacement of the blade tip at the release position relative to the centre of the kayak (Kendal & Sanders, 1992). Backward reach (0.82 ±0.08 m) was shorter than forward reach and was regarded as the less efficient part of the water phase (Kendal & Sanders, 1992). As the paddle blade is directed laterally away from the kayak during the water phase, it eventually becomes too difficult to apply the necessary propulsive force to continue to accelerate or maintain a constant velocity of the kayak, and a quick removal of the blade is necessary to prevent further drag. Paddlers with a shorter backward reach had a more effective stroke technique (Kendal & Sanders, 1992), but shortening backward reach too much may reduce overall water phase displacement enough to negatively affect performance.

Theoretically, paddlers may improve performance by becoming strong enough so that backward reach becomes more effective, or by limiting the stroke just before backward reach becomes ineffective. The time when backward reach becomes ineffective is unknown, and would rely on force-time measures of the water phase of the kayak stroke. It is likely that this time will vary widely among individual paddlers based on technique style, strength, equipment, and anthropometric characteristics.

Increasing forward reach and backward reach alone, do not guarantee greater water phase displacement, unless slip of the blade in the water is small. Slip was defined as the backward horizontal displacement of the blade tip in the water (Kendal & Sanders, 1992), and shown as a negative value to emphasise the backward direction of the paddle tip. Slip can be calculated from position data of the kayak and blade tip, when the blade tip is visible at the catch and release (slip = water phase displacement - forward reach - backward reach). Slip has ranged between -0.07 to -0.22 m, with the magnitude smaller for higher kayak velocities (Kendal & Sanders, 1992). Researchers should focus on the kinematic characteristics of technique that lead to reduced slip (or maximised lift), so that coaches can provide quick effective feedback to their paddlers without having to collect kayak or blade tip position data.

Aerial phase displacement

Aerial phase displacement refers to the displacement of the kayak during the aerial phase of the paddle. The aerial phase displacement ranged from 0.67 to 1.06 m, and was not related to average kayak velocity or other factors responsible for kayak velocity in studies analysing data for a group of paddlers (sample sizes ranged from 5 to 10) (Kendal & Sanders, 1992; Hay & Yanai, 1996). Greater aerial phase displacements occurred for male paddlers (1.04 ±0.06 m) compared to female paddlers (0.93 ±0.09 m), while maintaining similar aerial times for both males and females (Baker et al., 1999). The difference in aerial phase displacement was attributed to greater kayak velocity for males during the aerial phase, which was developed during the water phase via shortened water phase time (Baker et al., 1999). Shortening aerial phase time may be more important than increasing aerial phase displacement given the deceleration of the kayak during the aerial phase. The single male case study by Hay and Yanai (1996) showed a nearly perfect correlation between aerial phase displacement and average kayak velocity ($r = -0.93$, $p < 0.05$), with the strongest relationship occurring between aerial time

and average boat velocity (r = -0.98, p < 0.05), indicating that shortening aerial phase time and aerial displacement would likely lead to greater average boat velocities for this individual.

Stroke time

Stroke rate is more commonly used than stroke time in kayaking. Stroke rate is inversely proportional to stroke time (stroke rate = 1/stroke time), and is usually displayed as the number of strokes per minute (spm).

Studies reporting stroke rate and timing variables at maximal kayak velocity, race pace or during competition, using modern equipment (i.e. wing blade) on water were summarised in Table 3.2. Grouped results were listed in order of highest to lowest velocity, given studies often reported descriptive results of groups varying in skill, gender, and race distance. There was no significant difference in stroke rate between right and left sides for 32 elite male and 32 elite female paddlers participating in the Duisberg 2004 World Cup regatta, so assessing stroke rate of both or either side is acceptable in sprint kayaking (Qiu et al., 2005). Qiu et al. (2005) did not report kayak velocity or race time, however the 200-m relay MK1 stroke rate (141 spm) and 200-m relay WK1 stroke rate (128 spm) were similar to the 200-m elite MK1 stroke rate (138 spm) and 200-m elite WK1 stroke rate (128 spm) reported by Brown et al. (2011).

There was a large association between stroke rate and kayak velocity (r = 0.66, p < 0.01) using mean data from Table 3.2, which was not as high as expected. In one study, the average race velocity was calculated based on the total race time and race distance, while the stroke rate was measured over an unknown number of strokes 100 m before the finish line (Brown et al., 2011). The remaining studies reported velocity and stroke rates that were collected at the same time (either both variables were collected over a span of two strokes or both were collected over the full race distance). When excluding data reported by Brown et al. (2011), there was a very large association between stroke rate and average kayak or race velocity (r = 0.89, p < 0.01). This was in agreement with the very large association (r = 0.86, p < 0.001) reported by Mononen and Viitasalo (1995) and the very large association (r = 0.75, p < 0.05) reported by Hay and Yanai (1996).

Stroke rate collected at 100-m from the finish line may not be the best indicator of overall race performance. Plagenhoef (1979) suggested a good place for investigating the kinematics of the kayak stroke was three quarters into the race distance, though no data were presented to show that this distance was optimal.

The ability to increase stroke rate is likely important for enhancing kayak race time. Over a two-min all-out kayak ergometer test, elite male paddlers showed a non-significant increase in stroke rate as peak paddle force declined (Michael et al., 2012). An understanding of within-race variability of stroke rate is needed to design better testing/monitoring protocols for researchers, coaches, and paddlers.

Table 3.2. Quantitative measures of stroke rate (spm) during maximal velocity, competition and time-trials in sprint kayaking arranged in order from maximum to minimum mean kayak velocity in the direction of the finish line (Mean ± SD).

Average kayak velocity (m/s)	Protocol[a]	Level	Gender, boat & sample size	SR (spm)	ST (s)	ST_W (s)	ST_A (s)	Study
5.16[c]	Race pace[e]	Elite	MK1; 6	118	0.51	0.32 ±0.02	0.19 ±0.03	Hay & Yanai (1996)
5.13[b]	200-m race[d]	Elite	MK1; 46	138 ±6.8	0.44 ±0.02	0.24 ±0.03	0.20 ±0.03	Brown et al. (2011)
5.06[b]	500-m race[d]	Elite	MK1; 46	121 ±6.4	0.50 ±0.03	0.28 ±0.03	0.22 ±0.03	Brown et al. (2011)
4.99[c]	Max velocity[e]	Elite	MK1; 5	122 ±8.0	0.49 ±0.03	0.34 ±0.03	0.15 ±0.02	Kendal & Sanders (1992)
4.94[c]	1000-m pace[e]	Elite & National	MK1; 6	113 ±9.7	0.53 ±0.03	0.32 ±0.03	0.21 ±0.01	Baker et al. (1999)
4.78[b]	30 s all-out	Elite	MK1; 11	124 ±8	0.48 ±0.03	-	-	Bourgois et al. (1998)
4.60[c]	Race pace[e]	Elite	WK1; 4	110 ±10.8	0.55 ±0.05	0.35 ±0.03	0.19 ±0.03	Hay & Yanai (1996)
4.58[b]	200-m race[d]	National	MK1; 29	121 ±9.4	0.50 ±0.04	0.25 ±0.05	0.25 ±0.04	Brown et al. (2011)
4.53[b]	60 s all-out	Elite	MK1; 11	111 ±4	0.54 ±0.02	-	-	Bourgois et al. (1998)
4.50[c]	500-m pace[e]	Elite & National	WK1; 4	110 ±9.0	0.55 ±0.05	0.34 ±0.02	0.21 ±0.03	Baker et al. (1999)
4.50[b]	200-m race[d]	Elite	WK1; 32	128 ±10.8	0.47 ±0.04	0.24 ±0.03	0.24 ±0.02	Brown et al. (2011)
4.46[b]	500-m race[d]	Elite	WK1; 32	115 ±8.4	0.53 ±0.04	0.29 ±0.03	0.24 ±0.03	Brown et al. (2011)
4.40[b]	500-m race[d]	National	MK1; 29	113 ±7.2	0.54 ±0.04	0.31 ±0.03	0.23 ±0.02	Brown et al. (2011)
4.19[b]	120 s all-out	Elite	MK1; 11	99 ±4	0.61 ±0.02	-	-	Bourgois et al. (1998)
4.15[b]	200-m race[d]	National	WK1; 9	118 ±6.0	0.51 ±0.03	0.28 ±0.01	0.24 ±0.02	Brown et al. (2011)
4.10[b]	500-m race[d]	National	WK1; 9	117 ±6.4	0.52 ±0.03	0.29 ±0.03	0.24 ±0.01	Brown et al. (2011)
3.97[b]	1000-m trial	Elite	MK1; 13	89 ±4.7	0.67 ±0.04	-	-	Timofeev et al. (1996)
3.87[b]	200-m race[d]	Club	WK1; 10	114 ±9.4	0.53 ±0.03	0.27 ±0.03	0.26 ±0.02	Brown et al. (2011)
3.72[b]	500-m race[d]	Club	MK1; 9	100 ±9.8	0.60 ±0.06	0.32 ±0.05	0.29 ±0.04	Brown et al. (2011)
3.45[b]	500-m race[d]	Club	WK1; 10	102 ±9.8	0.60 ±0.06	0.30 ±0.03	0.30 ±0.06	Brown et al. (2011)
Not reported	200-m relay[d]	Elite	MK1; 15	141	0.43	0.28	0.15	Qiu et al. (2005)
Not reported	200-m relay[d]	Elite	WK1; 16	128	0.47	0.32	0.15	Qiu et al. (2005)

SR = stroke rate, SD = standard deviation, ST = stroke time, ST_W = water phase time, ST_A = aerial phase time, M = men, W = women, K1 = single paddler kayak. [a] Paddlers either performed in a race, a time trial, at a given pace, or over a period of time; protocols without superscripts indicated that stroke rate and stroke time data were collected for the full length of the trial; [b] Mean boat velocity was calculated from total trial time and kayak displacement; [c] Mean boat velocity was determined from video data of two consecutive strokes; [d] Stroke rate and stroke time data were collected 100 m before the finish line; [e] Stroke rate and stroke time data were collected over two consecutive strokes within a calibrated area after an initial acceleration period between 30-200 m.

Water phase time

Stroke time is composed of water phase time and aerial phase time. Water phase time is the time from the catch to release. In the literature there were two distinct ways of reporting water phase time. Absolute water phase time was reported in seconds and relative water phase time was reported as a percentage of the stroke cycle. Among the studies that collected velocity and stroke time data over the same period, fewer reported water phase times, so there was not enough data to determine an overall relationship. However, Hay and Yanai (1996) reported a very large correlation between average water phase time and average kayak velocity ($r = -0.83$, $p < 0.05$) for a group of 10 elite paddlers (six males; four females), indicating that shorter water phase times were associated with higher kayak velocity.

Among men's K1 500-m paddlers during competition, mean absolute water phase time was significantly shorter for international level (0.28 ±0.03 s) compared to national level (0.31 ±0.03 s) and club paddlers (0.32 ±0.05 s) (Brown et al., 2011). There were no significant differences in absolute water phase time between international (0.24 ±0.03 s) and national level (0.25 ±0.05 s) for the men's K1 200-m event (Brown et al., 2011). There were also no significant differences in mean absolute water phase time for the women's K1 500-m event between international (0.29 ±0.03 s), national (0.29 ±0.03 s) or club paddlers (0.30 ±0.03 s) (Brown et al., 2011). In the women's K1 200-m event, mean absolute water phase time appeared to be shorter among international (0.24 ±0.03 s) compared to national level paddlers (0.28 ±0.01 s), but was not statistically significant (Brown et al., 2011). Longer absolute water phase times were reported in elite males at maximal effort (0.34 ±0.03 s) (Kendal & Sanders, 1992) compared with those reported in elite males during K1 200-m (0.24 ±0.03 s) and 500-m (0.28 ±0.03 s) competition (Brown et al., 2011). When matched with the stroke rates for men's K1 500-m international paddlers reported by Brown et al. (2011), longer absolute water phase times reported by Kendal and Sanders (1992) were attributed to greater relative water phase times (69% compared to 56%).

Brown et al. (2011) reported the lowest relative water phase times; male 200-m, male 500-m, and female 500-m paddlers' relative water phase time averaged approximately 55%, and female 200-m paddlers averaged 50% among international level paddlers. Collecting data during competition was explained to have caused a difference in results (Brown et al., 2011) compared to Kendal and Sanders (1992) who reported a mean relative water phase time of 69% at maximal effort paddling, after a self-chosen distance greater than 50 m. Qiu et al. (2005) also reported relative water phase time during competition (male 200-m relay: 65%; female 200-m relay: 66 to 69%), which was closer to the 69% relative water phase time reported by other studies using both the flat blade and wing paddle (Plagenhoef, 1979; Kendal & Sanders, 1992). We also calculated a relative water phase time of 63% for elite male paddlers and 64% for elite female paddlers using data from Hay and Yanai (1996). Despite these differences in normative data between studies, Brown et al. (2011) proposed that shorter absolute water phase time (s) and longer relative water phase time (%) were associated with better performance.

Aerial phase time

Aerial phase time includes the time when the blade is not in contact with the water (Plagenhoef, 1979). The aerial phase has also been termed the recovery, glide, or run phase, however, given the definition (paddle out-of-water phase), the term "aerial" may be better suited. Like water phase time, there are two distinguishing measures of aerial phase time. Absolute aerial time refers to the time spent in the aerial phase in seconds, while relative aerial time refers to the time spent in the aerial phase as a percentage of the total stroke. Since higher stroke rates (less total stroke time) and greater relative water phase time are important for improving kayak velocity (Brown et al., 2011), then reducing both absolute and relative aerial times should also be important for improving kayak velocity. Shorter aerial phase times would reduce the time spent decelerating the kayak, given peak kayak velocity occurs before the blade exits the water, and the kayak decelerates during the entire aerial phase (Aitken & Neal, 1992; Kendal & Sanders, 1992). In a single case study of an elite male paddler, a nearly perfect correlation existed between aerial phase time and average kayak velocity ($r = -0.98$, $p < 0.05$), supporting that shorter aerial phase times were associated with greater boat velocity (Hay & Yanai, 1996). This finding did not apply to grouped results ($r = -0.30$, $p > 0.05$) (Hay & Yanai, 1996).

In competition, absolute aerial times ranged from 0.20 to 0.24 s among international level paddlers, 0.23 to 0.25 s among national level paddlers, and 0.26 to 0.30 s among club paddlers for the male and female K1 500-m and 200-m events (Brown et al., 2011). These absolute aerial phase times were longer than reported by Kendal and Sanders (absolute aerial time: 0.13 to 0.18 s). Both studies incorporated the use of the modern wing paddle blade design. Given similarities in stroke rate, the differences were due to a shorter relative aerial time reported by Kendal and Sanders (1992).

The best international paddlers had a relative aerial time of 31% of the stroke cycle during competition before the wing paddle blade design was introduced (Plagenhoef, 1979), and relative aerial time ranged 28 to 35% for elite paddlers not in competition after the wing paddle design was introduced (Kendal & Sanders, 1992; Hay & Yanai, 1996). During competition utilizing the wing paddle blade, there was a large difference of relative aerial phase times reported between studies. Qiu et al. (2005) reported 35% relative aerial time for male paddlers during competition, and 33% aerial time for female paddlers during competition. In contrast, Brown et al. (2011) reported an average relative aerial time of 55 to 56% in male 200-m and 500-m events, and 46 to 50% in female 200-m and 500-m events. Though Brown et al. (2011) reported longer relative aerial times compared to other studies, shorter absolute (s) and relative (%) aerial times were indicative of more elite men.

Characteristics of the paddler-kayak-paddle

Achieving an optimal stroke rate and displacement combination for peak performance is likely to vary depending on individual characteristics of the paddler, kayak and paddle (Table

3.3). Some of these characteristics have been investigated with regard to their correlation with performance time; however no characteristics have been correlated with stroke rate or stroke displacement. Indirect evidence from studies on anthropometry (Fry & Morton, 1991; Van Someren & Howatson, 2008) and equipment set-up (Ong, Elliott, Ackland, & Lyttle, 2006) supports that these characteristics may influence stroke rate or stroke displacement.

Table 3.3. Physical characteristics of the paddler, kayak and paddle.

Characteristic	Specific characteristics that may influence kinematics
Paddler	
Anthropometry	Mass, stature, girths, segment lengths, and body composition.
Strength	Maximum strength and strength endurance.
Physiology	Muscular control of movement, neurological control of movement, energy systems, cardiovascular system, and adaptations to training.
Kayak	
Material	Wood, fibreglass, carbon, Kevlar, honeycomb, combination of structural materials, and material coatings on the hull (regulated by international racing rules).
Size	Mass, width and length (regulated by international racing rules).
Hull shape	Rounded and v-shape.
Seat	Flat seat and swivel seat.
Footbar	Footbar distance to seat, surface area of footbar, and angle of footbar.
Paddle	
Material	Wood, fibreglass, carbon, Kevlar or combination of structural materials affects the mass and stiffness of the paddle.
Length	Shaft length, blade length, and total paddle length.
Rotation/offset	The rotation between the paddle blades.
Blade shape	Flat blade and wing blade (Conventional, Norwegian, and Turbo).
Blade surface area	Coefficient of drag.

Paddler characteristics

Research has not investigated the magnitude of the effects of individual characteristics (physiology, strength, and anthropometry) on performance via their effects on stroke rate and stroke displacement. Measures of strength are likely associated with the ability to maintain stroke displacement following a stroke rate increase, given the need to increase propulsive power. Having more fast twitch fibres are likely associated with the ability to increase stroke rate for short durations (Van Someren & Oliver, 2002), while measures of aerobic fitness could be associated with the ability to sustain a given stroke rate toward the end of a race for 1000-m distances (Forbes, Fuller, Krentz, Little, & Chilibeck, 2009).

Given high stroke rates and greater kayak velocity occurred in shorter race distances (refer to Table 3.2), large upper body musculature may be required to produce enough power to achieve or sustain high stroke rates without decreasing stroke displacement excessively. Relaxed biceps girth, flexed biceps girth and humerus breadth were correlated ($r \geq 0.70$, $p<0.05$) with 200-m and 500-m average race velocity, but not 1000-m average race velocity (Akca & Muniroglu, 2008). The strongest correlation was between flexed biceps girth and race time (200-m: $r = -0.80$, $p < 0.01$; 500-m: $r = -0.86$, $p < 0.01$). In contrast, paddlers with longer segment lengths may emphasise greater forward reach, which would enhance stroke

displacement more than stroke rate. However there were no significant correlations between segment lengths and performance.

Body mass (500-m: $r = -0.78$, $p < 0.01$; 1000-m: $r = -0.71$, $p < 0.05$) and body fat percentage (500-m and 1000-m: $r = -0.82$, $p < 0.05$) had a very large correlation with 500-m and 1000-m average kayak velocity (Akca & Muniroglu, 2008). There was no significant correlation between body mass and 200-m performance, and a significant but not very large, correlation between body fat percentage and 200-m performance ($r = 0.69$, $p < 0.05$) (Akca & Muniroglu, 2008). Greater mass of the system may affect the surface area of the kayak exposed to the water, which would increase surface drag. Subsequently stroke displacement would decrease. Over longer distances with lower stroke rates, the reduction of stroke displacement may negatively influence velocity while high stroke rates in 200-m races may counteract any reduction of stroke displacement. Specifically, reducing body fat within a healthy range may help enhance performance via increasing the stroke displacement, particularly for longer distance events.

Equipment set-up (kayak and paddle characteristics)

Paddler height accounted for over half of the variance in foot-bar distance ($R^2 = 0.59$, $p < 0.01$) and paddle grip width ($R^2 = 0.54$, $p < 0.01$) (Ong et al., 2005; Ong et al., 2006). Elite paddlers with foot-bar distances and paddle grip widths lower than the predicted set-ups based on a regression equation, performed 100-m trials at their preferred and predicted set-ups to determine the effect of using the prediction equation on average kayak velocity (Ong et al., 2006). Changing equipment set-up from preferred to predicted, led to increased stroke displacement but decreased stroke rate in all three paddlers, which was associated with slower performances in two paddlers. Increasing stroke rate is more important for performance than increasing stroke displacement, assuming stroke displacement is not compromised too much.

The effects of individual kayak and paddle characteristics on stroke rate have not been investigated. Theoretically, the remaining kayak characteristics would influence stroke displacement more than stroke rate. Material, size, and hull shape likely affect hydrodynamic drag, and are regulated by the International Canoe Federation. There was no biomechanics research on the effect of the swivel seat on technique and performance.

Paddle length may influence forward and backward reach, having an effect on stroke displacement. In contrast, an excessive paddle length may make it difficult to achieve a high stroke rate. Increasing the paddle blade surface area will increase the coefficient of drag (Sumner et al., 2003), which may reduce slip and increase stroke displacement. Increasing blade surface area beyond an individualized optimum may cause a paddler to fatigue too quickly and reduce stroke rate. The potential effect of paddle grip width is difficult to discern. When paddle grip width was increased, stroke rate decreased, but this was also in association with a change in foot-bar distance so a direct cause and effect relationship could not be established (Ong et al., 2006).

Quality of published work

Sample size

Amongst most biomechanical studies investigating elite or internationally experienced populations, sample size was low and ranged from five to 16 paddlers (Kendal & Sanders, 1992; Qiu et al., 2005). Studies included individual data in addition to grouped data to compensate for small sample sizes. One study grouped six male and four female elite paddlers to achieve a greater sample size of 10 (Hay & Yanai, 1996). Larger sample sizes of up to 26 paddlers (Van Someren & Palmer, 2003) were achieved by extending participant criteria to include top level club paddlers. Other biomechanical investigations have increased sample size by including canoe paddlers and kayak paddlers, however the movements in each category are distinct (Timofeev et al., 1996). The largest sample size among biomechanical studies included a notational analysis of international (male = 46; female = 32), national (male = 29; female = 9), and club (male = 9; female = 10) paddlers during competition (Brown et al., 2011). When sufficient sample size is not available, within-subject investigations with higher stroke samples may be more appropriate.

Paddler characteristics

Gender, age, and level of the paddlers were the most common paddler characteristics reported. The majority of paddlers assessed were male, with very little representation of female paddlers. Among biomechanics research, the mean age of participants was approximately 23 years, and ranged from 17 to 37 years in competitive paddlers. Most studies investigated elite paddlers who represented their country at an international competition. One study investigated shoulder recruitment patterns during kayak ergometer paddling for recreational paddlers ranging in age from 28 to 62 years of age (Trevithick et al., 2007). Kayaking research of national, regional, non-competitive paddlers and school children were limited to anthropometry (Aitken & Jenkins, 1998; Van Someren & Palmer, 2003; Van Someren & Howatson, 2008), surface electromyography of the upper body muscles during ergometer paddling (Dai, Ho, Chang, & Liu, 2004; Trevithick et al., 2007), and strength studies (Liow & Hopkins, 2003; McKean & Burkett, 2010). Investigating elite populations has narrowed the sample size substantially.

Study design

Most kayaking studies were limited to descriptive quantitative cross-sectional and case-series designs. Amongst experimental research, study designs were limited to time series studies in which there was no control group. Although double-blind randomized controlled trials are the most trustworthy source of information (Hopkins, 2000b), including a control group while studying elite athletes is considered unethical since withholding important information for training would be detrimental to the athletes' progress (Kraemer, 2005; Garcia-Palleres,

Sanchez-Medina, Carrasco, Diaz, & Izquierdo, 2009). The problem with cross-sectional studies is that the interpretation of cause and effect relationships between variables are difficult to discern (Hopkins, 2000b). Experimental designs are stronger to establish cause-and-effect relationships. However to overcome the absence of a control group, researchers must establish the reliability of the dependent variables using test-retest reliability measures (Kraemer, 2005). Few studies among kayaking biomechanics have explained the reliability of their measures, and no studies discussed the reliability of stroke rate and stroke displacement variables.

Quality of studies could be improved by increasing the number of trials performed or analysing individual stroke data over a large number of strokes. This is becoming possible on-water with improvements in GPS technology, accelerometers, and gyroscopes (Robinson, Holt, Pelham, & Furneaux, 2011). However sports scientists must still be wary when interpreting these data as some products have reportedly underestimated kayak velocity which is the criterion of performance (Janssen & Sachlikidis, 2010).

Limitations of the review

Low sample sizes (Kendal & Sanders, 1992), and not synchronizing the time when independent and dependent variables were collected, may have been partially responsible for the lack of evidence for the associations between kinematic variables and performance in our proposed model. Other studies did not aim to determine associations between the variables collected and performance (Timofeev et al., 1996; Bourgois et al., 1998; Baker et al., 1999; Qiu et al., 2005). Brown et al. (2011) measured stroke rate for two strokes, 100-m before the finish line in 200-m (50% of race distance) and 500-m events (80% of race distance), while average race velocity was reported rather than average kayak velocity occurring at the time when stroke rate was recorded. Excluding data from Brown et al. (2011), led to a greater association between stroke rate and average kayak or race velocity when calculating correlations using studies that collected the two variables over synchronized periods of time. This finding supports that stroke rate profiles over an entire race, need further investigation to determine when researchers can reliably measure variables that reflect the race mean.

The zero-order correlation values reported in our literature review do not include the effects of other variables on performance measures. Differences in research-aims led to variations in methodology, conditions, and performance, which could affect associations between the variables in our deterministic model and performance. Research reporting partial correlations and multiple regression analysis need to be conducted.

Practical implications

Coaches should use the kinematic deterministic model suggested (Figure 3.1) for prioritising the most important factors for influencing their paddlers' performance when performing live qualitative or quantitative video analyses for paddlers during training sessions.

With little evidence currently for biomechanical variables predicting sprint kayak performance, our recommendations should be considered as preliminary.

We recommend that coaches focus mostly on increasing stroke rate, while making an effort to simultaneously enhance or at least maintain kayak stroke displacement. Decreasing time in both water and aerial phases will lead to increased stroke rate. Successful paddlers had a larger relative water phase time, so decreasing aerial phase time while increasing stroke rate is important. Given normative relative water phase times range (50 to 69%), paddlers should make adjustments based on their own performances. The fastest average velocity reported, in the literature reviewed, occurred with a relative water phase time of approximately 63% for both male and female paddlers (Hay & Yanai, 1996).

The effect of individual characteristics of the paddler, kayak, and paddle on the ability to achieve and sustain an optimal stroke rate and displacement combination would be useful for coaches when making decisions about the most appropriate intervention for an individual paddler. There is currently no systematic method for measuring, predicting or monitoring optimal stroke rate and displacement combinations for individual paddlers; therefore research is required in this area.

Conclusions

We proposed a kinematic deterministic model using average kayak velocity as the performance criterion. Average kayak velocity is determined by stroke displacement and stroke time. Inversely proportional to stroke time, stroke rate can also be used. Stroke time had the largest correlation with 200-m race time ($r = 0.86$, $p < 0.001$), and stroke rate had a very large correlation with average kayak velocity over two consecutive strokes at race pace ($r = -0.83$, $p < 0.05$). There were no significant associations between stroke displacement and average kayak or race velocity, but this limitation was due to the lack of research available.

More descriptive data of stroke rate and kayak stroke displacements are needed to document or confirm the strength of the associations for all race distances, boat classes, and genders, given the variation of current normative data. The best distance within the race to assess stroke rate should be determined to allow easy stroke rate monitoring for coaches. A method for optimising stroke rate for sprint paddlers is needed before determining the effect of individual characteristics of the paddler, kayak, and paddle.

Chapter 4: Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition

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The article has been removed from the thesis (thesis pages 57-66) for copyright reasons, but may be accessed online by subscribers to the journal.

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Chapter 5: Sprint kayaking stroke rate reliability, variability and validity of the digitrainer accelerometer compared to GoPro video measurement

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Overview

Reliability, variability, and validity of stroke rate measured via a Digitrainer accelerometer and GoPro 60 Hz video camera were determined. Six elite New Zealand kayakers (three males, three females) performed three trials of 300-m sprints in a single kayak (K1) mounted with the Digitrainer and camera. Average individual within-trial variability and between-trial reliability and variability were calculated using data from 40 strokes beginning at 200-m. Both Digitrainer and video showed good reliability (Mdiff% ≤5%; ES ≤0.6), and moderate variability (ICC <0.67; TE% <10%). There was good agreement between Digitrainer and video stroke rates (r=0.86, p=0.000), however the Digitrainer overestimated stroke rate by 4 ±5 spm. Both systems can assess relative change in stroke rate, however video should be used when valid stroke rates are required.

Introduction

To enhance the practical implications for applied service work, biomechanics research should aim toward determining methods suitable for identifying change in an individual paddler or small groups of paddlers (i.e. an elite squad training under the same coach) which may be possible by using stroke-to-stroke data. Mononen and Viitasalo (Mononen & Viitasalo, 1995) identified stroke rate as the most important predictor of performance in sprint kayaking (r=0.86; p<0.001). Stroke rates can be mathematically derived from video or accelerometer data. Using videography requires post-event processing so does not allow direct feedback to the paddler during training. Alternatively, the Digitrainer GPS-accelerometer system (Polaritas GM Electronic Research, Design & Manufacturing Ltd. Budapest, HUN) offers stroke rate displayed on a screen for live feedback which may be useful for training programmes if reliable. Janssen and Sachlikidis (Janssen & Sachlikidis, 2010) reported that the minimaxX GPS-based accelerometer under-reported kayak velocity by 0.14-0.19 m/s and acceleration by 1.67 m/s^2 when compared to video-derived measurements of 12 trials performed at three stroke rates. Stroke rates of 60, 84, and 108 strokes per minute were prescribed using a metronome and confirmed during data analysis, but it was not clear whether stroke rate measures from the minimaxX were valid, or if the adherence to the metronome feedback was confirmed using

video data. Reliability and variability of stroke rate over a period of strokes have not been reported in sprint kayaking, nor has the accuracy of accelerometer derived stroke rates been documented. Therefore, this study aimed to determine the reliability, variability and validity of stroke rate measured via a Digitrainer GPS-accelerometer system and a GoPro 60 Hz video camera with post-event processing using QuickTime 7 Pro.

Methods

The methods were approved by the Auckland University of Technology Ethics Committee. Six New Zealand elite kayakers (three males and three females) aged 20-22 years volunteered for this study.

The Digitrainer recorded acceleration data in three axes at 125 Hz and boat location via GPS at 1 Hz throughout each trial. Data were stored in the internal memory, and TechniqueStudio software (Polaritas GM Electronic Research, Design & Manufacturing Ltd. Budapest, HUN) was used to review data. A GoPro digital video camera (GoPro, Half Moon Bay, USA) sampling at 60 Hz recorded blade entry points to calculate stroke rate. Stroke time was initially calculated by dividing the difference in frame numbers between the catch to the next catch by a constant 60, representing the frame rate of the video camera. Stroke rate was then derived by using the constant 60 divided by stroke time to convert the value to represent the number of strokes taken in one minute at that cadence. The calculations were reduced to one equation: 3600/(end frame – initial frame).

The Digitrainer was mounted to the back of the K1 boat behind the paddler, so that the paddler was not influenced by the display screen. The video camera recorded the Digitrainer screen for an initial 10 s for synchronization, then was secured within a waterproof casing and mounted to the front of the K1 boat to record blade entry points, which were later used to calculate stroke rate (see Figure 5.1 for equipment set-up). Paddlers were then asked to perform three 300-m sprints from a floating start at a self-selected constant race pace.

Beginning at 200-m, 40 single-sided strokes were analyzed. A single-sided stroke was defined from the first point of blade-water contact (catch) of one side to the catch of the opposite side for the video data. Video was reviewed with QuickTime 7 Pro (Apple Inc., Cupertino, USA). Frame numbers for each catch were entered into Excel (Microsoft, Redmond, USA). Stroke rate data from the Digitrainer was exported from TechniqueStudio software to Excel for analysis. All variables were log transformed to stabilise variance. Stroke rates were represented in strokes per minute (spm) of a single-sided stroke.

A five-point moving average was applied to the 40 stroke data samples, which reduced the sample size to 36 stroke rate values for each trial for each individual. The five-point moving average was used mainly to allow stroke rate trends throughout the 40-stroke trial to be compared between trials via the intra-class correlation analysis. Average individual within-trial reliability was assessed using the averaged coefficient of variation (CV%) calculated for each individual within each of the three trials. The CV% was calculated from the standard deviation displayed as a percentage of the mean.

The stroke rate from the Digitrainer was derived from the accelerometer which sampled at 125 Hz and had the ability to detect stroke rate to the nearest single digit (≤1% at stroke rates over 100). The error of one frame of video equated to a difference of three strokes per minute at the average stroke rate of 106, so 2.8% was the criterion for low variability for video-derived stroke rate. Lower variability is considered better than higher variability. Given the larger 2.8% for video than the 1% for the Digitrainer, 2.8% was also used as the criterion of low variability for the Digitrainer to enable comparison of the two systems. A coefficient of variation greater than the criterion for low variability was considered high.

Figure 5.1. An instrumented kayak with the Digitrainer (left) mounted on the flat surface of the kayak just behind the paddler, and camera (right) mounted in front of the paddler on the kayak bow.

Average individual between-trial reliability and variability were computed for each pair of trials (2-1 and 3-2) for each paddler separately using all strokes then individual results were averaged. Average individual between-trial reliability was determined by the percentage differences in the means (Mdiff%) and Cohen's effect sizes (ES). Good reliability was interpreted when the Mdiff% ≤5% and ES ≤0.6 (Bradshaw, Hume, Calton, & Aisbett, 2010). Moderate reliability was interpreted when only one criteria of good reliability was met (Mdiff% >5% or ES >0.6), and poor reliability was interpreted when neither criteria of good reliability were met (Mdiff% >5% and ES >0.6) (Bradshaw et al., 2010).

Between-trial variability (average individual and grouped) was determined using typical error expressed as a percentage of the mean (TE%), and intra-class correlation coefficients (ICC). Small variability was determined when the ICC >0.67 and TE% ≤10%, moderate variability was determined when only one criteria of small variability was met (ICC <0.67 or TE% >10%), and large variability was determined when neither criteria of small variability were met (ICC <0.67 and TE% >10%) (Bradshaw et al., 2010).

All data were calculated using Microsoft Excel (Microsoft, Redmond, USA), and the level for confidence limits was set at 90%. Pearson correlation coefficients (r) were calculated

(statistical significance set at p=0.05) using SPSS (IBM, Armonk, USA) to determine validity of the Digitrainer system for stroke rate using video data as the gold standard. The difference between stroke rate from the Digitrainer and video was calculated for each stroke for each individual's trials. The mean and standard deviation of the stroke rate difference was used to determine if the Digitrainer was overestimating or underestimating stroke rate compared to the video.

Results

Average individual descriptive statistics (means and standard deviations) and average individual within-trial variability (CV%) are summarised in Table 5.1. Average individual between-trial reliability (Mdiff%, ES) and average individual between-trial variability (TE%, ICC) for all trials for five-point moving average analysis of stroke rate are summarised in Table 5.2. Both Digitrainer and video showed good reliability (Mdiff% ≤5%; ES ≤0.6), and moderate variability (ICC <0.67; TE% <10%). A pearson correlation coefficient showed good agreement between the Digitrainer stroke rate and the video derived stroke rate (r=0.86, p=0.000) however the Digitrainer tended to overestimate stroke rate by 4 ±5 spm.

Table 5.1. Average individual within-trial descriptive statistics (mean ±SD) and variability (CV%) of stroke rate using five-point moving average (n=36) analysis.

Variables	Trial 1		Trial 2		Trial 3	
	Mean ±SD	CV%	Mean ±SD	CV%	Mean ±SD	CV%
Stroke rate: Digitrainer (spm)	108 ±2.8	2.6	106 ±2.3	2.2	106 ±2.6	2.4
Stroke rate: Video (spm)	103 ±2.3	2.2	101 ±1.8	1.8	102 ±2.1	2.0

Table 5.2. Average individual between-trial reliability (Mdiff%, ES) and variability (ICCr, TE%), using averaged individual five-point moving average (n=36) analysis.

Variables	Mdiff (%)	ES	Average reliability	ICC	TE (%)	Average variability
			Trials 2-1			
Stroke rate: Digitrainer (spm)	-1.42	-0.50	Good	0.22	2.01	Moderate
Stroke rate: Video (spm)	-1.55	-0.58	Good	0.40	1.45	Moderate
			Trials 3-2			
Stroke rate: Digitrainer (spm)	0.24	0.06	Good	0.28	2.05	Moderate
Stroke rate: Video (spm)	0.81	0.24	Good	0.26	1.61	Moderate

Discussion

This was the first study, to the authors' knowledge, in sprint kayaking to document the variation of stroke rate measures using individual stroke data using two different products for measuring stroke rate. There were three key findings of this study. First, the Digitrainer and video stroke rates were both reliable within- and between-trials when analysing individual data

using a five-point moving average. Within-trial variability was low when it was less than the error of measurement due to the precision of the equipment (1% for the Digitrainer and 2.8% for the video camera). Although both ways of measuring stroke rate were reliable, video seemed to be more reliable shown by the slightly lower coefficient of variations compared to the Digitrainer. Second, the Digitrainer and video stroke rates both had an acceptable (moderate) level of variability between trials. Although there seemed to be no difference in the variability between pairs of trials for both devices, we recommend using the first trial as a familiarisation trial, given reliability was better between trials 3-2. Third, the Digitrainer did not produce a valid stroke rate compared to the video data. Despite the strong relationship found between Digitrainer and video stroke rate, the mean difference for all strokes for each participant's trials was larger (4 ±5 spm) than the error of measurement due to the precision of the video camera (3 spm or 2.8%). The Digitrainer had a tendency to overestimate stroke rate, but the large standard deviation of the mean difference showed that it did not consistently overestimate stroke rate, nor overestimate stroke rate at the same value. Therefore an adjustment equation cannot be used. Given the good reliability, however, both systems are adequate for training and assessment feedback if used appropriately.

Providing immediate feedback on a console directly to the paddler is an advantage for the Digitrainer system. However the Digitrainer was more expensive than the video camera used in this study. An appropriate use for the Digitrainer would include using the immediate feedback for sub-elite paddlers to help with the consistency of the paddler's stroke rates or to make relative increases in stroke rate based on a self-selected stroke. The coach could also store data easily on a laptop and track improvements within a season, with little post-processing time.

Aside from the good reliability and greater accuracy, an additional benefit from the video is that each stroke can be divided into two or four phases offering a greater depth of analysis, but the disadvantage is that analyzing video for more than two to three strokes can be time-consuming. However, when accuracy is important, video should be used.

Conclusions

The Digitrainer and video stroke rates were reliable within- and between- trials, and their variability was moderate (acceptable) between trials. However, the Digitrainer was not valid for stroke rate measurement. Despite these findings, there were advantages and disadvantages for both systems, and we conclude that both devices can be used if used appropriately. Video should be used for research, when assessing elite paddlers' stroke rates, or anytime accuracy is important. When immediate feedback and quick post-event processing time outweighs the importance of a true stroke rate measure, then the Digitrainer is useful. It should be noted that the Digitrainer tended to overestimate stroke rate by 4 ±5 spm compared with boat mounted video sampled at 60 Hz, so only relative assessments should be made.

Chapter 6: A comparison of analysis methods for determining the reliability of stroke rate and stroke phase temporal variables in sprint kayaking

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McDonnell, L. K., Hume, P. A., & Nolte, V. (2013 submitted for review). A comparison of analysis methods for determining the reliability of stroke rate and stroke phase temporal variables in sprint kayaking. *Sports Biomechanics.*

Overview

This study compared different analysis methods (averaged individual vs. grouped; stroke-to-stroke vs. five-point moving average) for determining the reliability of stroke rate and stroke phase variables in sprint kayaking. Six elite paddlers (three males, three females) performed three trials of 300-m sprints in a single kayak. After an initial 200 m, 40 strokes were analysed using stroke-to-stroke ($n = 40$) and five-point moving average data ($n = 36$), for GPS and video-derived stroke rates. Video-derived average individual (as opposed to grouped) analysis using five-point moving average data was the recommended method for assessing stroke rate, resulting in low within-trial CV% (1.8-2.2%), good between-trial reliability (MDiff% ≤ 1.6%, ES ≤ 0.6) and moderate between-trial variability (ICCr ≤ 0.4, CV% ≤ 1.6%). Using this method, within-trial variability was considered low for all phases' and sub-phases' durations (*SD* ≤ 0.01 s for absolute durations; *SD* ≤ 2.9% for relative durations). Between-trial reliability was better between trials two and three (*MDiff%* < 3%; *ES* < 0.6) for most stroke duration variables. All stroke rate, phases' and sub-phases' durations were moderately reliable or better using 60 Hz video when trial one was treated as a familiarization trial.

Introduction

Sprint kayaking research identified stroke rate as an important correlate with performance (Mononen & Viitasalo, 1995; Hay & Yanai, 1996). Low sample sizes are generally used in sprint kayaking research (McDonnell, Hume, & Nolte, 2013a), therefore precise methodology for measuring stroke rate for an individual or small group of individuals would be useful for research and practical application. Stroke rate for individual paddlers or a small group of paddlers, can be assessed reliably over a large stroke sample ($n = 40$) using a 60 Hz video camera or the Digitrainer (a kayak designed gps-based accelerometer), and applying a five-point moving average applied to the data sets (McDonnell, Hume, & Nolte, 2012b). However, the previous work (McDonnell et al., 2012b) focused on the differences in equipment for measuring stroke rate using one method of analysis. There was a need to focus on comparing results from different analysis methods (averaged individual vs. grouped; stroke-to-stroke vs. five-point moving average) and discuss when each method may be appropriate in research and the practical environment to allow researchers and coaches to make informed decisions regarding their analysis needs.

One of the advantages of using video instead of the Digitrainer, was that phase divisions of the stroke could be assessed (McDonnell et al., 2012a). The kayak stroke can be divided into two phases (water and aerial), and the water phase can be further divided into sub-phases (entry, pull and exit) (McDonnell et al., 2012a). Unpublished research identified water phase duration as an important correlate with average boat velocity (Hay & Yanai, 1996). Theoretically, a decrease in absolute water phase duration and increase in relative water phase duration will enhance performance. First, the reliability of stroke timing variables needs to be established before studying the effects of performance interventions. Descriptive reliability data for stroke phase durations in sprint kayaking have not been reported. This study compared different analysis methods (averaged individual vs. grouped; stroke-to-stroke vs. five-point moving average) for determining the reliability of stroke rate and stroke phase variables in sprint kayaking.

Methods

Participants

Six healthy elite kayakers (three males and three females) aged 20-22 years volunteered for this study. Male paddlers averaged 80.3 ±7.8 kg and 180.9 ±6.9 m, and female paddlers averaged 64.0 ±5.8 kg and 166.2 ±1.2 m.

Equipment

The Digitrainer (Polaritas GM Electronic Research, Design & Manufacturing Ltd. Budapest, HUN) recorded acceleration data in three axes at 125 Hz and boat location via GPS at 1 Hz throughout each trial. The stroke rate from the Digitrainer is derived from the accelerometer data, and updates in real-time after each stroke. The Digitrainer was mounted to the stern deck of the kayak behind the paddler, so that the paddler was not influenced by the display screen, and results were uploaded to a computer following data collection. The GoPro HD Hero digital video camera (GoPro, Half Moon Bay, CA, USA) sampling at 60 Hz recorded the Digitrainer screen for an initial 10 s of synchronization, then was secured within a waterproof casing and mounted to the front of the boat to record blade entry points for assessing stroke rate (McDonnell et al., 2012b).

Procedure

Kayak sprint paddlers were asked to perform three 300-m sprints from a floating start at a self-selected constant race pace in K1 boats equipped with the Digitrainer and the waterproof digital video camera. An active recovery period of approximately five minutes was given between trials. Testing was performed on days with calm water conditions and when light winds would have the least impact on performance.

Data analyses

At the time of the study, it was not clear how long it would take for stroke-to-stroke data to become consistent. Plagenhoef (1979) suggested that three-quarters into a race distance was a good place to analyse data, assuming the paddler was providing their best effort. To encourage the best performance, paddlers performed their 300-m trials against another paddler of similar ability. The three quarter mark was considered 225 m, but the analysis began at 200-m to allow 40 single-sided strokes to be analysed for each paddler before the end of the trial. Allowing 200-m to achieve race pace before biomechanical analysis was also used in previous studies (Kendal & Sanders, 1992; Baker et al., 1999). Videos were reviewed with QuickTime 7 Pro (Apple Inc., Cupertino, USA). Video stroke rates were determined using frame numbers for each catch (initial contact between the blade and water) and were entered into Excel (Microsoft, Redmond, USA). Stroke rate data from the Digitrainer were exported from TechniqueStudio software to Excel for analysis. Stroke rates were represented in strokes per minute (spm) of a single-sided stroke.

Our original raw data set used for analysis consisted of one set of three trials of 40 consecutive single sided strokes for each device (video and Digitrainer) for each of the six individual paddlers. The original raw data sets were also conditioned to create a "raw" five-point moving average data set yielding 36 stroke samples per trial for all paddlers. A grouped data set was created by averaging the first stroke rate for all paddlers to create the first stroke sample, and so on until all 40 consecutive strokes were averaged between the paddlers to create a new grouped 40 stroke sample for each trial for each device. The five-point moving average was applied to the new grouped data set to create a five-point moving average grouped data set for each trial for each device. Reliability and variability were assessed for:

(A) Averaged individual within-trial variability – using means, standard deviations and coefficient of variations expressed as a percentage (CV%) calculated from the raw stroke-to-stroke and raw five-point moving average data for all six paddlers for each of the three trials individually, then presenting the average mean, standard deviation and CV% of the six paddlers for each trial.

(B) Averaged individual between-trial reliability and variability – using change scores for each pair of trials (T2-1 and T3-2) computed from log-transformed data, a data transformation technique to stabilise variance according to progressive statistics guidelines for presenting differences between values as percentages of the mean (Hopkins, 2000a). Values were computed for each paddler separately then averaged for each pair of trials for all paddlers for each device.

(C) Grouped within-trial variability – using a new data set created from averaging all paddlers' stroke rates for the first stroke of the first trial to create a new grouped data point for the first sample for the first trial, then repeating until there were forty averaged stroke rate samples for each of the three trials. Trial means, standard deviations and CV% were calculated for each trial.

(D) Grouped between-trial reliability and variability – using the grouped data set created from averaging all paddlers' data, between-trial reliability and variability values were

calculated the same way as for an individual analysis of the averaged individual between-trial reliability and variability (B).

(E) Five-point moving average analysis – A-D were recalculated using a five-point moving average applied to the original data sets as shown in the example.

The averaged individual analysis using a five-point moving average applied to the data sets were presented only for the following stroke phase durations based on a recommended observational model (McDonnell et al., 2012a):

(1) *Entry sub-phase duration (s and % stroke cycle)* – time from the catch (initial blade-water contact) to immersion (initial moment the blade becomes fully buried).

(2) *Pull sub-phase duration (s and % stroke cycle)* – time from immersion to extraction (last moment the blade is fully buried).

(3) *Exit sub-phase duration (s and % stroke cycle)* – time from extraction to release (last moment of blade-water contact).

(4) *Total water phase duration (s and % stroke cycle)* – time the paddle blade was in contact with the water, from catch to extraction, and includes entry, pull and exit sub-phases.

(5) *Aerial phase duration (s and % stroke cycle)* – time the paddle blade was not in contact with the water, from extraction to the catch of the opposite side.

Low within-trial variability is a measure of spread (e.g. expressed by a standard deviation or coefficient of variation). The lower the value, the more consistent the variables were within the trial. The criterion for low stroke-to-stroke variability was set at 2.8% for stroke rate measures as justified by previous research using the same methodology based on the maximum expected digitizing error (McDonnell et al., 2012b). A coefficient of variation greater than the criterion for low variability was considered high. Due to the small values of stroke phase duration means, variability for phase durations was interpreted using the standard deviation based on equipment error. A SD ≤0.01 s was used as the criterion for low variability for absolute stroke phases' and sub-phases' durations. A SD ≤2.9% was used as the criterion for low variability for relative stroke phases' and sub-phases' durations.

Between-trial reliability (averaged individual and grouped) is a measure of the repeatability of values between pairs of trials (2-1, 3-2), and was determined by the mean differences expressed as a percentage (*MDiff%*) and Cohen's effect sizes (*ES*). Good reliability was interpreted when the *MDiff%* ≤5% and *ES* ≤0.6 (Bradshaw et al., 2010). Moderate reliability was interpreted when only one criteria of good reliability was met (*MDiff%* >5% or *ES* >0.6), and poor reliability was interpreted when neither criteria of good reliability were met (*MDiff%* >5% and *ES* >0.6).

Between-trial variability (averaged individual and grouped) was determined using typical error of measurement expressed as a coefficient of variation (*CV%*), and intra-class correlation coefficients (*ICCr*) (Hopkins, 2000a). It is more advantageous to have lower variability between trials which is another indicator of consistency. Low variability was determined when the *ICCr* >0.67 and *CV%* ≤10%, moderate variability was determined when only one criteria of low variability was met (*ICCr* <0.67 or *CV%* >10%), and high variability was determined when

neither criteria of low variability were met (*ICCr* <0.67 and *CV%* >10%). The methods of interpreting reliability and variability were in accordance with the methods used by Bradshaw et al. (2010). All data were calculated using Microsoft Excel (Redmond, WA), and the level for confidence limits was set at 90%.

Results

Stroke-rate within-trial descriptive statistics (means and standard deviations) and variability (*CV%*) for each analysis are summarised in Table 6.1. Averaged individual stroke-to-stroke within-trial variability was high (*CV%* > 2.8%), while grouped individual stroke-to-stroke within-trial variability was low (*CV%* < 2.8%) for video and Digitrainer stroke rates for trials one, two and three. Averaged individual and grouped five-point moving average analysis showed low variability (*CV%* < 2.8%) for video and Digitrainer stroke rates for trials one, two and three.

Table 6.1. Average individual and grouped within-trial variability (mean, standard deviation, CV%) of stroke rate using stroke-to-stroke data (n=40) and five-point moving average (n=36) analyses measured from the Digitrainer and video for six elite paddlers.

Variable and analysis type	Trial 1		Trial 2		Trial 3	
	Mean ± SD	CV %	Mean ± SD	CV %	Mean ± SD	CV %
Average individual						
Stroke-to-stroke						
Stroke rate: Digitrainer (spm)	108 ± 4.3	4.0	106 ± 4.0	3.8	106 ± 3.9	3.6
Stroke rate: Video (spm)	103 ± 3.7	3.6	101 ± 3.2	3.2	103 ± 3.6	3.5
Five-point moving average						
Stroke rate: Digitrainer (spm)	108 ± 2.8	2.6	106 ± 2.3	2.2	106 ± 2.6	2.4
Stroke rate: Video (spm	103 ± 2.3	2.2	101 ± 1.8	1.8	102 ± 2.1	2.0
Grouped						
Stroke-to-stroke						
Stroke rate: Digitrainer (spm	108 ± 2.0	1.9	106 ± 2.4	2.3	106 ± 1.4	1.3
Stroke rate: Video (spm)	103 ± 2.3	2.2	101 ± 1.9	1.9	102 ± 1.8	1.8
Five-point moving average						
Stroke rate: Digitrainer (spm)	108 ± 1.6	1.5	106 ± 1.8	1.7	106 ± 0.7	0.7
Stroke rate: Video (spm)	103 ± 1.7	1.7	101 ± 1.4	1.4	102 ± 1.3	1.3

SD, standard deviation; CV%, coefficient of variation expressed as a percentage.

Stroke rate between-trial reliability (*MDiff%*, *ES*) and variability (*CV%*, *ICCr*) between both pairs of trials for each analysis are summarised in Table 6.2. Between both pairs of trials, good reliability (*MDiff%* < 1.6% and *ES* < 0.6) and moderate variability (*ICCr* < 0.5 and *CV%* < 3.5%) was observed for averaged individual stroke-to-stroke and five-point moving average analysis. Mixed results were observed for between-trial grouped reliability and variability. Compared to average individual analysis, grouped stroke-to-stroke and five-point moving average reliability was worse for video and digitrainer stroke rates between trials one and two, and worse for five-point moving average video reliability between trials two and three. Compared to average individual analysis, grouped five-point moving average variability improved for video and

Digitrainer stroke rates between trials one and two, and improved for video stroke rates between trials two and three.

All durations of absolute stroke phases and sub-phases in seconds, showed low variability ($SD ≤ 0.01$), and all relative stroke phases and sub-phases expressed as a percentage of the whole stroke showed low variability ($SD ≤ 2.9$) within each trial (Table 6.3). Absolute phase durations ($CV\% = 2.1-3.3\%$) and relative phase durations ($CV\% = 1.2-2.8\%$) were less variable than absolute sub-phases' durations ($CV\% = 4.4-7.8\%$) and relative sub-phases' durations ($CV\% = 4.0-7.5\%$) respectively (Table 6.3).

Between-trial reliability (*MDiff%*, *ES*) and variability (*CV%*, *ICCr*) between both pairs of trials are also summarised in Table 6.3. Between trials one and two, good reliability was observed for absolute durations of the exit sub-phase and the aerial phase (s), as well as the relative durations of the water phase and the aerial phase (%). Moderate reliability was observed for durations of absolute entry sub-phases (s), relative entry sub-phases (%), relative exit sub-phases (%), and absolute water phases (s). Poor reliability was observed for durations of absolute pull sub-phases (s) and relative pull sub-phases (%). Between trials two and three, reliability was good for all variables except absolute and relative entry sub-phases' durations, which showed moderate reliability. Between-trial variability (*CV%*, *ICCr*) was moderate for all phases' and sub phases' durations expressed in absolute (s) and relative time (%) for both pairs of trials.

Table 6.2. Average individual and grouped between-trial reliability (MDiff%, ES) and variability (ICCr, CV%) for stroke rate using stroke-to-stroke data (n=40) and five-point moving average (n=36) analyses measured from the Digitrainer and video for six paddlers.

Variable and analysis type	Trials 2-1						Trials 3-2					
	MDiff (%)	ES	Average reliability	ICCr	CV (%)	Average variability	MDiff (%)	ES	Average reliability	ICCr	CV (%)	Average variability
Average individual												
Stroke-to-stroke												
Stroke rate: Digitrainer (spm)	-1.3	-0.2	Good	0.27	3.3	Moderate	0.2	0.2	Good	0.21	3.4	Moderate
Stroke rate: Video (spm)	-1.5	-0.5	Good	0.21	3.1	Moderate	0.9	0.3	Good	-0.03	3.4	Moderate
Five-point moving average												
Stroke rate: Digitrainer (spm)	-1.4	-0.5	Good	0.22	2.1	Moderate	0.2	0.1	Good	0.28	2.1	Moderate
Stroke rate: Video (spm)	-1.6	-0.6	Good	0.40	1.5	Moderate	0.8	0.2	Good	0.26	1.6	Moderate
Grouped												
Stroke-to-stroke												
Stroke rate: Digitrainer (spm)	-1.6	-0.8	Moderate	0.50	1.5	Moderate	0.3	0.2	Good	0.41	1.5	Moderate
Stroke rate: Video (spm)	-1.7	-0.8	Moderate	0.52	1.4	Moderate	1.0	0.6	Good	0.54	1.2	Moderate
Five-point moving average												
Stroke rate: Digitrainer (spm)	-1.7	-1.1	Moderate	0.73	0.9	Small	0.4	0.3	Good	0.44	1.0	Moderate
Stroke rate: Video (spm)	-1.7	-1.2	Moderate	0.90	0.5	Small	0.9	0.7	Moderate	0.83	0.6	Small

MDiff%, mean difference as a percentage; ES, effect size; ICCr, Intra-class correlation coefficient; CV%, coefficient of variation expressed as a percentage.

Table 6.3. Average individual five-point moving average (n = 36) within-trial descriptive statistics (Mean, SD) and variability (CV%), and between-trial reliability (MDiff%, ES) and variability (ICCr, CV%) of durations of stroke sub-phases (entry, pull, exit) and phases (water and aerial).

A) Within-trial Variable	Trial 1 Mean ± SD	CV%	Trial 2 Mean ± SD	CV%	Trial 3 Mean ± SD	CV%
Entry duration (s)	0.11 ± 0.01	5.4	0.11 ± 0.00	4.4	0.10 ± 0.01	6.3
Pull duration (s)	0.18 ± 0.01	6.2	0.19 ± 0.01	4.6	0.20 ± 0.01	6.3
Exit duration (s)	0.08 ± 0.01	7.8	0.08 ± 0.01	6.9	0.08 ± 0.01	7.2
Water duration (s)	0.37 ± 0.01	2.9	0.38 ± 0.01	2.1	0.37 ± 0.01	2.6
Aerial duration (s)	0.22 ± 0.01	3.3	0.22 ± 0.01	2.8	0.22 ± 0.01	3.4
Entry duration (%)	18.6 ± 0.9	4.7	17.9 ± 0.8	4.3	17.1 ± 1.1	6.1
Pull duration (%)	30.9 ± 1.7	5.5	32.5 ± 1.3	4.0	33.4 ± 1.7	5.5
Exit duration (%)	13.5 ± 1.0	7.5	13.1 ± 0.9	6.7	12.7 ± 0.9	7.0
Water duration (%)	63.0 ± 1.0	1.5	63.5 ± 0.8	1.2	63.2 ± 1.0	1.6
Aerial duration (%)	37.0 ± 1.0	2.6	36.5 ± 0.8	2.1	36.8 ± 1.0	2.8

B) Between-trial Variable	Trials 2-1 MDiff (%)	ES	Average reliability	ICCr	CV (%)	Average variability	Trials 3-2 MDiff (%)	ES	Average reliability	ICCr	CV (%)	Average variability
Entry duration (s)	-1.22	-0.69	moderate	0.16	4.65	moderate	-4.95	-1.14	moderate	-0.11	5.95	moderate
Pull duration (s)	7.46	1.42	poor	0.25	5.00	moderate	1.83	0.13	good	0.25	4.73	moderate
Exit duration (s)	-1.23	-0.46	good	0.13	7.06	moderate	-2.91	-0.45	good	-0.15	7.76	moderate
Water duration (s)	2.61	1.25	moderate	0.31	1.97	moderate	-1.11	-0.52	good	0.29	1.94	moderate
Aerial duration (s)	0.63	-0.07	good	0.10	3.03	moderate	0.23	0.02	good	-0.24	3.64	moderate
Entry duration (%)	-3.23	-0.97	moderate	0.10	4.35	moderate	-4.56	-1.05	moderate	-0.11	5.74	moderate
Pull duration (%)	5.78	0.85	poor	0.13	4.76	moderate	2.55	0.53	good	-0.01	4.83	moderate
Exit duration (%)	-3.28	-0.61	moderate	0.08	7.19	moderate	-2.17	-0.32	good	-0.07	7.24	moderate
Water duration (%)	0.76	0.56	good	-0.03	1.43	moderate	-0.49	-0.44	good	-0.29	1.64	moderate
Aerial duration (%)	-1.23	-0.56	good	-0.03	2.44	moderate	0.90	0.43	good	-0.29	2.87	moderate

SD, standard deviation; CV%, coefficient of variation expressed as a percentage. MDiff%, mean difference expressed as a percentage; ES, effect size; ICCr, Intra-class correlation coefficient.

Discussion

All combinations of methods (averaged individual or grouped, and stroke-to-stroke or five-point moving average) showed acceptable reliability and variability for measuring stroke rate and stroke phase temporal variables using 60 Hz video and the Digitrainer. Video-derived stroke rates (approximately 100-108 spm) were in line with stroke rates observed in men's elite level K1 paddlers performing 120 s all-out on the ergometer (Bourgois et al., 1998), higher than stroke rates (89 ± 4.7 spm) observed in men's elite K1 1000-m time-trials on-water (Timofeev et al., 1996), and lower than the mean stroke rates (110-121 spm) observed in men's and women's elite K1 500-m competition (Brown et al., 2011). Mean stroke rates have reached 158 ± 8 spm in men's elite K1 200-m competition and 139 ± 6 spm in women's elite K1 200-m competition according to published research (McDonnell, Hume, & Nolte, 2013b). Determining meaningful differences in stroke rates depend on the mean stroke rate, sampling frequency, and reliability. Using 60 Hz video, stroke rate accuracy can be detected to the nearest 3 spm (2.8%) or better for rates up to 112 spm, 4 spm for rates 113-128 spm, 5 spm for rates 129-138 spm, and 6 spm for rates 139-150 spm. This study showed that the Mdiff% between trials was low (between -1.3 to -1.7%). Maintaining an equipment precision level of about 2-3 spm or less is recommended. Splitting 60 Hz video into fields, or digitising to the nearest half frame is recommended when stroke rates are expected to exceed 112 spm.

The finding that the five-point moving average led to reduced variability, but did not change the mean values, may be reflective of the fact that the moving average filter is ideal for reducing noise while retaining the real shape of the original data when interested in the general trend (Smith, 2003). A limitation of the five-point moving average is that it does not filter separate frequencies, so the "noise" reduction consists of both measurement error and paddler variability. Therefore, the five-point moving average is also expected to smooth asymmetries between right and left sided strokes to an extent. Asymmetries of biomechanical variables do not necessarily harm performance (Hay & Yanai, 1996), but if researchers were interested in this topic, then a five-point moving average applied before separating right and left strokes would not be advised.

Grouping data has the ability to further reduce the between trial typical error to <1.5% for stroke-to-stroke data and <1% for five-point moving average data. Grouped analysis uses a new data set created by averaging the individuals' data sets for each variable, so the amount of data extraction is the same for both analyses types if extracting stroke-to-stroke data. Grouped analysis saves time for researchers during the statistical analysis by only having to calculate statistics for the new data set, instead of each individual first. Sprint kayaking research has not previously used the grouped analysis method. Although using grouped analysis and a five-point moving average resulted in the lowest typical error between trials (<1%), greater effect sizes (0.7-1.2) between trials one and two, led to moderate average reliability interpretations. There was no difference in the mean differences between averaged individual and grouped methods, so either method can be used depending on the purpose of the analysis and cost of time to the researcher or coach.

Though the coefficient of variations ranged from 1-3% for absolute and relative phases' durations and 4-8% for absolute and relative sub-phases' durations, variability for this group of paddlers was considered low for all phases' and sub-phases' durations because the standard deviation for each measure did not exceed the maximum error due to the precision of the equipment ($SD \leq 0.01$ s for absolute durations; $SD \leq 2.9\%$ for relative durations). It is important to note that the variation expressed as the standard deviation for the relative durations is already expressed as a percentage of the stroke cycle, whereas the coefficient of variation is the percentage variation within the stroke relative to the phase. Variation within each phase will affect the variation in the preceding and subsequent phases, so from a practical perspective, it is a good idea to quantify the variation for each phases' duration normalised as a percentage of the stroke cycle to effectively make duration comparisons between sub-phases and phases. Pull sub-phase durations (varied by approximately 2% of the stroke cycle) were less consistent than durations of other sub-phases (approximately 1% for entry and exit sub-phases). The phase-defining positions were easily identifiable, so the variability of pull sub-phase times is likely due to a combination of not digitising the true phase-defining positions, and the variability of the paddler's technique (e.g. trunk rotation or blade depth) from stroke-to-stroke. Paddler fatigue within the trial and the number of stroke cycles analysed will affect within-trial variability. It is expected that within-trial variability will increase over longer stroke samples due to fatigue (e.g. stroke analysis of every stroke over a full race distance), and will decrease over short samples (e.g. two consecutive strokes). When reporting stroke rate or durations of phases and sub-phases, most studies have limited their analysis to two consecutive single strokes (Kendal & Sanders, 1992; Baker et al., 1999; Qiu et al., 2005; Brown et al., 2011), and only relationships between variables have been studied. Biomechanical studies investigating elite or internationally experienced populations have used five to 16 paddlers (Kendal & Sanders, 1992; Qiu et al., 2005). Given the small populations accessible in sprint kayak research, performance interventions could be tested on an individual basis if larger stroke samples were used. Sprint kayaking research can improve the quality and the meaningfulness of biomechanics research by performing case series study designs in which a set of strokes is treated as the sample size. Though our paddler sample size was small ($n = 6$), our findings showed that analyses of 40 consecutive strokes are reliable in elite paddlers.

Stroke phase durations' between-trial reliability was better between trials two and three for most stroke time variables compared to between trials one and two, indicating that trial one may be best suited as a familiarization trial. Average variability was moderate for all variables between both pairs of trials due to the low intra-class correlation coefficients ($ICCr < 0.4$). In contrast, the acceptable level of typical error expressed as a coefficient of variation ($CV\% < 10\%$) indicated that variability was reasonably small. It may be the case that $ICCr$ values in stroke-to-stroke data are inappropriate, given fluctuations in stroke-to-stroke changes do not need to be associated with the same corresponding strokes of a second trial, to achieve a good performance result. Further research is needed to determine if paddlers can make identifiable changes in durations of phases and sub-phases using 60 Hz video, and how those changes affect performance.

Practical implications

Our results provided methods to improve within-trial and between-trial variability and reliability using video and Digitrainer derived stroke rates. Measurement consistency is essential for determining cause and effect relationships of biomechanical variables on performance in individual paddlers or a small group of individual paddlers. Coaches need to be aware that if using average individual stroke-to-stroke data, stroke rate changes <3% are not detectable as a meaningful change due to the typical error expressed as a *CV%*. Using five-point moving average analysis provides better (lower) *CV%* between trials. Grouping data may save analysis time and result in better (lower) *CV%* between trials, but individual interventions cannot be made or determined from grouped data. To be able to normalise key findings to the greater kayak community, however, the number of paddlers tested are still important. A case series approach may be best for future sprint kayaking research.

Conclusions

Grouping data and using five-point moving average analysis was useful for improving (lowering) within-trial and between-trial variability of video and Digitrainer stroke rate data for 40 consecutive single stroke samples in six elite sprint kayak paddlers. When assessing small groups, using averaged individual data compared to grouped data led to more reliable results between both pairs of trials. The mean difference and typical error percentages were acceptable for both individual and grouped five-point moving average analyses. Researchers and coaches should choose the best analysis (lowest *CV%*) depending on the purpose and time cost of the analysis. Using our recommended individual five-point moving average analysis, within-trial variability was good for all durations of stroke phases and sub-phases for each trial. Between-trial reliability and variability of stroke phases' and sub-phases' durations were best between trials two and three, therefore trial one may need to be treated as a familiarization trial when performance reliability is important.

Chapter 7: The effect of intensity on technique in kayak ergometer paddling

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Overview

The purpose of this study was to determine the effect of exercise intensity on kayak ergometer paddling technique. Seven elite male sprint kayak paddlers volunteered for a biomechanical analysis of the onset and durations of leg, trunk, pull, and thrust arm motions with respect to the double-stroke cycle using high-speed video (300 Hz) during a routine incremental ergometer test. Leg motion, trunk rotation, trunk angle, and forward reach were also of interest across intensities. The stages that most reflected the paddlers' training zones L2, L4, and L5 were selected based on blood lactate concentration and heart rate; 19 strokes were assessed for each intensity. Meaningful differences between intensities, calculated by subtracting scores of a later trial from the scores of an earlier trial (L4-L2, L5-L4, L5-L2), were determined when the true difference was likely greater than the smallest worthwhile change (SWC = 0.02 s for absolute times, 1% for relative times, 1° for angles, 0.01 m for distance variables). Uncertainty of the true difference was expressed using the mean difference ±90% confidence intervals (MDiff ±CI). Effect sizes (ES, 0.2-0.5 = small, 0.6-1.1 = moderate, 1.2-1.9 = large, ≥2.0 = very large) were reported to determine qualitative outcomes for meaningful differences. The key variables that showed clear outcomes (large to very large) for all paddlers between each pair of intensities were stroke time (right-sided, L4-L2 MDiff ±CI: -0.12 ±0.01 s; L5-L4 MDiff ±CI: -0.12 ±0.01 s), leg time duration (L4-L2 MDiff ±CI: -0.10 ±0.02 s; L5-L4 MDiff -0.08 ±0.02 s), trunk time duration (L4-L2 MDiff ±CI: -0.08 ±0.02 s; L5-L4 MDiff ±CI: -0.05 ±0.01 s), and pull time (L4-L2 MDiff ±CI: -0.08 ±0.01 s; L5-L4 MDiff ±CI: -0.04 ±0.00 s). Larger changes in power output between intensities yielded greater changes in stroke time and durations of limb actions.

Introduction

Sprint kayaking technique has not been documented well during exercises of varying intensities. Kayaking technique has been described as a push-then-pull arm motion coupled with trunk rotation (Mann & Kearney, 1983). Little attention has been given to leg motion in kayaking, or how the legs, trunk, thrust and pull arm interact throughout the stroke. Stroke rate and stroke displacement variables were identified as kinematic determinants of paddling performance with greater support for stroke rate being strongly associated with performance time after a review of data from multiple studies (McDonnell et al., 2013a). While it was expected that stroke rate will increase as a result of increased force production at higher intensities, how segmental sequencing and other important kinematic variables are affected by the change of intensity and stroke rate is unknown.

The kayak ergometer has been used for paddlers to reasonably simulate their on-water physiology (Van Someren, Phillips, & Palmer, 2000; Sitkowski, 2008) and paddling technique (Begon et al., 2008). Stroke rate, entry angle, propulsive time, propulsive/aerial time ratios, scapular girdle rotation, elbow and wrist trajectories, and vastus lateralis muscle activity were similar between ergometer and on-water performance in elite paddlers (Begon et al., 2008; Fleming, Donne, Fletcher, & Mahony, 2012). While kayakers did not reproduce trunk roll on the ergometer, and shoulder kinematics differed in the frontal plane for the draw shoulder (side of propulsion) between ergometer and on-water paddling, all joints (shoulder, elbow and wrist) exhibited closeness in their positions in the anteroposterior axis between the ergometer and on-water paddling (Begon et al., 2008; Fleming et al., 2012). Therefore, the ergometer is a reasonable tool for initial sagittal-plane biomechanical investigations of paddle shaft angle, stroke rhythm and joint centres. Further research was needed to quantify timing of the arms, trunk, and legs relative to the stroke cycle at various training intensities to provide coaches with information on how technique is expected to change with increasing intensity, and what characteristics are associated with changes of stroke rating during exhaustive efforts. The purpose of this study was to determine the effect of intensity on technique kinematics and stroke rate during ergometer paddling.

Methods

Participants

Seven elite male sprint kayak paddlers volunteered for the study. The paddler's mean and standard deviation age, height, and body mass were 25 ± 5 y, 183.8 ± 4.4 cm, and 82.2 ± 5.8 kg respectively. All testing protocols were approved by the university ethics committee, and informed consent was obtained from each paddler prior to data collection.

Equipment

Video data were collected using one Casio Ex-F1 video camera, sampling at 300 Hz, and placed five meters away, levelled and perpendicular to the long axis of a Dansprint kayak ergometer (Dansprint ApS, Hvidovre, Denmark) to view the sagittal plane of the paddler's right side. The footplate on the kayak ergometer was adjusted to the comfort of the paddler. The camera's 300 Hz sampling rate was confirmed after comparison with two digital atomic clocks and two digital stopwatches for a period of 10 s. A LED light, connected to a manual trigger, was taped to the front of the footplate with the light in view of the video camera for manually synchronizing trial time with video time. Power output was measured using the kayak ergometer. Power feedback of individual strokes was provided on a display console for the duration of the test so paddlers could achieve a desired power output target for each stage of the incremental test. A RS800sd Polar heart rate monitor (Polar Electro, Kempele, Finland), and Lactate Pro blood lactate analyzer (Arkray Inc, Kyoto, Japan) were used to measure aerobic

performance during the test. Trunk angle measures were digitised manually using Kinovea (Joan Charmant & Contrib., Bordeaux, France). The forward lean trunk angle from the vertical axis to the segment created by the hip and shoulder markers could only be measured when trunk rotation appeared to be negligible. This position was easier to qualitatively detect, so Kinovea was an appropriate use of software for this measure. Video data were also digitised semi-automatically using Vicon Motus (Vicon, Centennial, USA) to obtain joint centre coordinates and time data. Continuous scaled filtered coordinates, right knee angle, paddle shaft angle, and time data were calculated within the Vicon Motus programme, then exported to a customized Labview programme (National Instruments Corporation, Austin, TX, USA) designed to calculate the remaining discrete variables (Table 7.2). No continuous or waveform data was used in the final analysis.

Procedure

Retro-reflective markers were placed bilaterally on the hands (head of the 3rd metacarpal), wrists (styloid process of the ulna), right shoulder (acromion process), right hip (trochanterion), right knee (lateral epicondyle of the femur), and right ankle (lateral malleoulus) for each paddler. White tape located on the paddle-shaft centre and 10 cm away from the paddle-shaft centre toward the right side of the paddler, allowed paddle shaft angle measurements. Each paddler performed an incremental step-test to exhaustion on the ergometer (Bonetti, Hopkins, & Kilding, 2006). All paddlers were familiar with the assessment. Initial work load was set at 90 W with increases of 20 W between each four minute stage until the required power output could no longer be maintained. Paddlers were given 60 s of rest between each stage to standardize the time taken for blood lactate measurement. The starting power output was chosen based on the paddlers' previous ergometer assessment results ensuring that at least six stages (i.e., 24-minutes of work were completed prior to volitional exhaustion). Each four minute stage was videoed, beginning the video no later than one minute into each stage.

Data analyses

Stages that best reflected L2, L4, and L5 training zones were selected based on meeting the corresponding ranges for lactate in Table 7.1. If more than one stage met the associated criteria for lactate, then the stage that also met the corresponding range for heart rate was chosen (Seiler & Tønnessen, 2009). One paddler had two stages that met the lactate and heart rate criteria for L2, so the later stage was chosen for analysis. L5 corresponded with the last completed trial for all paddlers. The team's exercise physiologist confirmed the stage selection prior to analysis. For the aerobic, anaerobic, and sprint pace stages, the stroke sample began with 10 double strokes before the three minute mark and continued for 10 double strokes following the three minute mark. The original sample selected was 40 strokes, however only a

right sided analysis was possible and starting the analysis from the beginning of the left sided stroke after digitisation caused the sample to be reduced to 19 double-sided strokes.

Table 7.1. Stages that best reflected three common training zones and corresponding intensities relative to VO2max were selected based on lactate and heart rate values (Seiler & Tønnessen, 2009).

Training zone	VO$_2$max (%max)	Lactate (mmol/L)	Heart rate (%max)
L2	66-80	1.5-2.5	75-85
L4	88-93	4.0-6.0	90-95
L5	94-100	6.0-10.0	95-100

The kayak stroke begins with the catch position, which is defined as the first instant of contact between the paddle blade tip and the water. On the ergometer, the 'catch' was redefined as the 'beginning of the stroke', measured by a 40° shaft-angle between the horizontal and paddle shaft. This shaft angle was observed during our on-water biomechanics service work of national team paddlers, and was supported by normative catch ranges reported in literature (Szanto, 2004). Kinematic actions thought to be important for the propulsion of a right sided stroke were actions of the leg, trunk, thrust arm and pull arm (Logan & Holt, 1985; Cox, 1992; Kendal & Sanders, 1992; Szanto, 2004; Brown et al., 2011) and were presented as a proportion of a double sided stroke (0% was set to the beginning of the left stroke, and 100% was set to the beginning of the next left sided stroke, each defined by a 40° paddle shaft angle) (Szanto, 2004; McDonnell et al., 2012a). Variables were limited to a sagittal plan analysis and defined in Table 7.2.

Normality of all data sets was checked by reviewing probability-probability plots (P-P plots), which determines how well the data fit to a normal distribution. When normality was questionable in some individual cases, inferences using log-transformed data were checked. This control ensured that presented data did not differ from results using log-transformation, which is ideal when presenting change scores as percentages. All data were presented as raw mean differences rather than as percentages, given the small values of the means observed.

The effect of intensity on each variable was assessed for each individual using a 19-stroke sample at each of three intensities using a magnitude-based inferences approach described in greater detail by Hopkins, Marshall, Batterham, and Hanin (2009). In brief, meaningful differences between intensities, calculated by subtracting scores of a later trial from the scores of an earlier trial (L4-L2, L5-L4, L5-L2), were determined when the true difference was likely greater than the smallest worthwhile change, and when the benefit/harm ratio was greater than 66%. Uncertainty of the true difference was expressed using the mean difference ±90% confidence intervals (MDiff ±CI). The benefit/harm ratio (odds of benefit to odds of harm) of >66% ensures that the value is much more likely to be beneficial than harmful or much more likely to be an effect in one specific direction on the positive/negative scale than an effect in the other direction. Effect sizes (ES, 0.2-0.5 = small, 0.6-1.1 = moderate, 1.2-1.9 = large, ≥2.0 = very large) were reported to determine qualitative outcomes for meaningful differences. The mean individual differences (MDiff) ±90% confidence intervals (CI) and effect sizes (ES) were

averaged for all seven elite paddlers. Smallest worthwhile change scores were 0.04 s for double stroke time, 0.02 s for left and right stroke time and all absolute segmental sequencing times, 1% of the stroke cycle for all relative segmental sequencing times, 1° for angle measures, and 0.01 m for distance-related variables. Digitisation accuracy was within 0.005 m, and digitisation of angle measures varied by 1°, though angle accuracy could not be attained. Smallest worthwhile changes for double and single stroke times were derived based on previous research identifying a change of three single sided strokes per minute as a meaningful change (McDonnell et al., 2012b), and all remaining smallest worthwhile changes were derived from the averaged individual within-trial standard deviation for all unit-related measures. It should be noted that this was a conservative approach given these variables had not been experimentally investigated previously.

The values measured for each of the intensities were subtracted from an individual's mean value for that variable to derive change scores for the correlation analysis. Changes of each variable were correlated with changes in stroke rate using a Pearson product correlation analysis with the statistical significance threshold set at $p < 0.05$ to identify variables important for improving performance via increasing stroke rate (McDonnell et al., 2013a).

Table 7.2. Description of kinematic variables for kayak ergometer analysis.

Variable (abbreviation)	Description
Stroke time variables	Assessed using time in seconds and relative time as a percentage of double-stroke time.
Double stroke time (ST double)	Time of the left and right strokes each beginning at a 40° paddle-shaft angle.
Left stroke time (ST left)	Time from the beginning of the left stroke to beginning of the right stroke.
Right stroke time (ST right)	Time from the beginning of the right stroke to beginning of the left stroke.
Segmental sequencing variables	Assessed using time in seconds and relative time as a percentage of double-stroke time.
Time to (TT) each segmental sequencing variable	Time from the left stroke beginning to the onset of each segmental sequencing variable.
Leg time	Time from the right peak knee flexion angle to the right minimum knee flexion angle.
Trunk time	Time from when the horizontal backward velocity of the right shoulder marker was >0.1 m/s to when the velocity became <0.1 m/s. This was developed due to a plateau in time when the marker was at its most anterior position which led to greater variability of movement time. A threshold (0.1 m/s) that would improve the variability and cut off no more than 5% of the movement time was selected and implemented for the duration of thrust time and pull time.
Thrust time	Began when the horizontal forward velocity of the left paddle shaft marker >0.1 m/s, after the horizontal paddle-shaft position had been achieved on the left side of the paddler's body; the left hand marker was usually not visible from a right-sided view of the sagittal plane at its onset. Thrust time finished when the horizontal forward velocity of the left hand marker <0.1 m/s or when the thrust arm was no longer the top arm indicated by the horizontal position of the paddle shaft on the right side of the paddler's body, whichever came first.
Pull time	Time from when the horizontal forward velocity of the right wrist marker was >0.1 m/s to when the velocity became <0.1 m/s.
Angular variables	Assessed in degrees; using a 2D sagittal plane view.
Minimum knee angle (KA min)	The minimum right-sided knee flexion angle.
Knee range of motion (KA ROM)	The minimum knee angle subtracted from the peak right-sided knee flexion angle.
Trunk angle	The degree of forward trunk lean (trunk segment created by the shoulder and hip markers) with respect to the vertical axis, at the moment when trunk rotation appeared to be negligible.
Distance-related variables	Assessed in meters
Trunk preparation displacement	The horizontal displacement between the right shoulder's most anterior position and its position at the stroke beginning.
Trunk stroke displacement	The horizontal backward displacement of the shoulder marker from the right-sided stroke beginning to the most posterior marker position.
Forward reach (FR)	The horizontal distance between a fixed point on the ergometer seat and the right wrist marker at the time of the stroke beginning.

Results

Power outputs were ~70% for L2, 90% for L4, and 100% for L5. Right sided stroke times were equivalent to the single-sided stroke rates of 77 spm, 91 spm, and 98 spm for L2, L4, and L5 intensities respectively (Table 7.3). Stroke rate increased by ~7% for every 10% increase in power output between both pairs of intensities (L4-L2 and L5-L4), therefore 0.7 was a consistent ratio for the change of stroke rate to the change of power output. Most absolute time-to and durations of leg, trunk, pull and thrust arm actions decreased as intensity increased. Intensity did not seem to affect most relative proportion of segmental sequencing actions. However from L2 to L4, relative pull time became longer and the thrust arm action was initiated later. From L4 to L5, relative leg extension time became shorter and the thrust arm time was initiated slightly earlier, but not as early as during the L2 intensity. There were greater degrees of knee extension at higher intensities along with greater overall knee range of motion. Large changes in trunk angle occurred at higher intensities, with an exception between L2 and L5 intensities, as the mean trunk angle difference was smaller than the smallest worthwhile change.

Increasing stroke rate was largely associated with shortening the absolute time-to and durations of the leg, trunk and pull actions (Table 7.3). Increasing stroke rate was also associated with longer left-sided stroke times and shorter right-sided stroke times, longer time-to trunk action, longer pull arm action, and shorter time-to and duration of thrust actions relative to the stroke cycle. Greater knee extension (reduced minimum knee flexion angle) closely matched the increase in range of motion, and was associated with increased stroke rate. A reduction in trunk preparation displacement was associated with increased stroke rate.

An example of a segmental sequencing analysis of the paddler with the best performance history is shown in Figure 7.1. The right-sided stroke beginning is the line that divides each white and grey bar which both comprise the duration of each action. The example shows a slight asymmetry in stroke time, where the right-sided stroke beginning occurs after 50% of the double stroke time. Typically, however, asymmetries were not noteworthy. All stroke actions shown in Figure 7.1 commenced prior to the beginning of the right-sided stroke which was representative of most paddlers. In most paddlers at most intensities, the coordinative movement patterns of the kayak stroke was one of a sequential leg-thrust-trunk-pull action with an occasional variable thrust action. This sequential action became more simultaneous at higher intensities. This paddler also showed a relatively later thrust arm finish time with increasing intensity.

Table 7.3. Descriptive statistics of kinematic variables at aerobic (L2), anaerobic (L4) and sprint-paced (L5) kayak ergometer exercise, and the associations with a change in stroke rate.

Variable	L2 mean ± SD	L4 mean ± SD	L5 mean ± SD	Stroke Rate Pearson r[a]
ST double (s)	1.58 ± 0.02	1.34 ± 0.02	1.24 ± 0.02	-0.98**
ST left (s)	0.80 ± 0.02	0.68 ± 0.01	0.63 ± 0.01	-0.97**
ST right (s)	0.78 ± 0.01	0.66 ± 0.01	0.61 ± 0.01	-0.99**
TT leg (s)	0.57 ± 0.03	0.48 ± 0.02	0.46 ± 0.03	-0.90**
Leg time (s)	0.66 ± 0.03	0.56 ± 0.03	0.48 ± 0.03	-0.89**
TT trunk (s)	0.67 ± 0.03	0.58 ± 0.02	0.54 ± 0.02	-0.92**
Trunk time (s)	0.63 ± 0.03	0.55 ± 0.02	0.50 ± 0.02	-0.95**
TT thrust time (s)	0.59 ± 0.01	0.54 ± 0.01	0.48 ± 0.01	-0.80**
Thrust time (s)	0.57 ± 0.04	0.47 ± 0.03	0.45 ± 0.03	-0.67**
TT pull time (s)	0.75 ± 0.02	0.63 ± 0.01	0.58 ± 0.01	-0.96**
Pull time (s)	0.59 ± 0.01	0.52 ± 0.01	0.48 ± 0.01	-0.98**
ST left (%)	50.3 ± 0.1	50.7 ± 0.1	51.0 ± 0.1	0.60**
ST right (%)	49.7 ± 0.1	49.3 ± 0.1	49.0 ± 0.1	-0.60**
TT leg (%)	35.8 ± 1.6	35.6 ± 1.7	36.9 ± 2.1	0.03
Leg time (%)	42.0 ± 2.0	41.7 ± 2.0	39.1 ± 2.0	-0.25
TT trunk (%)	42.0 ± 1.9	42.8 ± 1.4	43.4 ± 1.2	0.45*
Trunk time (%)	40.1 ± 2.1	41.0 ± 1.5	40.5 ± 1.5	0.28[b]
TT thrust time (%)	37.3 ± 0.8	40.3 ± 0.8	39.1 ± 0.8	-0.45*
Thrust time (%)	36.8 ± 2.9	35.5 ± 2.0	36.1 ± 2.3	0.03
TT pull time (%)	47.1 ± 0.8	47.0 ± 0.6	46.5 ± 0.6	-0.36[c]
Pull time (%)	37.9 ± 0.9	38.9 ± 0.6	38.9 ± 0.7	0.63**
KA min (°)	19.3 ± 1.3	14.3 ± 1.5	12.6 ± 1.3	-0.73**
KA ROM (°)	33.8 ± 1.7	39.1 ± 2.1	40.9 ± 1.7	0.76**
Trunk angle (°)	8.0 ± 0.8	10.2 ± 1.0	10.8 ± 1.0	0.80**
Trunk preparation displacement (m)	0.11 ± 0.01	0.10 ± 0.01	0.08 ± 0.01	-0.70**
Trunk stroke displacement (m)	0.17 ± 0.01	0.18 ± 0.01	0.18 ± 0.01	0.12
FR (m)	0.62 ± 0.01	0.64 ± 0.01	0.59 ± 0.01	-0.26[c]

a = Correlation coefficient between individual change score from the mean and the change of stroke rate, b = likely meaningful positive correlation (odds > 75%) despite non-significance of the p-value; c = likely meaningful negative correlation (odds > 75%) despite non-significance of the p-value; d = displacement; TT = time to movement initiation; KA = knee angle; ROM = range of motion; FR = forward reach; * = significance of $p < 0.05$.

Table 7.4. The effect of various intensities on sprint kayaking ergometer kinematics (n = 19 strokes per trial) averaged for seven elite sprint kayak paddlers.

Variable	SWC	L4-L2			L5-L4			L5-L2			Paddler
		MDiff; ± 90% CI	ES	Qualitative Outcome	MDiff; ± 90% CI	ES	Qualitative Outcome	MDiff; ± 90% CI	ES	Qualitative Outcome	effect
ST double (s)	0.04	-0.24; ±0.01	-11.9	very large	-0.10; ±0.01	-5.1	very large	-0.35; ±0.01	-17.0	very large	7-7-7
ST left (s)	0.02	-0.12; ±0.01	-8.4	very large	-0.05; ±0.01	-3.4	very large	-0.17; ±0.01	-11.8	very large	7-7-7
ST right (s)	0.02	-0.12; ±0.01	-9.3	very large	-0.06; ±0.01	-4.1	very large	-0.18; ±0.01	-13.4	very large	7-7-7
TT leg (s)	0.02	-0.09; ±0.01	-3.5	very large	-0.02; ±0.01	-0.6	moderate	-0.11; ±0.02	-4.1	very large	6-4-7
Leg time (s)	0.02	-0.10; ±0.02	-3.4	very large	-0.08; ±0.02	-2.7	very large	-0.18; ±0.02	-6.1	very large	7-7-7
TT trunk (s)	0.02	-0.09; ±0.02	-3.6	very large	-0.04; ±0.01	-1.3	large	-0.13; ±0.02	-4.9	very large	7-4-7
Trunk time (s)	0.02	-0.08; ±0.02	-3.0	very large	-0.05; ±0.01	-1.9	large	-0.13; ±0.02	-4.9	very large	7-7-7
TT thrust time (s)	0.02	-0.05; ±0.01	-3.5	very large	-0.06; ±0.01	-4.4	very large	-0.11; ±0.01	-7.9	very large	6-5-7
Thrust time (s)	0.02	-0.10; ±0.02	-3.0	very large	-0.03; ±0.02	-0.5	unclear	-0.13; ±0.02	-3.4	very large	6-5-6
TT pull time (s)	0.02	-0.11; ±0.01	-7.7	very large	-0.06; ±0.01	-3.5	very large	-0.17; ±0.01	-11.2	very large	7-5-7
Pull time (s)	0.02	-0.08; ±0.01	-7.5	very large	-0.04; ±0.00	-3.8	very large	-0.12; ±0.00	-11.5	very large	7-7-7
ST left (%)	1.0	0.3; ±0.3	0.5	trivial	0.3; ±0.3	0.6	trivial	0.6; ±0.3	1.1	trivial	1-0-2
ST right (%)	1.0	-0.4; ±0.3	-0.5	trivial	-0.3; ±0.3	-0.5	trivial	-0.6; ±0.3	-1.1	trivial	1-0-2
TT leg (%)	1.0	-0.1; ±0.9	-0.1	trivial	1.3; ±1.1	1.0	moderate	1.2; ±1.0	0.8	moderate	4-4-4
Leg time (%)	1.0	-0.3; ±1.1	-0.2	trivial	-2.6; ±1.2	-1.5	large	-2.9; ±1.2	-1.6	large	4-5-4
TT trunk (%)	1.0	0.9; ±0.9	0.3	small	0.6; ±0.7	0.5	trivial	1.4; ±0.9	0.7	moderate	2-2-4
Trunk time (%)	1.0	0.9; ±1.1	0.6	moderate	-0.5; ±0.9	-0.3	trivial	0.5; ±1.1	0.3	trivial	3-2-2
TT thrust time (%)	1.0	3.0; ±0.5	3.9	very large	-1.3; ±0.5	-1.9	large	1.8; ±0.5	2.0	very large	4-2-5
Thrust time (%)	1.0	-1.3; ±1.6	-0.1	unclear	0.6; ±1.4	0.9	unclear	-0.7; ±1.6	0.7	moderate	4-4-3
TT pull time (%)	1.0	-0.1; ±0.4	-0.1	trivial	-0.5; ±0.4	-0.7	trivial	-0.5; ±0.4	-0.8	trivial	2-3-4
Pull time (%)	1.0	1.0; ±0.4	1.5	large	0.0; ±0.4	0.3	trivial	1.0; ±0.5	1.8	large	4-2-4
KA min (°)	1.0	-5.3; ±0.8	-4.2	very large	-1.7; ±0.8	-1.3	large	-7.0; ±0.7	-5.5	very large	6-4-6
KA ROM (°)	1.0	5.3; ±1.1	2.8	very large	1.9; ±1.1	1.2	large	7.1; ±1.0	3.9	very large	6-4-7
Trunk angle (°)	1.0	2.3; ±0.5	2.5	very large	0.6; ±0.6	0.7	trivial	2.9; ±0.5	3.2	very large	5-2-5
Trunk preparation displacement (m)	0.01	-0.01; ±0.01	-1.3	large	-0.02; ±0.01	-2.6	very large	-0.03; ±0.01	-3.9	very large	4-5-6
Trunk stroke displacement (m)	0.01	0.01; ±0.01	1.2	large	0.00; ±0.01	-0.3	trivial	0.01; ±0.01	0.9	moderate	3-2-3
FR (m)	0.01	0.02 ±0.01	2.1	very large	-0.05 ±0.01	-3.4	very large	-0.03 ±0.01	-1.3	large	6-3-3

SWC = smallest worthwhile change; MDiff = mean difference; CI = confidence interval; ES = effect size; Paddler effect = number of paddlers experiencing clear meaningful changes in the direction of the MDiff, with respect to each pair of trials (L4-L2)-(L5-L4)-(L5-L2). Qualitative outcomes of trivial and unclear effects were based on the mechanistic inferences based on MDiff, CI and SWC, not the effect sizes (ES).

Time as a percentage of a double stroke (%)
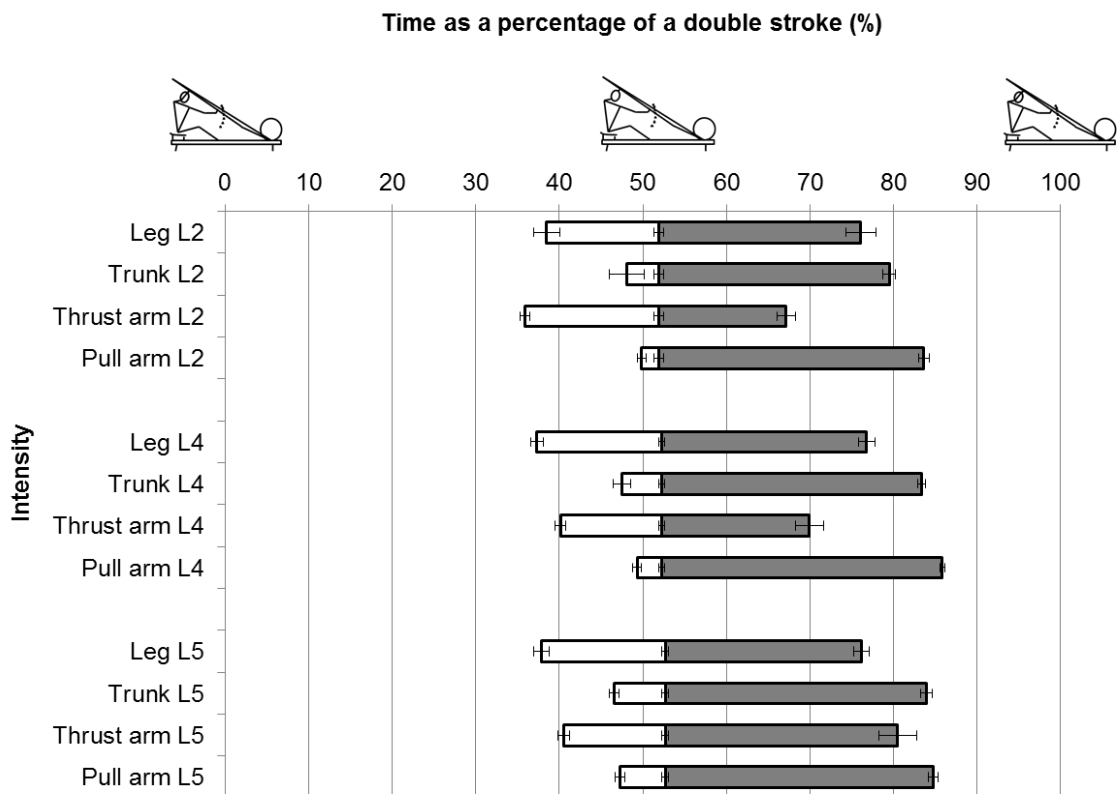
The durations of each action span the length of the white and grey bars combined, where the white bar section is the length of time prior to the right catch. The left error bars indicate the 19-stroke standard deviation in the time to initiation, middle error bars indicate the 19-stroke standard deviation of time to the right catch, and right error bars indicate the 19-stroke standard deviation of the time to the end of each action.

Figure 7.1. Sequential sequencing of the leg, trunk, thrust and pull actions at three different intensities (L2 = aerobic, L4 = anaerobic, L5 = sprint) on a kayak ergometer.

The effect of intensity on kinematics is shown in Table 7.4 using averaged individual results. Some individuals experienced opposite effects compared to the norm, so to strengthen the implications of this research for the applicability to the wider kayak population, the number of paddlers experiencing meaningful changes in the direction of the mean difference was also noted for each pair of trials (see column titled 'Paddler effect' in Table 7.4). The key variables that showed clear outcomes for all paddlers between each pair of intensities were stroke time, leg time duration, trunk time duration, and pull time. The coordination changes relative to the stroke cycle differed substantially between paddlers. Increasing intensity from L2 to L5 led to increased knee angle range of motion for all paddlers. The change in range of motion of the knee was attributed mainly to greater leg extension as intensity increased between each pair of trials.

Overall for the group, trunk angle was less at the aerobic intensity compared to the two higher intensities. Trunk preparation displacement decreased when increasing intensity. There were large changes in trunk displacement during the right sided stroke between L2 and L4

intensities, but trivial differences occurred overall in the trunk stroke displacement between the L4 and L5 intensities. Forward reach at the stroke beginning increased from L2 to L4 intensity, but decreased by a greater magnitude between L4 and L5 intensities.

Discussion

Stroke rate is well known as a key determinant of boat velocity, and has primarily been investigated at maximal/race pace (Kendal & Sanders, 1992; Hay & Yanai, 1996) or during competition (Brown et al., 2011; McDonnell et al., 2013b). The stroke rates observed for L5 in our study averaged 98 spm. This stroke rate is within the range of average stroke rates reported on-water (89-113) for elite men's K1 1000-m pace (Timofeev et al., 1996; Baker et al., 1999) and for elite paddlers on all-out ergometer tests lasting 120 s (Bourgois et al., 1998). Our reported L2 and L4 stroke rates, 77 spm and 91 spm, were respectively below and above stroke rates reported for both on-water and ergometer paddling at 85% of VO_2max (82 ± 2 spm) (Fleming et al., 2012). Given L2 is ~66-80% VO_2max and L4 is ~88-93% VO_2max (Seiler & Tønnessen, 2009), our measurements matched those of the elite populations in reported literature.

After normalizing changes as percentages, the change in stroke rate from L2 to L4 was twice as large (14%) as the change in stroke rate from L4 to L5 (7%). This was both interesting and convenient, as the increase in power output relative to L5, was also double for L2 to L4 (20% increase) than compared to L4 to L5 (10% increase), thus stroke rate increased by ~0.7 times the increase in power output between intensities. Sports performance analysts derived a coefficient of variation value based on the derivative of power (rate of change) as a percentage of the function of power ($P = kv^3$, where P = power, k = a constant, v = velocity), and determined that the coefficient of variation for power output would be proportional to three times the change in velocity (Hopkins, Schabort, & Hawley, 2001; Bonetti & Hopkins, 2010). Therefore, stroke rate increases of ~2.1% may be required for a 1% expected increase in velocity (0.7 x 3%). A possible reason for the linear increase of stroke rate with increase in power output across a large span of training intensities is possibly the selection of low stroke rate values (77-98 spm). This estimate may differ at higher stroke rates, where larger and larger increases of stroke rate would be required to make the same percentage change in velocity. Stroke rate changes as a function of power for 500-m and 200-m paddlers, who achieve stroke rates up to 125 spm and 168 spm respectively should be determined using shorter test durations.

Forward reach is indicative of increased stroke displacement assuming little change in backward reach or slip (Kendal & Sanders, 1992; Brown et al., 2011; McDonnell et al., 2013a). Forward reach was greater among the international paddling population compared to national and club paddlers and was therefore identified as an important determinant for performance (Brown et al., 2011). In our study, forward reach increased from L2 to L4 intensity, but shortened between L4 and L5, while stroke rate increased continually. There was a trend for a reduction in forward reach with increasing stroke rate at higher intensities (r = -0.25). Forward reach is limited to the anthropometric dimensions of the body along with subtle changes in

technique like trunk angle (i.e. forward lean) and trunk rotation (indicated in the present study by anteroposterior shoulder displacement), which were also maintained at higher intensities. While our findings and past research (Kendal & Sanders, 1992; Brown et al., 2011) support forward reach may be important to an extent, Plagenhoef (1979) stated that the best elite paddlers did not enter their blades as far forward as possible. The coaching literature advocated by the International Canoe Federation presents mixed opinions. They do not address forward reach specifically, but one source explains that the bottom arm should be nearly straight, but not locked out to prevent shock to the elbows or shoulders upon a forceful entry of the blade (Endicott, 1992). Another source states that the arm on the pulling side is completely extended forward, but does not support this statement with empirical evidence (Szanto, 2004). It is possible that coaches of elite paddlers may over-emphasize the importance of forward reach without any resulting additional performance benefit (Plagenhoef, 1979). Our findings that forward reach was reduced at sprint intensities, and decreasing pull arm time was most associated with increasing stroke rate and power output, support the notion that it may be best to reach out only to a distance where the paddler can apply large propulsive forces immediately following the catch (Kendal & Sanders, 1992).

Lift and drag propulsive forces are determined by a coefficient of drag or lift, fluid density, surface area of a body perpendicular to fluid flow, and relative velocity of the body with respect to the fluid. Therefore, under the same water conditions using the same paddle and technique pattern, lift and drag are primarily determined by the relative velocity of the paddle blade with the water. A previous kayak computer simulation study found increased pelvis motion, attributed by a greater pedalling motion with the legs, increased paddle tip velocity and the propulsive impulse (Begon, Colloud, & Sardain, 2010). Our results were supportive of the importance of the leg drive shown by the faster and later occurring leg-drive relative to the stroke cycle from anaerobic to sprint pace. The delay in the time-proportion of the leg-drive based on the overall group results, supports the concept that paddlers did not want to waste any leg motion before the beginning of the stroke (the catch, on water). With the reduction in forward reach, the increased leg extension movements appeared to be responsible for maintaining the trunk stroke displacement between the higher intensities.

Leg-arm timing is an important distinguishing factor of ability level (Brown et al., 2011). Between the highest intensities, the later initiation of the leg-drive and tendency for an earlier initiation of the pull arm for some paddlers added support that coordinating the leg and arm actions is also likely an important propulsive factor within the elite level. Greater coordination of the trunk and pull arm actions were noticeable at the higher intensities, which is also supportive that the muscles of the lower abdomen are important for the propulsive force production in kayaking (Brown, Lauder, & Dyson, 2010).

Our study shows the leg-thrust-trunk-pull actions occurring at 36%, 37-40%, 42-43%, and 47% of the double-stroke cycle where the right stroke began at 50%, thus all propulsive actions were initiated in a sequential order and before the initiation of the right stroke for most paddlers. These findings are in contrast to the current Canadian coaching resources that state that the blade should be fully buried in the water before any rotation is initiated

(, accessed 4th November, 2013). While it would be ideal to minimize knee extension, trunk, and pull movements before the start of the stroke (i.e. catch on water), Logan and Holt (1985) suggested that in such a dynamic movement such as kayaking, holding the body in an isometric state such that no wasted movement occurred before the catch is unrealistic. The slight initiation of knee extension may help develop proper tension on the foot-board in preparation for a well-connected, high force-producing water-phase. Early forward initiation of the thrust arm in our study was likely more of a blade-positioning strategy rather than wasting potential propulsive actions before the 'catch'. Successful paddlers characteristically move their blades a greater distance forward toward the catch position when recovering from the previous stroke (Kendal & Sanders, 1992), and our results support that this action is guided by the thrust and pull arms both moving forward at this time. The total backward horizontal displacement of the shoulder before the beginning of the stroke in our study (counter-rotation) was 0.11-0.08 m. Counter-rotation was minimized at higher intensities and was largely related to changes in stroke rate ($r = -0.70$). Given the backward horizontal actions of the pull arm were likely initiated before the beginning of the stroke, on-average, the maximum forward reach is also attained just before blade entry. Overall, we support the notion that while these paddlers should reduce wasted movement, initiation of these actions just before the catch position (if on water) may be necessary for building to the appropriate segmental velocities to achieve optimal propulsion by the time the blade is fully buried in the water phase. This notion needs further investigation with an on-water analysis.

While we made theoretical implications for on-water performance of sprint kayak paddlers based on the results of this study, our study was limited to a sagittal plane kayak ergometer analysis. The beginning of the stroke was determined based on a downward 40° paddle-shaft angle with respect to the horizontal axis. The beginning of the stroke was based on personal experience digitising on-water catches during day-to-day service work for national team paddlers who participated in this study. This may have led to some 'catch-estimation' errors between intensities. Therefore the results relative to the stroke cycle and absolute time to initiation of movements should be interpreted with caution and treated as estimates until confirmed with on-water analyses. The measured knee angles may have also differed from actual knee flexion angles. For example, the feet are typically placed closer on the foot-bar than hip width distance, which causes the leg to be on a slightly skewed angle to the camera. This may make measured 2D knee angles slightly less than the actual knee flexion angle. In contrast, any medial directed "collapsing" of the knee may make measured 2D knee angles slightly larger than the actual knee flexion angle. Qualitative review of frontal plane video in the same paddlers on the ergometer revealed slight collapsing of the knee before leg extension, but during the leg-drive (knee extension movement), the knee appeared to have good alignment with the ankle and hip. Therefore while actual angles may have differed from measured angles, it is unlikely that this slight skewedness affected the establishment of relative minimum and maximum knee measures indicating leg drive time and range of motion. The absence of a 3D study should not have influenced the take-home messages regarding trunk rotation greatly.

Trunk rotation was indicated by the anteroposterior displacement of the shoulder. This method had previously been used to indicate trunk rotation in a notational analysis and differentiate ability levels in sprint kayaking (Brown et al., 2011). It should be noted that the differences between intensities was of more interest than the actual measures. Confidence can be placed in the changes between intensities identified in this study because the smallest worthwhile changes were set to match the combined digitising error and paddler variability.

Conclusions

Larger changes in power output between intensities yielded greater changes stroke time and durations of limb actions. Based on the consistent ratios of stroke rate change to power change between L2, L4, and L5 training intensities for stroke rates ranging up to 100 spm, ~2.1% change in stroke rate expressed in single strokes per minute may be necessary for 1% improvements in velocity or performance time.

Kayaking is one of a sequential leg-thrust-trunk-pull action, where each action was initiated before the beginning of the stroke (estimated by a 40° paddle-shaft angle) for most paddlers, with more variability in the timing of the thrust arm action. Our findings support the notion that paddlers should focus on reaching as far forward as possible without hindering their ability to quickly direct the paddle backward, as decreasing forward reach was inevitable and decreasing pull arm time was the most important variable for increasing stroke rate and power output. Our findings also support the importance of trunk rotation and leg extension movements at high intensities or during exhaustive exercise, theoretically for achieving greater paddle tip velocity when the blade enters the water.

Chapter 8: Measuring on-water kinematic performance determinants and symmetry for K1 200-m sprint kayaking time-trials

This chapter will be submitted for journal review as:

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Overview

This study assessed the reliability, symmetry, and on-water data collection methods of kinematic performance determinants for 200-m sprint kayaking time-trials. Twelve competitive male paddlers with average 200-m performance times ranging 40-50 s, performed five 200-m time trials on two testing days one week apart, in a single kayak. Performance time, stroke rate and stroke phase times were extracted from 60 Hz video data for the duration of each time-trial; the first ten acceleration strokes were excluded from analysis. Within-paddler reliability was assessed using the smallest worthwhile change (0.3 x typical error), mean difference, and intra-class correlation coefficients (ICCr) between each trial and the reference trial two (T3-T2, T4-T2, T5-T2) with trial one treated as a familiarization trial for the reliability analysis. Magnitudes of stroke rate asymmetries were correlated with performance times of each individual's 10 trials separately using a Pearson correlation coefficient (r) with significance set at $p < 0.05$. Validity of measuring stroke rate for two consecutive strokes for all trials was tested at intervals of 10% between 20-80% of the time-trial using the mean difference, smallest worthwhile effect, and ICCr. Smallest worthwhile changes were 0.7% for performance time, 1.2% for stroke rate, 0.003 s for water and aerial time, 0.002 s for entry, pull, and exit time, 0.2% for relative water, aerial, entry and exit times, and 0.3% for relative pull time. There were no differences (mean difference < smallest worthwhile changes) between trials for all variables between T3-T2 and T4-T2. Between T5-T2, meaningful changes occurred for stroke rate (1.7%), water phase time (-0.005 s) and pull phase time (-0.004 s). Average stroke rate asymmetries were ~4 spm, and were not associated with worse performance except for one paddler with asymmetries ≥10 spm. The difference between a trial's mean stroke rate and two strokes sampled at 50% of the stroke time was small at -0.7 spm (-0.5%). There were measurable differences of 2.2 and -2.2 spm (±1.8%) at 40% and 60% of the race time. Overall, 200-m performance times are reliable for four trials after trial one is disregarded for familiarization. However, technique is only reliable for the trials 2, 3, and 4 due to possible fatigue in the fifth trial. Stroke rate asymmetries less than 4 spm are common, but not likely harmful for performance. Assessing stroke rate over two consecutive strokes at 50% of a time-trial is a valid measure of mean stroke rate when taking repeated samples.

Introduction

Stroke rate may be one of the best biomechanical predictors of sprint kayak performance, particularly for K1 200-m race time, as shorter race times were associated with higher stroke rates (r=0.86; p<0.001) (Mononen & Viitasalo, 1995). A two-stroke analysis is often used in research (Kendal & Sanders, 1992; Hay & Yanai, 1996; Baker et al., 1999; Qiu et al., 2005; Brown et al., 2011), but the two selected strokes are not always sampled during the same proportion of a race, and may not necessarily be reflective of the mean stroke rate, or be responsible for performance times. It is not probable that paddlers race at a constant race pace or utilise constant technique patterns throughout the race as their muscles lose their ability to produce force when fatigued. Research is needed for when a two-stroke sample can be validly collected to represent the mean stroke rate.

Some researchers have investigated stroke timing parameters on-water for all or most strokes of a time trial (usually excluding the start), but none of these studies have shown changes in these potential performance predicting variables throughout a race or time-trial duration (Plagenhoef, 1979; Mononen & Viitasalo, 1995; Timofeev et al., 1996). No researchers have yet established what a meaningful effect would be for these variables with the use of a reliability study. Further, paddling performances have been judged on the symmetry of stroke rhythm (Qiu et al., 2005), without knowing to what extent asymmetries are normal or if asymmetries are harmful for performance.

Research is needed for establishing the magnitude of change of kinematic variables that would be meaningful for performance in sprint kayaking. This study aimed to assess the reliability, symmetry, and alternative data collection methods of kinematic performance determinants for 200-m sprint kayaking on-water time-trials.

Methods

All procedures used in this study were approved by the university ethics committee. Each paddler gave written informed consent, and all testing occurred on the same pre-measured 200-m course marked with land-based reference markers for the start and finish.

Participants

The 12 competitive male kayak paddlers who participated in this study (mean ±SD age: 27 ±7 y, height: 180 ±4 cm, mass: 84 ±8 kg) were all free of injury at the time of data collection.

Equipment

The GoPro HD Hero 60 Hz digital video camera (Woodman Labs, Inc, Half Moon Bay, CA, USA) was secured within a waterproof casing and mounted to the front of the boat to record blade entry and exit points for assessing stroke rate and stroke phase times (Figure 8.1). The

boat-mounted camera was also used to digitise the race start based on the first movement of the paddler. A stationary land-based 300 Hz Casio Ex-F1 digital video camera (Casio Computer Co., Ltd, Shibuya, Tokyo, Japan) recorded the sagittal plane of the kayak crossing the finish line. The land-based and bout-mounted camera were synchronised to enable calculation of 200-m race time.
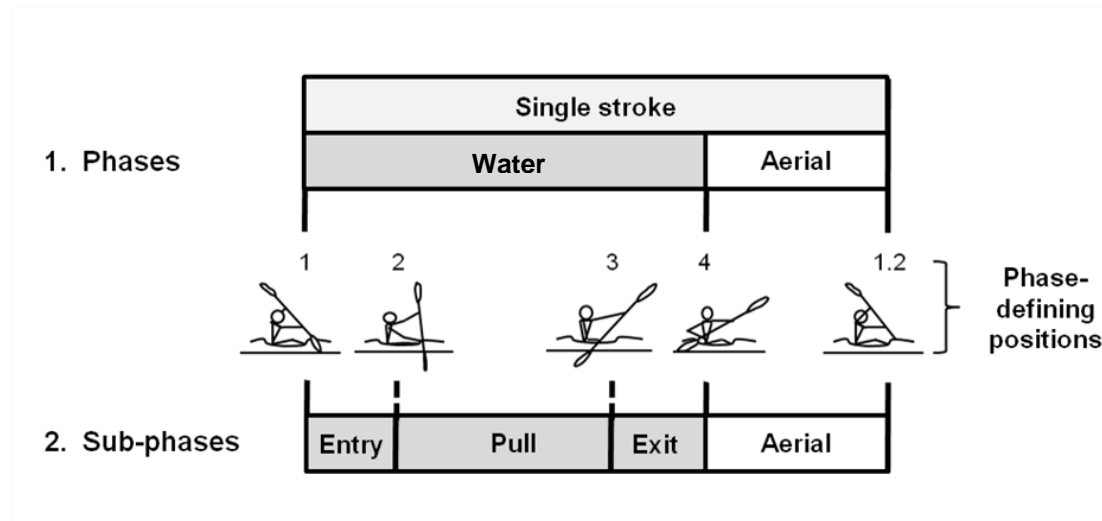
Figure 8.1. Catch (1), immersion (2), extraction (3) and release (4) positions were used for temporal analysis of the sprint kayak stroke. The catch of the opposite side (1.2) comprises the end of a full single-sided stroke.

Procedure

Time-trials were carried out using land-based reference markers of a pre-measured 200-m course in a relatively protected area of the lake commonly used for sprint kayak training during poor weather conditions. Following a warm-up, paddlers performed five 200-m time-trials from a floating start in K1 boats equipped with a bow-mounted waterproof digital video camera. Paddlers had 15-20 minutes recovery between trials. A brief warm-up period of five minutes occurred prior to each consecutive time-trial. Race times were provided to paddlers following each trial, and paddlers were encouraged by the researchers to perform a best effort for each trial. Adequate rest for a full recovery (as much as possible with five time-trials) was confirmed verbally with each paddler prior to commencing the next trial to ensure the paddler was ready to produce a best effort. Paddlers returned one week later for a re-test of all five time-trials at the same time of day, and with the same boat, paddle, and warm-up.

Reliability analysis

Data were reviewed using QuickTime 7 Pro (Apple Inc., Cupertino, USA) and manually digitised by entering frame numbers into Excel (Microsoft, Redmond, USA). Race times were extracted from synchronised video of the start and finish for all trials (trials 1-5). Stroke rate, phase, and sub-phase times were extracted for every stroke (approximately 90 strokes per trial).

Stroke-to-stroke data for the initial acceleration period, the first ten strokes, were excluded from the analysis. Trial one was treated as a familiarisation trial and was also excluded from the reliability analysis (McDonnell et al., 2012b).

Between-trial reliability was assessed using individual trial means for performance time, stroke phase times (water, aerial) and sub-phase times (entry, pull, exit). The smallest worthwhile change is typically calculated by 0.3 multiplied by the within-subject coefficient of variation (CV) for elite athletes competing in solo sports where performance is derived by a single outcome measure (Hopkins et al., 2001; Bonetti & Hopkins, 2010). This number (0.3 of a CV) was derived from simulated data assuming the smallest worthwhile change would be one where the athlete increases his/her chances of winning one extra medal every 10 competitions (Hopkins et al., 2001). This definition can be transferable to sub-elite performers as the number necessary to beat a competitor of equal ability one extra time every 10 competitions. Typical error can be expressed as a coefficient of variation by log transformation of the raw data before calculating the change scores between trials divided by the square root of two, then back-transformation to yield a coefficient of variation as a percentage (Hopkins, 2000a). Typical error expressed as a coefficient of variation and mean differences were best represented as percentages via log transformation for performance time and stroke rate. However, we opted to report mean difference and typical error as raw values for water, entry, pull, exit, and aerial times because larger errors were not proportionately observed in values with a larger mean, and very similar raw errors were observed between variables. Additionally, there were no differences in the outcome of the results using log transformed data expressed as a percentage compared to using raw mean differences and typical errors for all phase times and sub-phase times. Therefore our smallest worthwhile changes were calculated based on 0.3 multiplied by the typical error that was unaffected by the mean difference (Hopkins, 2000a).

The first criteria of good reliability between trials was interpreted when there were trivial or no clear differences between trials, where a clear change was interpreted based on the likelihood that the magnitude of true difference (uncertainty was expressed using 90% confidence intervals) was greater than the smallest worthwhile effect, and when the benefit/harm ratio was greater than 66% (Batterham & Hopkins, 2005). The benefit/harm ratio (odds of benefit to odds of harm) of >66% ensures that the value is much more likely to be beneficial than harmful or much more likely to be an effect in one specific direction on the positive/negative scale than an effect in the other direction. The thresholds of benefit and harm were set to ± the smallest worthwhile effect. The second criteria of good reliability was when ICCr ≥0.67 (Bradshaw et al., 2010).

Symmetry analysis

Right and left sided stroke rates were calculated using visual inspection of the starting stroke and a customised LabView programme to calculate the mean left and right sided stroke rates for each trial (excluding the initial starting 10 single strokes). Trial one was included in this analysis to allow adequate sampling (n = 10 trials) for a 12-paddler case series approach in

order to estimate a threshold for when asymmetries could be harmful to an individual's performance. Asymmetries were interpreted when the average stroke rate difference was greater than the smallest worthwhile change (1.2%) between left and right sides. The raw magnitude of the asymmetry was correlated with performance time for each trial for each individual using a Pearson correlation coefficient with significance set to $p < 0.05$ to determine if asymmetries may have been detrimental to performance. The size of the association was interpreted as trivial ($r < 0.10$), small ($r = 0.10$-0.29), moderate ($r = 0.30$-0.49), large ($r = 0.50$-0.69), very large ($r = 0.70$-0.89), or nearly perfect ($r = 0.90$-1.00) (Hopkins, 2002).

Validation of a two-stroke sampling method for assessing stroke rate

Mean stroke rates for two consecutive strokes were assessed between 20-80% of the total race time at increments of 10%. Data were extracted using a customised LabView programme. Differences between the stroke rate sampled at each interval of the profile, and the mean stroke rate of the trial, were assessed using the mean difference as a percentage, 90% confidence limits, and interpreted using the smallest worthwhile effect and effect size. An ICCr value of 0.90 was necessary to validate this method for use in research.

Results

Reliability

With a smallest worthwhile change in 200-m time of 0.7%, the difference in performance time between T1-T2 (Mean difference ±90% confidence interval: -1.0 ±0.8%) was of sufficient magnitude to identify a possible change. The small change found (Cohen's effect size, ES = 0.2) in performance time between T1-T2 rationalizes the exclusion of trial one, and use of trial two as our baseline trial for the reliability analysis. Baseline-trial descriptive statistics and the between-trial effect statistics (excluding trial one) are shown in Table 8.1. The typical errors for each variable were very similar for each pair of trials, so only the average was reported for clarity. The magnitude of the possible increase in relative water time (%) between T3-T2 was considered trivial (ES = 0.0). The remaining changes were observed between trials T5-T2. Possible changes occurred for stroke rate, water time (s), entry time (%), and exit time (%); effect sizes were 0.2, -0.1, -0.1, and 0.0 respectively. Therefore, only stroke rate had a small meaningful change while the changes were trivial for water time (s), entry time (%), and exit time (%). There was a small reduction in pull time between T5-T2 (ES = -0.2). The differences between all other variables between all trials did not show any meaningful changes using the smallest worthwhile effects. The ICCr values for all variables between all pairs of trials were large enough to meet the second criteria for good reliability.

Table 8.1. Within-trial descriptive statistics and between-trial reliability of performance time, stroke rate, phase times, and sub-phase times in 12 competitive club male sprint kayak paddlers performing two separate testing sessions of 5 x 200-m time-trials on-water.

Variable (n = 24 samples per trial)	T2 Mean ± SD	TE$_{ave}$	T3-T2 MDiff% ± 90% CI	T3-T2 ICCr ± 90% CI	T4-T2 MDiff% ± 90% CI	T4-T2 ICCr ± 90% CI	T5-T2 MDiff% ± 90% CI	T5-T2 ICCr ± 90% CI
200-m time (s)	46.2 ±3.2	2.3%	-0.3 ±1.2	0.87 ±0.09	-0.1 ±1.0	0.94 ±0.04	0.0 ±1.1	0.93 ±0.05
Stroke rate (spm)	122.0 ±11.0	3.9%	0.5 ±1.8	0.85 ±0.10	0.5 ±1.8	0.83 ±0.11	1.7 ±2.1 *	0.80 ±0.13
Water time (s)	0.332 ±0.036	0.012	0.000 ±0.006	0.91 ±0.07	-0.001 ±0.005	0.91 ±0.06	-0.005 ±0.006 *	0.88 ±0.08
Entry time (s)	0.110 ±0.017	0.006	-0.001 ±0.003	0.90 ±0.07	-0.001 ±0.003	0.90 ±0.07	-0.001 ±0.003	0.90 ±0.07
Pull time (s)	0.137 ±0.028	0.008	0.001 ±0.004	0.93 ±0.05	-0.001 ±0.003	0.96 ±0.04	-0.004 ±0.004 **	0.89 ±0.08
Exit time (s)	0.086 ±0.015	0.003	-0.001 ±0.001	0.98 ±0.02	0.000 ±0.002	0.95 ±0.03	0.000 ±0.002	0.95 ±0.04
Aerial time (s)	0.165 ±0.021	0.009	-0.002 ±0.004	0.87 ±0.09	-0.002 ±0.004	0.84 ±0.11	-0.003 ±0.005	0.77 ±0.14
Water time (%)	66.8 ±3.1	0.6	0.2 ±0.3 *	0.97 ±0.02	0.1 ±0.3	0.97 ±0.02	0.2 ±0.4	0.93 ±0.05
Entry time (%)	22.0 ±2.2	0.6	0.1 ±0.3	0.95 ±0.03	0.1 ±0.3	0.94 ±0.04	0.2 ±0.3 *	0.90 ±0.07
Pull time (%)	27.6 ±5.3	1.1	0.2 ±0.5	0.97 ±0.02	0.0 ±0.4	0.98 ±0.02	-0.4 ±0.6	0.94 ±0.04
Exit time (%)	17.2 ±2.2	0.5	-0.1 ±0.3	0.95 ±0.04	0.0 ±0.2	0.97 ±0.02	0.3 ±0.3 *	0.91 ±0.06
Aerial time (%)	33.2 ±3.1	0.6	-0.2 ±0.3	0.97 ±0.02	-0.1 ±0.3	0.97 ±0.02	-0.2 ±0.4	0.94 ±0.04

TE$_{ave}$ = between-trial typical error averaged for T3-T2, T4-T2, T5-T2, and expressed as a percentage for 200-m time and stroke rate and as the raw typical error for all other variables. Smallest worthwhile changes were: 0.7% (200-m time), 1.2% (stroke rate), 0.003 s (water and aerial time), 0.002 s (entry and pull time), 0.001 s (exit time), 0.2% of the stroke cycle (relative water, aerial, entry and exit time), and 0.3% of the stroke cycle (relative pull time). Changes (*possible, **likely) were interpreted using mechanistic inferences and when the benefit/harm ratio >66 (Batterham & Hopkins, 2005).

Symmetry

Descriptive statistics, the differences between left and right sided stroke rates, and the correlation coefficient between asymmetry magnitude and performance time for each paddlers' ten trials are shown in Figure 8.2. As a group, stroke rate was lower for the left-sided stroke (121 spm) and higher for the right-sided stroke (125 spm) with an average difference of ~4 spm (3.3%) between sides. All paddlers except one, had a meaningful difference (>1.2%) in stroke rate between left and right sided strokes. Mean asymmetries ranged 0.9-9.4% for each paddler, and were equivalent to asymmetries of 1-12 spm as raw values. Paddler 3 had a significant correlation between asymmetry magnitude and his performance times ($r = 0.84$, $p = 0.003$) shown in Figure 8.2. The differences between left and right-sided stroke rates were 12 ±2 spm for all of his ten trials (asymmetries were not less than 10 spm for any trial). In contrast, paddler 2 had a large negative significant correlation between asymmetry magnitude and his performance times ($r = -0.68$, $p = 0.03$), but his stroke rate asymmetries were much smaller (4 ±2 spm). No other paddlers had statistically significant correlations between asymmetry magnitude and performance times. However, paddlers 1, 5, 6, 9, 10, 11, and 12 had possible trends toward better performance with greater asymmetries. Paddlers 7 and 8 may have had possible trends toward worse performance with greater asymmetries.

Two-stroke sampling method for stroke rate

The mean stroke rate profile for the group of paddlers, and individual examples of stroke rate profiles are shown in Figure 8.3. Measuring stroke rate at ~50% of 200-m time corresponded best with the mean stroke rate for the group (Table 8.2).

A follow-up frequency analysis with intervals of 2 spm (measurement error when sampling individual strokes), showed that about 68% of all samples were within ±2 spm of the actual mean for the time-trial. Differences of about ±4 spm were seen in 22%, differences of ±6 spm were seen in 9%, and a difference of 8 spm was seen in 1% of the 120 trials sampled (Figure 8.4).
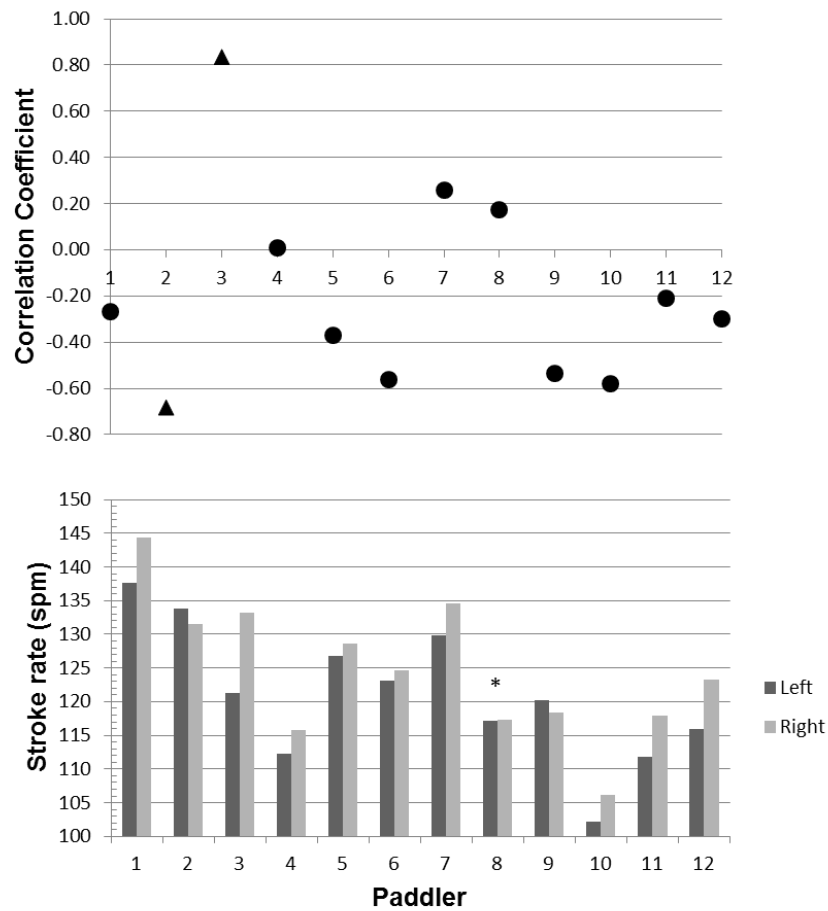
* denotes no meaningful difference <1.2% in stroke rate between sides; ▲ *denotes statistical significance, p <0.05.*

Figure 8.2. Average left and right stroke rate descriptive statistics for each individual in order of performance rank, and the association between asymmetry magnitude and 200-m time.

Table 8.2. The accuracy of using a two-stroke sample for estimating mean stroke rate of a 200-m time-trial.

Sample comparison	MDiff% ± 90% CI	ICCr ± 90% CI	ES	Inference
20%-Mean SR	5.2 ± 0.6	0.90 ± 0.02	0.7	Overestimation, most likely
30%-Mean SR	3.4 ± 0.4	0.97 ± 0.01	0.4	Overestimation, most likely
40%-Mean SR	1.7 ± 0.4	0.97 ± 0.01	0.2	Overestimation, very likely
50%-Mean SR	-0.6 ± 0.4	0.96 ± 0.01	-0.1	Trivial difference, most likely
60%-Mean SR	-1.8 ± 0.4	0.95 ± 0.02	-0.2	Underestimation, very likely
70%-Mean SR	-2.9 ± 0.4	0.95 ± 0.02	-0.4	Underestimation, most likely
80%-Mean SR	-4.2 ± 0.4	0.94 ± 0.02	-0.6	Underestimation, most likely

SR, stroke rate; MDiff%, mean difference expressed as a percentage; CI, confidence interval; ICCr, intra-class correlation coefficient; ES, effect size.
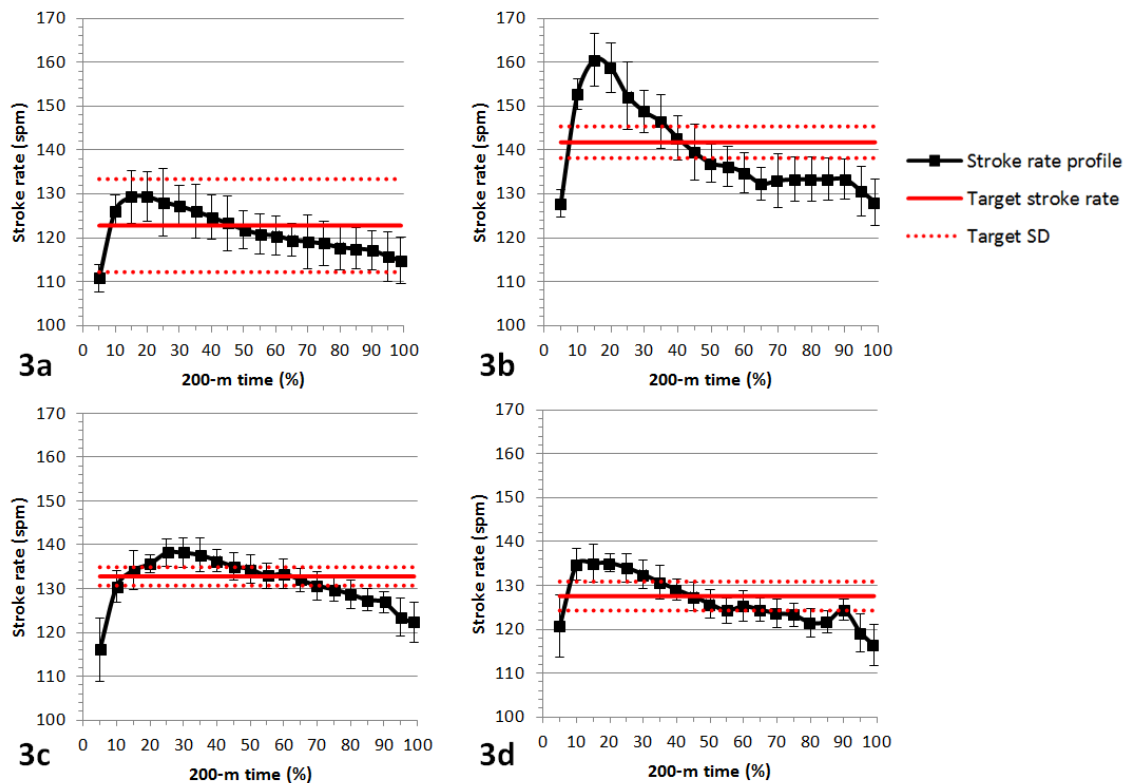
Figure 8.3. The group's mean (3a) stroke rate (123 spm) plotted across the group's mean stroke rate profile ± standard deviation (between-paddler variation), and examples of within-paddler profiles with respect to their mean stroke rate ± standard deviation of all 10 trials for the 1st ranked paddler (3b), 2nd ranked paddler (3c) and 3rd ranked paddler (3d) showed that the mean stroke rate corresponded with stroke rate observed between 40-60% of the profile and depended on the paddler's profile.
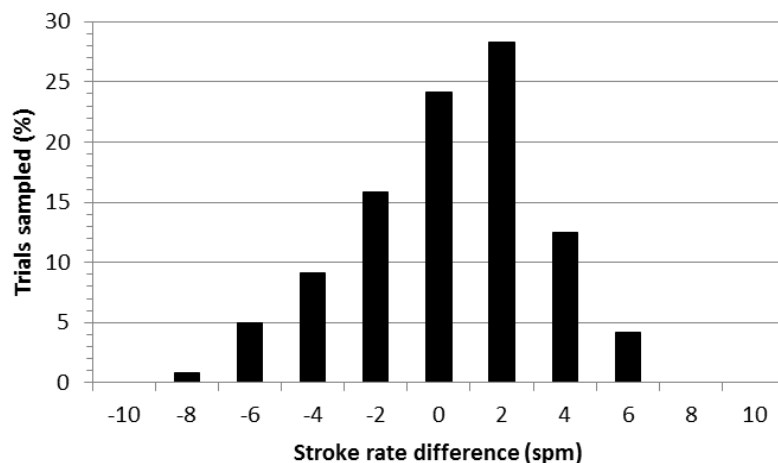
Figure 8.4. If choosing to sample two consecutive strokes at 50% of a 200-m time-trial, accurate stroke rates to within ±2 spm are limited to 68% of the trials (n = 120 trials).

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Discussion

All variables (200-m performance time, stroke rate, phase and sub-phase times) were reliable between trials T3-T2 and T4-T2. Using the smallest worthwhile changes 0.7% for performance time, 1.2% for stroke rate, 0.003 s for water and aerial time, 0.002 s for entry, pull, and exit time, 0.2% for relative water, aerial, entry and exit times, and 0.3% for relative pull time, no meaningful effects between trials T3-T2 or T4-T2 were observed. The mean difference in stroke rate between trials (0.5%) were comparable to that of elite paddlers in another study (0.8%) (McDonnell et al., 2012b). The smallest worthwhile changes in phase and sub-phase times are likely suitable for use at the elite level for assessing the means of 200-m time-trials. The smallest worthwhile change in performance time was larger than that of elite paddlers (0.3%) placing in the A finals of world cup and world championship competitions (Bonetti & Hopkins, 2010). It was expected that our paddlers would have a higher level of variability given their non-elite status. Even within the elite ability level, the variability of men's K1 200-m B finalists were much larger (3.4%) than the A finalists (0.8%) (Bonetti & Hopkins, 2010). The performance times of our athletes ranged between 40-50 s (4-5 m/s average pace), which aligns with performance ability ranging from club level to lower-end national level (Brown et al., 2011). Our paddlers performed with reasonably low variability (2.3%) for their performance level. However, our findings are limited to repeat trials on the same day when weather conditions are also likely to be more consistent than the variability observed between competition days (Bonetti & Hopkins, 2010). While these smallest worthwhile changes were appropriate for group use, the large between-subject standard deviations shown for trial two, and large 90% confidence intervals between all pairs of trials are supportive that coaches should opt to determine the smallest worthwhile changes for each athlete to make the most meaningful decision regarding an individual's improvement. While determining the smallest worthwhile change in performance time may take considerable time, it is the most important variable to individualize.

While a number of possible changes were observed in the technique patterns (stroke rate, phase and sub-phase times) between trials T5-T2, absolute water time (s), relative entry and exit times (%) effect sizes were trivial. Nevertheless, a small increase in stroke rate (1.7%) and small decrease in pull time (-0.004 s) were observed between T5-T2. Given there were no changes in performance time between T5-T2, our results indicate that the increase in stroke rate was possibly compensating for a shorter stroke as the paddlers became fatigued, resulting in a maintenance of performance with a reduction of stroke displacement. Increasing stroke rate in trial five, was accomplished by decreasing the amount of time the blade was in contact with the water (pull time). Michael, Rooney, and Smith (2012) suggested that the most effective stroke would be one where the propulsive force is rapidly achieved, as large as can be, maintained for as long as possible, and reduced to zero in the shortest amount of time. A fast entry time, maintaining a longer pull time, and achieving a quick exit time are therefore temporal characteristics of a good stroke. In contrast, achieving a longer pull time could be due to lower force production following muscular fatigue, and in this case would be detrimental to performance. The propulsive force is also proportional to the relative velocity of the paddle

blade in the water, thus a high turn-over of the blade as indicated by a high stroke rate, is necessary for achieving a high propulsive force. These principles combined along with our results, indicate that pull time may heavily influence the effectiveness of stroke rate. Further research is needed to clarify the effect of increasing stroke rate on pull time and performance.

The notion that technique asymmetries may be harmful for performance is based on the premise that symmetrical force profiles of right and left sides are needed to minimize kayak yaw, roll, and pitch (Michael et al., 2012), and greater boat movements (roll and pitch; yaw excluded from the methods) have been observed in paddlers of lower performance abilities (Brown et al., 2011). Asymmetries in stroke rhythm have also been of interest in previous research (Qiu et al., 2005), though the theoretical rationale had not been stated. There has been no evidence of the direct association between asymmetries and performance until now. Although we did not consider asymmetries of the stroke phases, we did observe substantial asymmetries between right and left sides for stroke rate, which would have indicated substantial asymmetries in the phase times. The magnitude of asymmetries did not seem to be associated with lower stroke rates or poorer performance times between individuals in our study. Our results support that asymmetries for the group averaged ~4 spm, and were only harmful for an individual above a certain magnitude where his lowest asymmetry was 10 spm. This finding supports that some asymmetries, likely induced by strength differences, between sides of the body are normal to an extent, and such strength asymmetries may become more pronounced when the paddler approaches their maximal paddling speeds. It would be worthwhile for researchers to quantify the force asymmetries that are harmful for performance. From a performance perspective, we suggest that the threshold for acceptable stroke rate asymmetries should be 4 spm given this was the group's norm. Asymmetries >4 spm should be assessed further to determine the extent of performance harm for that individual, and asymmetries ≥10 spm should be considered harmful.

Analysing two consecutive strokes is common practice in kayak biomechanics research (McDonnell et al., 2013a). While it is best to assess stroke rate for an entire race profile, this approach is not always feasible in research of competitions or for coaches on a consistent basis. The best place for a two-stroke analysis was originally recommended as 75% of the race distance (for 500-m and 1000-m distances), however the rationale and evidence were not provided (Plagenhoef, 1979). Other research had assessed technique at 50% of the race distance for 200-m and 80% of the race distance for 500-m, which both coincided with 100-m before the finish-line (Brown et al., 2011). Our findings support that 50% of the race-time is when stroke rate best corresponds with the mean stroke rate of the trial. From our personal experience with elite athletes' split times for 200-m race distances, 50% of the race distance is close to 50% of the race time (51% of the race time). While the other samples were not valid measures of mean stroke rate for the trials, the high ICCr values between 20-80% of the trial time do indicate that the reliability was good when assessing stroke rate at any stage of the race as long as the assessment was performed at the same part of the race.

We must note that on an individual basis, the best place to assess stroke rate (to achieve a valid measure of mean stroke rate) can range between 40-60% of the time-trial depending on

the paddler's typical profile. Therefore to enhance the quality of subsequent two-stroke analyses for day-to-day training feedback or research, when mean stroke rate accuracy is important, the proportion of the race that best coincides with mean stroke rate for each paddler should be pre-determined. However, the highest quality analysis requires a stroke-to-stroke analysis of all stroke rates.

To improve the level of accuracy when assessing 200-m stroke rates and phase times with 60 Hz video, phase-defining positions were digitised to the nearest half frame. We were able to accept a lower smallest worthwhile effect than the measurement error of one frame (0.008 s) because after averaging about 80 strokes, much of the error introduced in digitising would balance out to well below that of one frame. Therefore if coaches or researchers were to use a two-stroke analysis, either a larger sampling rate or a larger smallest detectable change may be needed to determine if changes truly existed. The reason why we observed trivial differences with the real mean stroke rate, when sampling two strokes at 50%, was likely due to a large sample size of 120 trials. While we used all ten trials to allow adequate sample size for investigating individual associations between asymmetries and performance, the effect of any intervention on improving asymmetry and subsequently its effect on performance needs to be confirmed using reliable trials. Typically, the most reliable trials were trials 2, 3, and 4.

Conclusions

Repeat testing of 200-m performances was reliable for up to four trials after trial one was excluded as a familiarisation trial, however, technique differed in the fifth trial likely due to fatigue. The smallest worthwhile changes in performance time should be individualised, however the smallest worthwhile changes in stroke rate, phase and sub-phase times could be applied to all levels of paddlers for a within-day analysis. Within-day testing is likely more reliable than between-day testing, thus care needs to be taken when using these smallest worthwhile changes in the practical environment. Based on group norms, asymmetries up to 4 spm are not likely harmful for performance. Coaches may want to consult a strength coach for minimising asymmetries between 5-9 spm as a preventative measure, and stroke rate asymmetries ≥10 spm should be considered harmful for performance. A two-stroke assessment of stroke rate can be accurately performed between 40-60% of a time-trial, but the validity varies between individuals. Statistically, assessing stroke rate for two strokes at 50% of the time-trial best reflected the mean stroke rate.

Chapter 9: The effect of metronome feedback on stroke rate in sprint kayaking

This chapter will be submitted for journal review as:

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013 to be submitted for review). The effect of metronome feedback on stroke rate in sprint kayaking. Research Quarterly for Exercise and Sport.

Overview

This study determined the efficacy of metronome feedback for achieving target stroke rates and its effect on 200-m performance time. Twelve competitive club male paddlers performed five 200-m time trials per day for two days (one week apart) in a single kayak with a bow-mounted GoPro HD Hero 60 Hz video camera to determine their average self-selected stroke rates (SS). Each paddler was given two weeks to perform a familiarization protocol with the metronome before repeating the two days of five 200-m time trials set to various cadences around their self-selected stroke rates. The efficacy of metronome feedback and the effect of stroke rate on 200-m performance were assessed using the mean difference as a percentage (MDiff%) for 200-m time and stroke rate and mean difference as a raw value (MDiff) for stroke rhythm variables. Interpretations were made based on the likelihood of the true value (90% confidence intervals accounted for uncertainty of the measured effect) being greater than the smallest worthwhile effect, and was qualitatively described by interpreting effect sizes (ES). Trials 1 and 5 were excluded from the analysis to assess the most reliable trials. Anticipating trial 1 exclusion, trial 2 was designed to be the baseline trial. The effect of stroke rate on 200-m kayaking performance and stroke rhythm was assessed between trials two to three (Target rates: SS to SS+5 spm) and two to four (Target rates: SS to SS+10 spm). There were trivial differences between the measured stroke rate and target stroke rate for the SS trial (ES: -0.1), however stroke rates were under target for SS+5 spm (ES: -0.2) and SS+10 spm (ES: -0.5). Individuals varied in their adherence to metronome feedback. Metronome feedback was effective for increasing stroke rate in trials 3 and 4 by 2.9% and 4.2% respectively for most paddlers even though the desired stroke rates were not reached. The acute increase in stroke rate led to reductions in the water and aerial phase times. The reduction in water phase time was attributed primarily to a reduction in pull sub-phase time. While the reduction in pull sub-phase time may have been detrimental toward stroke efficiency, this intervention led to a meaningful performance time enhancement of 0.9-1.0%. The results support that augmented feedback is important to incorporate into the training environment. The metronome is a useful tool for maximising a paddler's performance via stroke rate control.

Introduction

Stroke rate is potentially the most important kinematic determinant of sprint kayak performance (McDonnell et al., 2013a), however the effect of increasing stroke rate during on-

water performance has not been tested. To improve performance, a feedback system would be useful for controlling stroke rates at designated targets. When attempting to achieve a target rate, it would also be important to document the efficacy of the feedback for implementing the intervention in a practical environment.

Based on commercial equipment available, visual or auditory feedback can be provided for stroke rate in sprint kayaking. When timing tasks are important, auditory feedback is more effective as a feedback tool (Doody, Bird, & Ross, 1985), likely by minimising the brain processing time required to make motor adjustments for increasing or decreasing stroke rate. In a sport where stroke rate may have such importance, it is surprising that the effectiveness of auditory feedback in sprint kayaking has not been documented. Therefore, this study aimed to determine the efficacy of metronome feedback for achieving target stroke rates. Subsequently, the effect of increasing stroke rate on performance, phase and sub-phase times were also assessed.

Methods

All procedures used in this study were approved by the university ethics committee. Each paddler gave written informed consent, and all testing occurred on the same pre-measured 200-m course marked with land-based reference markers for the start and finish.

Participants

The 12 competitive male kayak paddlers who participated in this study (mean ±SD age: 27 ±7 y, height: 180 ±4 cm, mass: 84 ±8 kg) were all free of injury at the time of data collection.

Equipment

The GoPro HD Hero 60 Hz digital video camera (Woodman Labs, Inc, Half Moon Bay, CA, USA) was secured within a waterproof casing and mounted to the front of the boat to record blade entry and exit points for assessing stroke rate and stroke phase times (Figure 9.1). A stationary land-based 300 Hz Casio Ex-F1 digital video camera (Casio Computer Co., Ltd, Shibuya, Tokyo, Japan) recorded the sagittal plane of the kayak crossing the finish line to calculate 200-m performance time after being manually synchronized with boat mounted video by performing a maneuver consisting of raising the paddle above the head then slapping the back of the paddle blade against the water quickly. The first point of contact between the blade and water was used as a synchronisation mark.
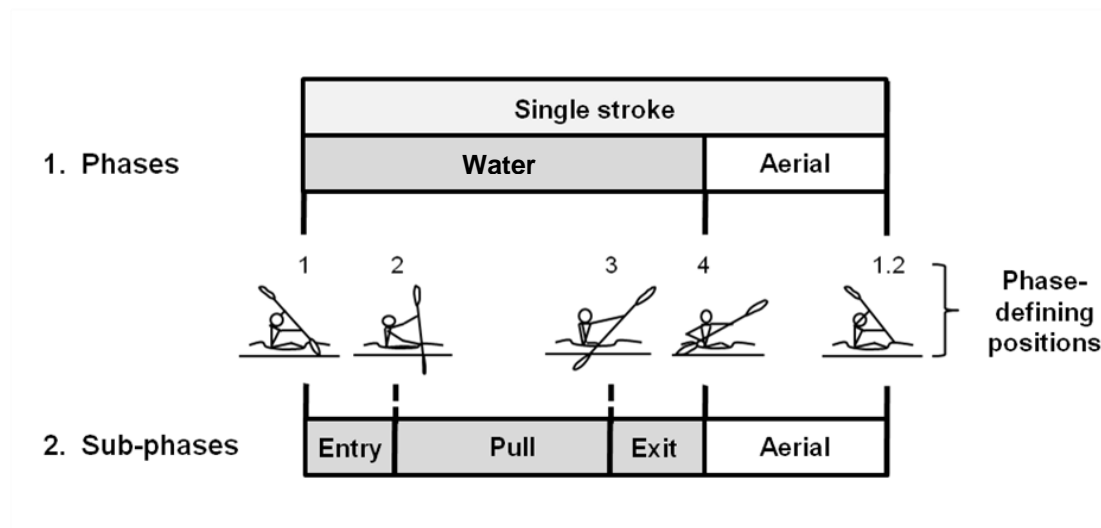
Figure 9.1. Catch (1), immersion (2), extraction (3) and release (4) positions were used for temporal analysis of the sprint kayak stroke. The catch of the opposite side (1.2) comprises the end of a full single-sided stroke.

Procedure

Individual self-selected (SS) stroke rates were determined using the average stroke rate of 10 time-trials of 200-m performed over two separate days with no metronome feedback. Paddlers had two weeks to perform a familiarisation protocol to become familiar with the five target stroke rates ranging from 5 spm below their self-selected to 15 spm above their self-selected. Paddlers performed 20 strokes on the kayak ergometer at each target stroke rate, then 20 strokes in their K1 kayak at each target stroke rate, and on separate days performed 1 x 200-m time trial at each of the five target stroke rates. On the first intervention testing day, following a warm-up, paddlers performed five 200-m time-trials from a floating start in K1 boats equipped with a bow-mounted waterproof digital video camera. Trial 1 was performed at 5 spm below the self-selected stroke rate. Trial 2 was considered the baseline trial, and was set to target the self-selected stroke rate. Paddlers aimed to target 5, 10, and 15 spm higher than the self-selected stroke rate for trials 3, 4, and 5. Paddlers had 15-20 minutes recovery between trials. A brief warm-up period for about five minutes occurred prior to each consecutive time-trial. Race times were provided to paddlers following each trial, and paddlers were encouraged by the researchers to perform a best effort for each trial. Adequate rest for a full recovery (as much as possible with five time-trials) was confirmed verbally with each paddler prior to commencing the next trial to ensure the paddler was ready to produce a best effort. Paddlers returned one week later for a re-test of all five time-trials at the same time of day, and with the same boat, paddle, warm-up, and metronome feedback settings.

Analyses

Data were reviewed using QuickTime 7 Pro (Apple Inc., Cupertino, USA) and manually digitised by entering frame numbers into Excel (Microsoft, Redmond, USA). Race times were extracted from synchronised video of the start and finish for all trials (trials 1-5). Stroke rate was extracted for every stroke (approximately 90 strokes per trial). Stroke rate data for the initial acceleration period, the first ten strokes, were excluded from the analyses. After data analyses showed that trial one was best treated as a familiarisation trial, and fatigue had altered technique for trial five, both trials one and five were excluded from further analyses.

The effect of metronome feedback was assessed using the difference between mean stroke rate and the target stroke rate. Each trial (2, 3, 4) was assessed separately to determine the effectiveness of metronome feedback for normal self-selected, +5 spm, and +10 spm targets (n = 24 samples per trial). Good efficacy was considered when the mean difference was likely less than the smallest worthwhile change in stroke rate (1.2%), using 90% confidence intervals to estimate the uncertainty of the mean difference. Moderate efficacy was considered when the feedback led to a measurable increase in stroke rate compared to the self-selected trial. Poor efficacy was considered when the stroke rate was measurably below the self-selected stroke rate.

The effect of increasing stroke rate on performance time, phase and sub-phase times was assessed using the mean difference, smallest worthwhile effects, with outcomes based on the likelihood of a beneficial or harmful effect and standardised effect sizes (Batterham & Hopkins, 2005). The smallest worthwhile changes were 0.7% for performance time, 0.003 s for water and aerial time, 0.002 s for entry, pull, and exit time, 0.2% for relative water, aerial, entry and exit times, and 0.3% for relative pull time, determined from a previous reliability study using the same participants.

The paddlers' ability to adhere to metronome feedback was documented by plotting the actual-target stroke rate difference for each paddler in order of pre-test (average of 10 time-trials with no metronome feedback) performance rank. Paddlers were also ranked in order (1-12) of best to worst stroke rate adherence for each trial based on the largest difference magnitude, and their ranking scores were averaged to identify the best and worst responders to feedback.

Results

Paddlers adhered to the metronome feedback for the self-selected stroke rates only (Table 9.1). Overall, accuracy to the target rate was compromised slightly when attempting to increase the stroke rate by 5 spm (4%), and missed the target by 1.6% on average, which is considered a small but meaningful difference. When attempting to increase stroke rate by 10 spm (8%), paddlers missed the target by about 4.1%. Results of the combined days and intervention days separately, show no improvement of metronome adherence for the intervention day two.

Table 9.1. Metronome effectiveness for repeat testing days and individual testing days to show that familiarisation was not likely an issue for metronome adherence.

Combined days	MDiff% ± 90% CI	ES	Qualitative Outcome
A-T Self-selected	-0.5 ± 0.9	-0.1	Trivial, likely
A-T +5 spm	-1.6 ± 0.8	-0.2	Under target, likely
A-T +10 spm	-4.1 ± 1.1	-0.5	Under target, most likely
Day 1			
A-T Self-selected	-0.2 ± 1.7	0.0	Unclear, need more data
A-T +5 spm	-1.0 ± 1.6	-0.1	Trivial, possibly under target
A-T +10 spm	-3.5 ± 1.7	-0.4	Under target, very likely
Day 2			
A-T Self-selected	-0.7 ± 1.1	-0.1	Trivial, likely
A-T +5 spm	-2.2 ± 0.6	-0.3	Under target, most likely
A-T +10 spm	-4.7 ± 1.7	-0.6	Under target, most likely

A-T, actual – target stroke rates; MDiff%, mean difference expressed as a percentage; ES, effect size.

Although paddlers achieved stroke rates under the target stroke rate using a metronome, the use of the metronome was found effective for increasing stroke rate of a meaningful magnitude (>1.2%) compared to the self-selected trial. Paddlers increased their stroke rates by 2.9% (~4 spm) from trials two to three, and increased their stroke rates by about 4.2% (~5 spm) from trials two to four. Subsequently, the effect of increasing stroke rate by these magnitudes on performance, phase and sub-phase times are shown in Table 9.2. A small increase in stroke rate of 2.9-4.2% led to a small, but meaningful performance time enhancement of 0.9-1.0%.

Table 9.2. Effect of stroke rate on performance time, phase and sub-phase times in sprint kayaking 200-m time-trials.

Variable (n = 24 samples per trial)	T2 Mean ± SD	T3-T2 (+4 spm)			T4-T2 (+5 spm)		
		MDiff ± 90% CI	ES	Qualitative outcome	MDiff ± 90% CI	ES	Qualitative outcome
200-m time (s)	46.3 ±2.6	-0.9 ±0.8	-0.2	Beneficial, possibly	-1.0 ±0.9	-0.2	Beneficial, possibly
Stroke rate (spm)	122.4 ±9.7	2.9 ±0.8	0.4	Increased, most likely	4.2 ±1.1	0.5	Increased, most likely
Water time (s)	0.329 ±0.033	-0.008 ±0.003	-0.2	Decreased, most likely	-0.012 ±0.003	-0.3	Decreased, most likely
Entry time (s)	0.106 ±0.014	0.000 ±0.001	0.0	Trivial, very likely	-0.001 ±0.002	-0.1	Trivial, likely
Pull time (s)	0.138 ±0.028	-0.008 ±0.002	-0.3	Decreased, most likely	-0.010 ±0.003	-0.4	Decreased, most likely
Exit time (s)	0.085 ±0.014	-0.001 ±0.002	0.0	Unclear	-0.001 ±0.001	0.0	Trivial, likely
Aerial time (s)	0.167 ±0.019	-0.005 ±0.002	-0.3	Decreased, very likely	-0.008 ±0.003	-0.4	Decreased, most likely
Water time (%)	66.3 ±3.5	0.1 ±0.3	0.0	Unclear	0.3 ±0.3	0.1	Trivial, possibly
Entry time (%)	21.4 ±2.5	0.6 ±0.2	0.2	Increased, very likely	0.7 ±0.3	0.3	Increase, most likely
Pull time (%)	27.8 ±4.7	-0.8 ±0.4	-0.2	Decrease, very likely	-1.1 ±0.5	-0.2	Decrease, very likely
Exit time (%)	17.2 ±2.2	0.4 ±0.3	0.2	Increase, likely	0.6 ±0.3	0.3	Increase, very likely
Aerial time (%)	33.7 ±3.5	-0.1 ±0.2	0.0	Unclear	-0.2 ±0.3	-0.1	Trivial, possibly

SD, standard deviation; MDiff, mean difference reported as a percentage for 200-m time and stroke rate and raw value for other variables; ES, effect size.

Stroke rate was increased by reductions in both absolute water and aerial phase times. There were no meaningful differences in the relative water and aerial phase times when presented as a percentage of the stroke cycle. The water phase time reduction was attributed mostly to a decreased pull phase time. Entry and exit sub-phase time changes remained trivial with the small stroke rate increases, and consequently, relative entry and exit sub-phase times lengthened relative to the stroke.

The difference between actual and target stroke rates were plotted for each paddler in order of performance rank (Figure 9.2). Good responders to stroke rate feedback (top third of the population with the best overall adherence and in order of the best adherence) were performance ranked paddlers 11, 4, 5, and 3. Poor responders (bottom third of the population with the worst overall adherence but in order of best adherence) were performance ranked paddlers 10, 2, 7, and 9.
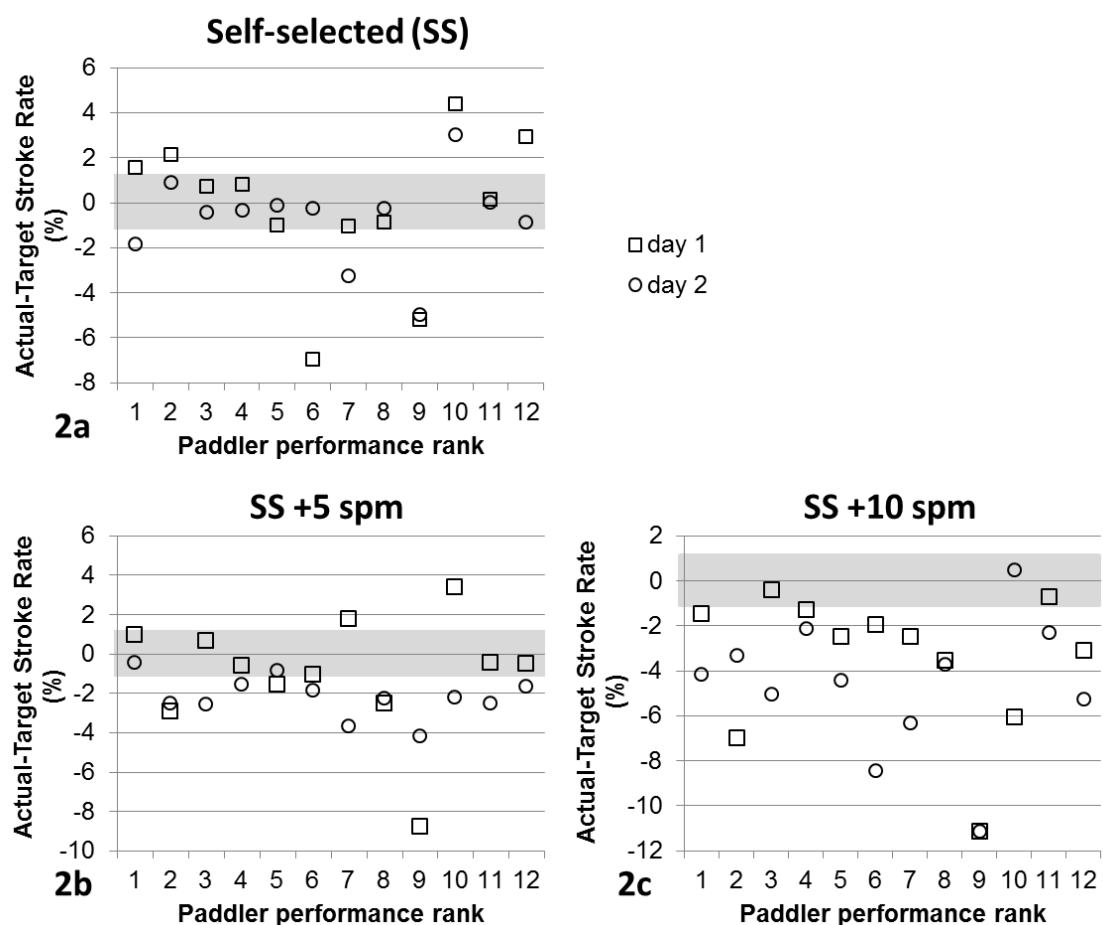
Full adherence to feedback is shown in the grey region (±1.2% from target). Negative values indicated stroke rates were under target. Values less than -4% in 2b and less than -8% in 2c were under the self-selected stroke rates.

Figure 9.2. Metronome stroke rate feedback adherence for each paddler for both intervention testing days.

Examples of stroke rate profiles without and with metronome feedback are shown in Figure 9.3 for the fastest and slowest paddlers participating in this study. Both paddlers responded moderately well to metronome feedback compared to the group.
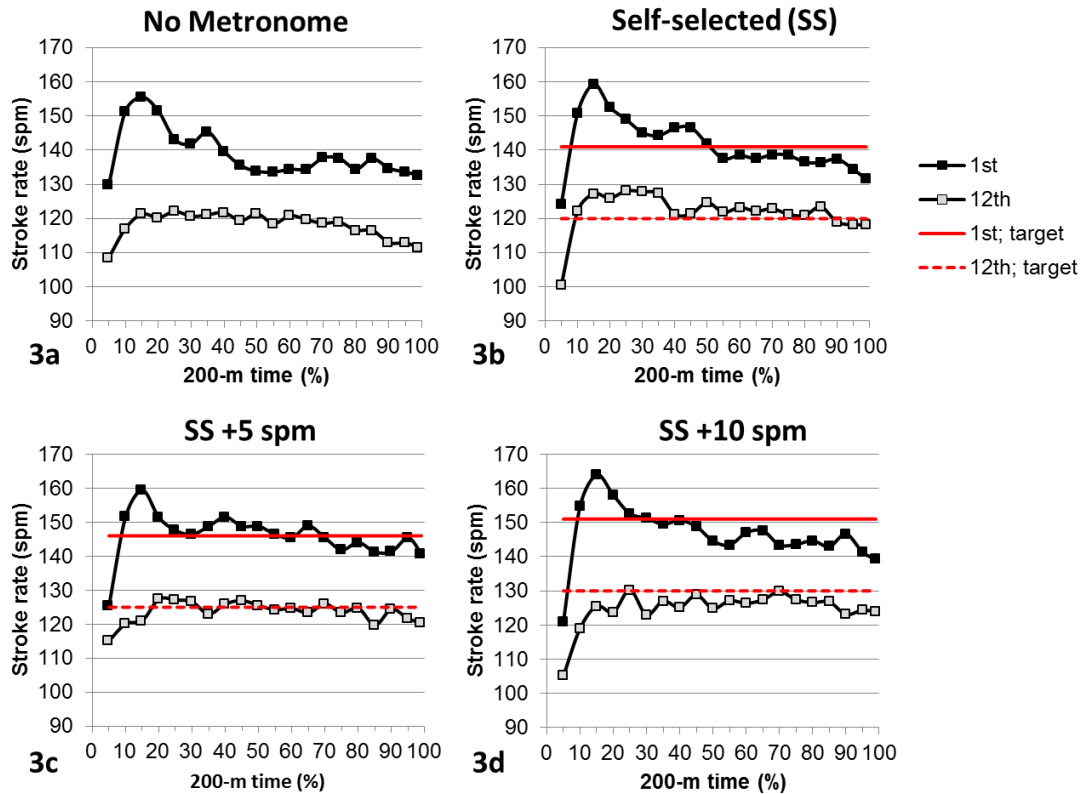
Mean stroke rates in 3a were similar to the target rate for 3b; both paddlers were over target for 3b; both were on target for 3c; and under target for 3d; both achieved their highest average stroke rates in 3d.

Figure 9.3. Single trial examples of stroke rate profiles without (3a) and with metronome feedback (3b-3d) in the fastest (1st) and slowest (12th) paddlers.

Discussion

This is the first known study to use metronome feedback in sprint kayaking to attempt to elicit a stroke rate increase of substantial size when paddlers are racing at maximal capacity. Given stroke rate is proportional to power output and an increase of substantial size would increase the intensity (Szanto, 2004), we expected this would be a difficult challenge for the paddlers. Our first main finding was that paddlers were able to increase stroke rates using metronome feedback, however they typically underachieved the target rate. Authors of swimming research have found similar underachievement of the target stroke rates at maximal race pace, attributed toward fatigue in the later part of the maximal-paced trial (Thompson, MacLaren, Lees, & Atkinson, 2002). Nevertheless, metronome feedback was still effective for

increasing stroke rate in our study by 2.9% and 4.2% compared to the normal self-selected stroke rates typically observed during maximal 200-m sprints.

Overall, increasing stroke rate by 2.9-4.2% led to a meaningful enhancement in performance time of 0.9-1.0%. This finding supports that the paddlers' ability to self-pace is not good enough to consistently achieve their best performance at maximal capacity, and augmented feedback (i.e. external feedback) of stroke rate is important to incorporate in the training environment. A higher stroke rate was achieved with small reductions in absolute water and absolute aerial phase times. Authors of previous research had suggested that increasing relative water phase time was indicative of more elite performance (Brown et al., 2011), but in our acute intervention, there was no change in the relative water (~66%) and relative aerial (~34%) phase times. Our relative water phase times were already approaching the upper limit of relative water phase times (~69%) reported in literature (Plagenhoef, 1979; Kendal & Sanders, 1992; Qiu et al., 2005). The change in water phase time was attributed mostly toward a decrease in pull time. Pull phase time did not maintain its length relative to the stroke cycle, as it would have been expected that a large propulsive force, assumed to be maximised during the pull phase, should be maintained as long as possible for an effective stroke (Michael et al., 2012). However, it appears that simply achieving a fast paddle-blade velocity is important for maintaining adequate power output for propulsion given the observed improvement in performance. Further research is needed to confirm the relationships between stroke rate and paddle-blade velocity to support this theory.

Stroke rate profiles of 200-m races in sprint kayaking normally exhibit a negative slope (McDonnell et al., 2013b), which was also apparent in our results of 200-m time-trials before metronome feedback was implemented. Previous studies in cycling, swimming, and kayaking research have observed that better performances typically occured in pacing profiles with a higher initial power output despite an inevitable gradual decline in power for the race duration in races lasting less than two minutes (Bishop, Bonetti, & Dawson, 2002; Tucker & Noakes, 2009). Therefore, when using a single non-adjustable metronome frequency, paddlers would need to anticipate a higher stroke rate for the beginning of the time-trial, and then rely on the feedback to help sustain the stroke rating later in the race as fatigue sets in. It may be useful for coaches to set a target rate slightly higher than the desired outcome if using single non-adjustable frequency metronome feedback, or to pursue a metronome feedback system that can provide variable stroke rate frequency feedback throughout the race.

The findings from Thompson et al. (2002) were supportive that metronome feedback led to less random error in swimmers' hand-placement frequency, and subsequently less variability in performance times compared to split-time feedback from the pool-side clock when swimming at submaximal pace. Subsequently, metronome feedback was found important for better regulating pacing at various training intensities. This is likely transferable to kayaking, given there appeared to be a slightly higher and more consistent stroke rate between 50-90% of the time-trial for the top paddler at the normal self-selected stroke rate. Even when increasing stroke rate by +5 spm (about 4%), there appeared to be less of a reduction in stroke rate toward the end of the trial for the fastest and slowest paddlers who both adhered well to the feedback in

that particular trial. Pacing strategies are regulated by the brain; complex algorithms, largely based on memory of a similar performance at the same distance with input of physiological responses, are developed to ensure the current pace will not cause pre-mature fatigue or systematic failure (Gibson et al., 2006). During an effort, there is an alternating cycle where modifications in muscular power output are made to regulate pace followed by a period of uncertainty about the appropriateness of the mechanical change based on the physiological response. This cycle causes fluctuating variability in pace throughout an athletic effort (Gibson et al., 2006). Prescribed metronome feedback based on or near a paddler's self-selected stroke rate may help bypass the periods of time when there is uncertainty about the appropriateness of a pace. With potentially less focus on the metabolic responses to paddling there may be a more constant and efficient pacing strategy. In contrast, a metronome setting too high could eventually lead to a metabolic response the brain cannot ignore, and pacing could become regulated again based on physiological capacity to finish the race. Since the brain-based algorithms for regulating pacing strategy seem to be largely based on an athletes' memory of tolerating physiological responses for a given period of time (Gibson et al., 2006), and metronome feedback was helpful for achieving and sustaining a higher stroke rate, incorporating more time-trials with metronome feedback in a paddler's training routine may lead to better retention of a faster more efficient and optimal pacing strategy on race-day without feedback.

Stroke rate adherence was not consistently better for day 2 for all trials, so paddlers likely received adequate familiarisation of the metronome. This supports the notion that audio feedback using a metronome yields quick results with minimal familiarisation (Thompson et al., 2002). However, we have provided some initial evidence that there are stroke rate responders and non-responders. Higher performing paddlers tended to have better adherence to metronome feedback at self-selected stroke rates and 5 spm above self-selected stroke rate than lower performing paddlers, but not always. Given force is proportional to the paddle blade's velocity squared, larger forces are possibly required to make the same stroke rate increase when starting at higher ratings. While the best and worst paddlers were able to achieve target stroke rates at 10 spm above their self-selected stroke rate at some point during their 200-m performances, their inability to sustain the high stroke rating led to a lower than expected average stroke rate. This possibly limited their performance enhancement when attempting to increase stroke rate by 10 spm (Figure 9.3d). Therefore, ability to increase stroke rate for acute metronome feedback to be effective may be due to any number of factors that would be related to the ability to produce and sustain a high force. Such factors can include, but are not limited to, initial self-selected stroke rate (e.g. higher stroke rates may be more difficult to increase), paddle blade surface area (Sumner et al., 2003), upper body girths or mesomorphy (Aitken & Jenkins, 1998; Ackland et al., 2003) and resistance to fatigue (Abbiss & Laursen, 2008). It may be helpful to identify characteristics that differentiate successful 200-m specialists from 500-m and 1000-m specialists, given stroke rates are higher in the shorter race distances (McDonnell et al., 2013a), in order to provide more insight into the characteristics that identify paddlers who may respond well to stroke rate enhancements.

While this research identified the usefulness of metronome feedback to acutely increase stroke rate which led to a successful performance enhancement, this research could not confirm the effectiveness of metronome feedback for long-term retention of a higher stroke rate in the absence of feedback. Augmented feedback may result in poor long-term retention of optimal pacing strategies (Schmidt, 2003; Sherwood & Lee, 2003). In order for augmented feedback to be effective for retaining optimal pacing strategies in sprint kayaking on race day in the absence of feedback, the paddler should learn to estimate errors between their actual and target stroke rate and learn to associate internal cues (i.e. physiological pacing, or changes in force-production) with augmented feedback (Schmidt, 2003; Sherwood & Lee, 2003). Because a changing pacing profile in short-duration sprints is inevitable, it may be better for the paddler to train with visual instantaneous feedback of a measured stroke rate rather than target one average stroke rate. A recent development that may improve stroke rate feedback and control is the Vaaka Kayak Cadence sensor (www.vaaka.co.nz, accessed 4th November, 2013). The Vaaka device collects stroke rate data and can display stroke rate on a gps-based sports watch such as the Garmin Forerunner or any device with ANT+ wireless technology. An advantage of visual feedback is that the paddler can choose when to receive feedback, and coaches can easily upload the data for review at a later time. Anecdotally, some of the paddler's participating in the present study described the metronome as "slightly annoying" despite its benefit. Further research is needed to investigate the effectiveness of other feedback modes (visual, auditory, tactile or multi-modal) during training and the frequency of feedback needed to retain long-term performance benefits from a stroke rate enhancement without growing dependency on feedback in sprint kayaking.

Conclusions

Individuals varied in their adherence to metronome feedback by over-achieving and under-achieving target stroke rates at self-selected and 5 spm above self-selected stroke rates. Most paddlers under-achieved the target stroke rate at 10 spm higher than self-selected stroke rates. On average, paddlers showed the capability of increasing stroke rate by 2.9-4.2%, which led to a performance time enhancement of 0.9-1.0%. Metronome feedback is a useful tool for stroke rate control in sprint kayaking. However, paddlers tended to under achieve the exact target rate during 200-m time-trials, which was likely attributed toward fatigue following 50% of the trial time.

Chapter 10: Discussion and conclusions

The overall aim of this thesis was to determine the effect of stroke rate on sprint kayaking performance. Four main questions emerged: (1) what stroke rates are required to achieve medal winning times?; (2) what are the typical self-selected stroke rates of New Zealand paddlers?; (3) do paddlers respond well to stroke rate feedback?; (4) what is the effect of increasing stroke rate on performance and technique? With limited pre-existing sprint kayaking biomechanics research, a number of unexpected additional contributions have been made in the area of sprint kayaking performance and technique analysis as a result of the thesis studies. This chapter binds the thesis as a cohesive whole, by highlighting the contributions from the findings of two literature reviews, one quantitative descriptive performance analysis, two quantitative experimental reliability studies, two quantitative experimental biomechanical studies, and one quantitative experimental intervention study.

Theoretical underpinning for investigating stroke rate

Flat-water sprint kayaking is a variant of canoeing, where a paddler is seated in narrow boats consisting of one, two or four paddlers (termed K1, K2, K4 respectively) and uses a double-bladed paddle for means of propulsion. Paddlers race on calm water producing cyclical right and left sided strokes in their own lane across distances of 200-m, 500-m, and 1000-m. Higher boat velocities are achieved in shorter event distances (i.e. 200-m compared to 500-m and 1000-m) and higher boat velocities are also achieved with the more paddlers in the boat (i.e. K4 compared to K2 and K1 boats) (Bonetti & Hopkins, 2010). Given the lack of research available in K1 boats and no published biomechanical research in kayaking team boats, the thesis was limited to K1 boats or individual paddlers with a focus on the fastest individual event, the K1 200-m event.

Over the years, advances in equipment design, such as the introduction of the wing paddle in the late 1980's and narrower hull shapes have appeared to assist with reductions in performance time (Michael, 2009). The wing paddle blade is shaped like a foil, so that if a paddler were to direct the paddle more laterally rather than straight backward, they could generate a lift force. This led to a change in technique, where paddlers initially burry the paddle blade, then draw the blade more laterally before withdrawing the blade from the water (Kendal, 1992). Information on the altered muscle mechanics of the "classic" technique compared to the current technique with the wing blade is limited, but the wing blade has helped reduce loading of the deltoid and triceps muscles during the middle of the water phase, and more activity can be seen by the dorsal muscles (Di Puccio, 2008). Overall, the propulsive actions in kayaking require leg extension, trunk rotation, a pushing action of the top arm, and a pulling action of the bottom arm. Muscles of the trunk and legs exhibit activation throughout the stroke cycle. Quadriceps (i.e. Rectus Femoris) exhibit greater activation than the hamstrings (i.e. Biceps Femoris), the ipsilateral Latissimus Dorsi (the side of the pulling arm) exhibits greater activation than the contralateral Latissimus Dorsi (side of the pushing arm), but ultimately the activity of

the External Obliques and Rectus Abdominis were best correlated with peak force, namely the contralateral rectus abdominis (Brown, 2010). Muscle activity of the Pectoralis Major has been overlooked in sprint kayaking research, but bench press is a common weight training exercise used to support the primary and secondary muscles of the push arm (Liow, 2002), namely the Pectoralis Major, Anterior Deltoid, and Serratus Anterior.

An effective stroke is one where the peak force is as large as possible, rapidly generated, sustained as long as possible, then reduced to zero as quickly as possible (Michael et al., 2009). Rowing and kayaking research has described this ideal force-time profile as a more trapezoid-like shape than triangular (Issourin, 1990; Kleshnev, 1999; Coker, 2010). With the same peak force, a more trapezoid shaped force-time profile would have a greater impulse indicated by the area under the force-time curve (Coker, 2010). A greater impulse will increase boat velocity by increasing the momentum of the boat. Propulsive forces occur by increasing the propulsive drag and lift forces acting between the paddle blade and water. Drag force, F_D, is a function of a unitless coefficient of drag, C_D, fluid density, ρ, paddle velocity relative to the fluid flow, V, and the frontal area of the paddle blade, A: $F_D = \frac{1}{2}C_D \rho V^2 A$ (Sumner et al., 2003). Lift force, F_L, is a function of similar factors where the primary difference is a unitless coefficient of lift, C_L: $F_L = \frac{1}{2}C_L \rho V^2 A$ (Sumner et al., 2003). Another main difference between drag and lift force, is that the paddle velocity relative to the fluid flow, V, refers to the paddle velocity in the posterior direction for drag and lateral direction for lift. Performance enhancements can also be achieved by minimising aerodynamic and hydrodynamic drag. Michael (2009) offered a comprehensive review on the different types of drag and influencing factors of drag. The conclusion of the review was that international racing rules have limited the changeable factors that would reduce drag, and the main concern for kayaking performance should be to maximize blade or paddle force.

One theory to increase paddle force, is to increase the paddle blade's velocity. While it was not possible to measure velocity of the paddle blade for this thesis, it was presumed that if a paddler was asked to increase their stroke rate, they would increase the paddle blade's velocity and thereby increase force production. Previous rowing research supported that an increase in stroke rate up to 40 spm, a high stroke rate for rowing, led to increased force and power output (Kleshnev, 1999). The changes to stroke phase and sub-phase times caused by increasing stroke rate were unknown in kayaking. If the stroke were to be split into phases that could align with the loading, maintenance and off-loading of force, then theories can be developed for kinematic characteristics of an effective paddling stroke on the assumption that achieving a trapezoidal force-time curve is ideal. While investigating stroke rate (or stroke time), there was an equally important need to understand how stroke rate may influence the stroke phase durations, and subsequently, how each factor is related to performance.

Kayak models

A model in general refers to a graphical or mathematical description of a system or process, and is used as a basis for theoretical or empirical understanding of that system or

process (Chow & Knudson, 2011). In the area of applied kinesiology, a four-task model for qualitative analysis was introduced to help coaches evaluate movement in a scientific way. The four tasks consist of preparation, observation, evaluation, and intervention (Knudson & Morrison, 2002). With the purpose of improving performance of a given movement, preparation includes background research by gathering knowledge (Knudson & Morrison, 2002). Knowledge is usually organised according to the observational strategy chosen; an observational strategy usually focuses on movement phases or critical features (Hay & Reid, 1988; Knudson & Morrison, 2002). One of the major findings of this thesis was the disparity in observational models for the phase categorization of sprint kayaking (McDonnell et al., 2012a). This is an issue in kayaking because stroke phase durations have also been used as critical features (Plagenhoef, 1987; Kendal & Sanders, 1992; Hay & Yanai, 1996; Timofeev et al., 1996; Qiu et al., 2005; Brown et al., 2011), in the sense that phase durations have been used as "key features of a movement that are necessary for optimal performance" (Knudson & Morrison, 2002). Thus disparity exists for both movement phases and critical features in sprint kayaking, limiting coaches' preparation for a systematic analysis.

Seven different observational models for phase divisions of the kayak stroke cycle were identified in the kayak biomechanics literature (McDonnell et al., 2012a). Inconsistent kayak stroke cycle definitions and differences in phase divisions of the stroke led to difficulty when comparing stroke rate and stroke rhythm results between studies. An analysis of the differences in models, and the development of a single multi-purpose model was needed to allow future kayaking performance biomechanics research to be streamlined toward a common goal. The limitations of the methodological approach seemed to have only influenced differences for one model that used a 2D ergometer analysis to identify phases divided by positions of the paddle shaft (Trevithick et al., 2007). In a 3D ergometer analysis, researchers have estimated the relative height of the water from the mean height of the hip joints to determine water-contact defined positions such as the catch and release likely based around 3D modelling the paddle shaft and blade length (Begon et al., 2008). However, the specific methods for how water-contact positions were estimated on the ergometer were not stated. The remaining models that were used in descriptive or experimental research used video analysis of at least the side view to identify stroke phases and all used the catch position (initial blade-water contact) at some point in their model (Plagenhoef, 1979; Mann & Kearney, 1983; Kendal & Sanders, 1992; Hay & Yanai, 1996; Baker et al., 1999; Qiu et al., 2005; Begon et al., 2008; Brown et al., 2011). The visibility of the catch opposite the side of the camera videoing or filming from the side view is questionable if the camera is level. Some researchers have either supplemented side view video with a front view (Kendal & Sanders, 1992) or at least two cameras were used for a 3D analysis (Plagenhoef, 1979; Baker et al., 1999; Begon et al., 2008). The remaining possible paddle-shaft defined and body defined positions are clearly visible from the side view or could be determined by 3D analysis, so aside from the study by Trevithick et al. (2007), methodological limitations were not likely responsible for the range of models previously used in the literature.

After critical review of the kayaking observational models incorporating nine different phase-defining positions, a two-tiered model was recommended (Figure 2.4). We recommended a single stroke cycle from the initial water contact of one paddle blade to initial water contact of the paddle blade of the opposite side as the stroke cycle definition. The first tier of our suggested observational model consisted of a two-phase division: water and aerial phases, both in reference to the time the paddle blade was in contact with the water and not in contact with the water, respectively. This type of two-phase division was the most common model used in research (Kendal & Sanders, 1992; Hay & Yanai, 1996; Baker et al., 1999; Brown et al., 2011). A second tier of the observational model was developed by dividing the water phase into three sub-phases, the entry, pull, and exit (Figure 2.4). The aerial phase was also included to allow a four-phase division of the stroke cycle which was similar to the phase division identified for rowing (Nolte, 2005). This exact four-phase division had not been previously defined well in kayaking research, but allows for simple to detailed division of the stroke cycle according to the amount of paddle blade-water contact. This division separates the stroke based on the opportunity to apply a propulsive force. This model has potential to be adapted by adding key positions as a third tier in the future when research identifies other instants of time as important performance determinants.

Following, observation, coaches are challenged with the task of evaluating movement. Models for evaluating human movement are vast, however models for qualitative analyses have been summarised by two approaches: the sequential method and the mechanical method (Hay & Reid, 1988). Coaches often use a sequential method for evaluating movement, where the observed movement is compared to a mental image of good form (Hay & Reid, 1988; Knudson, 2007). However, the sequential method may lead to overemphasis on error detection, as "good form" is a subjective ideal (Hay & Reid, 1988; Knudson & Morrison, 2002). The mechanical method of evaluating human movement is based on relevant biomechanical variables or principles. Instead of focusing on ideal form, evaluation is focused on "critical features". Hay and Reid (1988) recommended using a deterministic model for identifying and organising the priority of critical features. The deterministic model is a hierarchical structure of mechanical factors with the performance criterion on top (e.g. average boat velocity), and all factors at one level should completely determine the factors included at the next highest level (Chow & Knudson, 2011).

From a kinematic perspective in kayaking, a deterministic model based on the work of Hay and Yanai (1996) and Kendal and Sanders (1992) identified stroke displacement and stroke time as important performance determinants. This model was further expanded based on the suggested observational model (McDonnell et al., 2012a) by adding phase and sub-phase displacements and times. Pre-existing research had supported stroke time ($r = -0.75$ to -0.86, $p<0.05$) or stroke rate ($r = 0.89$, $p<0.01$) as important determinants of average boat velocity (Mononen & Viitasalo, 1995; Hay & Yanai, 1996; McDonnell et al., 2013a). The magnitude of the relationships between stroke time and velocity and stroke rate and velocity were similar, therefore coaches may decide to provide feedback to paddlers using stroke rate. The ultimate performance goals for elite K1 men's 200-m paddlers would be to achieve stroke rates of 144-168 spm and for elite K1 women's 200-m paddlers to achieve stroke rates of 130-148 spm to

achieve velocities required to medal at a world championship (McDonnell et al., 2013b). Evidence of the importance of stroke displacement for achieving a high velocity was mixed and unclear (McDonnell et al., 2013a). Analysis of data from 12 paddlers performing a 200-m time-trial supported that better paddlers tended to have lower stroke times, higher stroke rates, and no further clarity was achieved for the influence of stroke displacement (Figure 10.1). Anecdotally, stroke displacement improvements are still a focus for elite paddlers.

A possible problem a paddler may encounter by trying to increase the turn-over of the paddle blade is that with a shorter stroke time, impulse may be lower unless counteracted by a larger peak force, which is effectively the goal when increasing stroke rate. A second possible problem with increasing stroke rate is that with less stroke time, paddlers may shorten the stroke. A shortened stroke would have a negative effect on stroke displacement unless blade slip decreased as a result of enhanced lift force. Boat displacement has been identified as the sum of forward reach and backward reach minus the slip (Kendal & Sanders, 1992). Mechanically, stroke rate increases can only improve performance as long as stroke displacement either increases simultaneously or is not reduced too much. It appears that the appeal of increasing stroke rate is to enhance the peak propulsive force. Further research is needed to better simulate the interactions of stroke rate, displacement and their influence on impulse, boat momentum, and physiological efficiency during time-trials. A data-base of normative performance determinants for all boats (K1, K2, and K4), distances, and genders in sprint kayaking would further assist coaches during the evaluation task.

Kayak velocity fluctuates throughout the stroke as propulsive and drag forces act to accelerate or decelerate the kayak. Kayak velocity typically begins to increase shortly after the catch and continues to increase until just before the blade is released from the water (Kendal & Sanders, 1992; Janssen & Sachlikidis, 2010), thus the water phase (catch to release) is mostly propulsive. During the aerial phase, the time when neither paddle blade is in contact with the water, boat velocity continues to decline (Kendal & Sanders, 1992; Janssen & Sachlikidis, 2010). The longer time spent decelerating increases the intra-stroke kayak velocity, which is inadvisable for achieving an efficient stroke. This knowledge has led researchers to believe that minimizing the absolute and relative aerial phase durations would enhance performance (McDonnell et al., 2013a). Minimizing relative aerial phase duration would subsequently increase relative water phase duration, therefore it was also thought that a relatively longer water phase might have been a metric of a good stroke. Our experimental findings confirmed that a decrease in aerial phase duration was indicative of better performance, however the relationships between relative phase durations and average boat velocity were not discernible. Performance was related to decreases in both absolute water and aerial times at self-selected stroke rates, and larger decreases were observed for water phase time compared to aerial phase time when increasing stroke rate (Chapters 8 and 9).

From the perspective of technique, greater paddle rotations in the positive or negative direction about the paddle's longitudinal axis, *yaw angle*, decreases the drag coefficient (Sumner et al., 2003). Similarly, greater forward or backward tilt of the paddle, *pitch angle*, will also decrease the drag coefficient (Sumner et al., 2003). Higher yaw and pitch angles are

observed at the entry and exit phases of the kayak stroke, along with lower frontal area of the paddle blade given the partial contact between the blade and the water during these sub-phases (McDonnell et al., 2012a). Whereas during the pull sub-phase, the paddle is more "squared up", indicating yaw and pitch angles closer to zero, and the frontal area of the blade is maximised. Therefore, the drag force is expected to be lower at the entry and exit sub-phases and higher during the pull sub-phase. This thesis confirms that better paddlers characteristically have shorter entry and exit sub-phase times, but an unclear association was observed for relative pull time ($r = 0.27$, $p>0.05$) and absolute pull time ($r = -0.07$, $p<0.05$) (Figure 10.1).

Kayaking technique involves actions of the legs, trunk, thrust and pull arms, where the thrust arm has been defined as the top arm performing a push action. Kayaking has been described as a push-then-pull action coupled with trunk rotation (Mann & Kearney, 1980). Logan and Holt (1985) stated that any wasted movements with the body position should be minimised to allow optimal positioning of the body for propulsion during the water phase, so a segmental sequencing analysis was of interest for this thesis. Most of the kayak biomechanics research has aimed to describe technique at maximal pace or sprint pace (Plagenhoef, 1979; Mann & Kearney, 1980; Logan & Holt, 1985; Kendal & Sanders, 1992; Baker et al., 1999), however, coaches often implement video analysis during sub-maximal training, particularly on aerobic training days when intensity is low. Chapter 7 showed evidence that individuals varied in their technique changes between three common training intensities (L2, ~66-80% VO_2max; L4, ~88-93% VO_2max; L5, ~94-100% VO_2max). The key variables that showed clear large to very large outcomes for all paddlers between each pair of intensities were stroke time, leg time duration, trunk time duration, and pull arm time duration, all decreasing with increasing intensity and stroke rate. Overall, kayaking could be described as a sequential leg-thrust-trunk-pull action, each likely occurring before the catch in most paddlers, with a variable onset and duration of the thrust arm. The thrust arm describes the top arm acting in a pushing motion and the pull arm describes the bottom arm or arm on the side of paddle blade-water contact. Movement initiation before the catch is likely due to anticipation of the catch and the fast-paced action of body segments in kayaking at high stroke rates (>90 spm). While this early action is likely inevitable, paddlers should consider minimising wasted action as much as possible prior to the blade entering the water. Paddlers should also focus on reaching as far forward as possible without hindering their ability to quickly direct the paddle backward (Kendal & Sanders, 1992), as decreasing forward reach was inevitable and decreasing pull arm time was the most important variable for increasing stroke rate. Trunk rotation and leg extension movements are important at high intensities or during exhaustive exercise, theoretically for achieving greater paddle tip velocity when the blade enters the water (Michael et al., 2012).

Associations between velocity and:
Stroke rate: 0.79*
Water phase time (%): -0.07
Aerial phase time (%): 0.07
Entry time (%): -0.30
Pull time (%): 0.27
Exit time (%): -0.45†
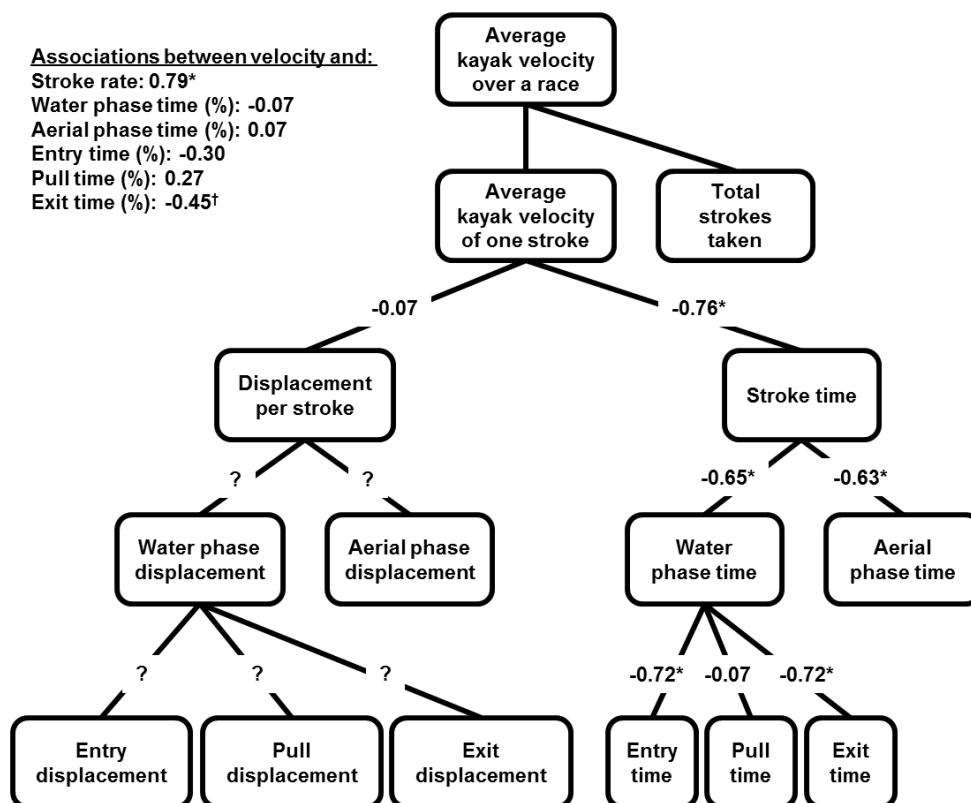
Indicates statistical significance, p<0.05; † non-significant, but a likely correlation. Additional correlations were calculated for common related variables: stroke rate and relative phase times as a percentage of the stroke cycle.

Figure 10.1. Associations between average kayak velocity over a 200-m time-trial and the corresponding lower box for twelve paddlers.

Methods for assessing paddling performance

Kayak biomechanics research has often implemented a two-stroke analysis to identify characteristics important for performance (Hay & Yanai, 1996; Baker et al., 1999; Brown et al., 2011). This thesis investigated the validity of using a two-stroke analysis for predicting accurate mean stroke rate values. While assessing stroke rate at any part of the race was reliable, overall the most valid measure of mean stroke rate occurred when sampling two strokes at 50% of the race time (Chapter 8). While this measure was labeled as statistically valid, it needs to be strongly noted that using this technique yields acceptable accuracy of ±2 spm for only 68% of the trials. Therefore this methodological approach is limited to acting only as an estimate or rough snap-shot of what might occur in a race or time-trial. The two-stroke analysis is not best-practice for determining optimal stroke rates or the effect of an intervention in general.

Averaged individual analysis of 20-40 strokes for sample sizes <10 paddlers was reliable (McDonnell et al., 2012b), and was implemented to identify meaningful changes in technique between intensities (Chapter 7). While this type of analysis was useful for assessing sub-maximal training exercise, it is not appropriate for research pertaining to maximal performance.

New Zealand's sub-elite paddlers stroke rates (chapters 8 and 9) were higher than that of the New Zealand elite paddlers (Chapters 5 and 7), and this was likely attributed toward longer trial durations for the elites (300-m and four-minute tests) compared to 200-m time-trials for sub-elites. Pacing strategies are largely dependent on knowledge of the distance being performed and adjustments to the metabolic responses to prevent pre-mature fatigue before the athlete reaches the finish (Gibson et al., 2006). Therefore the mechanical responses observed by the biomechanist are largely influenced by the paddler's perception of their metabolic response, and therefore during a biomechanical analysis that is concerned with the characteristics associated with a winning performance, the metabolic responses also need to be simulated to achieve realistic mechanical measures.

It is recommended to assess the effect of an intervention on performance using a minimum of ten participants (Hopkins, Hawley, & Burke, 1999). To determine the smallest worthwhile change, a reliability study must be performed. Typically, the smallest worthwhile changes of athletes competing in solo-sports are detected from one third of the within-subject coefficient of variation in performance time or other variable of interest (Bonetti & Hopkins, 2010). Meaningful differences in 200-m performance times, stroke rate, phase times and sub-phase times were not detected in the absence of an intervention for up to four time-trials when trial one was excluded from the analysis (Chapter 8). Testing both elite and sub-elite paddlers indicated that trial one was more variable in 200-m performance time of sub-elites (Chapter 8) and in stroke rate and phase times of elite paddlers (McDonnell et al., 2012b). The smallest worthwhile changes of 1.2% (stroke rate), 0.003 s (water and aerial time), 0.002 s (entry and pull time), and 0.001 s (exit time) should be suitable for highly competitive through to elite level 200-m paddlers when all strokes of a time-trial are assessed (Chapter 8). The smallest worthwhile change of world championship A-finalist elite paddlers was 0.3% race time, but elite B-finalists varied by approximately three times that of A-finalists (Bonetti & Hopkins, 2010). The smallest worthwhile change in the group of sub-elite paddlers tested for the final intervention was 0.7% and displayed better performance reliability than the elite B-finalists reported in literature (Bonetti & Hopkins, 2010). The level of reliability observed in the sub-elite group was likely attributed toward having testing occur in the same body of water with the majority of the time-trial course protected from the wind. Since performance time variability is likely to differ depending on the body of water and group of paddlers, performance time variability should be assessed for each group if possible. Once the most appropriate smallest worthwhile effect is established for a group of paddlers, the effect of an intervention is best assessed using magnitude-based inferences to determine the likelihood (replacing significance) of an effect, then effect sizes to discuss the magnitude of an effect in qualitative terms (Batterham & Hopkins, 2005). The major conceptual advantage of using magnitude-based inferences is that researchers can differentiate important change from change that is unimportant or declare unclear outcomes. Whereas using statistical significance, the researcher is limited to showing consistent change across a group regardless of its practical importance.

Video analysis of stroke-to-stroke data can be time consuming. GPS-based accelerometers and instrumented paddles have been used to collect kinematic and kinetic data.

Janssen and Sachlikidis (Janssen & Sachlikidis, 2010) reported that the minimaxX GPS-based accelerometer under-reported kayak velocity by 0.14-0.19 m/s and acceleration by 1.67 m/s^2 when compared to video-derived measurements of 12 trials performed at three stroke rates but did not quantitatively confirm the level of reliability or accuracy of stroke rate measures using the minimaxX. This thesis confirmed that video measurement of stroke rate and stroke phase times is still the gold standard for accurate measurements (McDonnell et al., 2012b). In other words, video is still used as the standard by which we compare the accuracy of GPS or accelerometer measures. Although reliable for stroke rate measurement, the Digitrainer gps-based accelerometer tended to overestimate stroke rate by 4 ±5 spm (McDonnell et al., 2012b). The device would have been considered valid if the difference was less than 3 spm based on the maximum possible error due to video digitisation. Given the limits of the video frame rate used in this research (60 Hz), one may expect video to have greater variability than the accelerometer based approach with the digitrainer (125 Hz). However, the limits of frame rate of the video camera (60 Hz) did not appear to affect the variability in stroke rate when comparing the video camera (trials 2-3 CV% = 1.8-2.0%) with accelerometry data collected at 125 Hz (trials 2-3 CV% = 2.2-2.4%). One plausible explanation for this is that there may be greater variability in the timing of boat acceleration thresholds used to calculate stroke rate from the digitrainer than the variability in timing of the blade-water contact used to calculate stroke rate from the video. Given this rationale, it is uncertain if validity of accelerometry data is truly possible to achieve. Nevertheless, these devices may still be useful in the research or practical environment. GPS-based accelerometer devices offer large amounts of information with minimal processing time, therefore researchers and coaches should be weary of the accuracy, or at least the reliability, of these measures before training evaluations or interventions are made.

The Vaaka Kayak Cadence sensor is a new commercial product that has been released to the consumer market in New Zealand and is becoming more available worldwide (www.vaaka.co.nz/products.htm, accessed 4th November, 2013). The sensor is attached to the middle of the kayak paddle shaft and can be integrated with any GPS-based sports watch that uses ANT+ wireless technology. For example, stroke rate can be displayed directly on a Garmin forerunner watch mounted to the kayak for a visual feedback display. Distance per stroke can also be derived from the velocity measured by the Garmin and stroke rate measured by the sensor, and all data can be logged for post-event processing. There is no published reliability or validity data available for this device, however the product website contains positive reviews about the effectiveness of the feedback for improving stroke rate or distance per stroke from two paddlers who have recently stepped into the limelight of international success (www.vaaka.co.nz, accessed 4th November, 2013). This product was released after the commencement of the final thesis study, and would have significantly reduced the time-cost of the analyses if it were available earlier. It is therefore recommended to pursue the applications of this device in both the training and research environments.

This thesis could have been strengthened with blade force measures (Aitken & Neal, 1992; Hildebrand & Drenk, 2006; Helmer, Farouil, Baker, & Blanchonette, 2011), velocity of the paddle blade tip and accurate intra-stroke kayak velocity synchronized with boat-mounted

video. While the technology exists, it is not widely accessible commercially. A cost-effective and widely available movement analysis system for kayaking that included these measures will allow higher quality research studies to be completed.

The kayak ergometer has been another useful equipment innovation. The kayak ergometer allows sport-specific training to continue during inclement weather, as it has been useful for reasonably simulating on-water physiology (Van Someren et al., 2000; Sitkowski, 2008) and paddling technique (Begon et al., 2008). However, some differences have been identified in the frontal plane shoulder kinematics between kayak ergometers and on-water paddling (Begon et al., 2008; Fleming et al., 2012). This compromises the ability to use ergometers for 3D studies or 2D frontal plane analyses, but 2D sagittal plane analyses should reasonably replicate movement patterns that would likely occur on-water in the same paddlers. Stroke rate, entry angle, propulsive time, propulsive/aerial time ratios, scapular girdle rotation, elbow and wrist trajectories, vastus lateralis muscle activity, and all joints trajectories (shoulder, elbow, and wrist) in the anteroposterior plane were similar between ergometer and on-water performance in elite paddlers (Begon et al., 2008; Fleming et al., 2012). While kayak ergometer research has allowed greater focus on the potential contributions of the legs (Brown et al., 2010), since they are more easily measured on land, research is still needed to confirm these findings on-water. Nevertheless, the kayak ergometer offers a great tool for narrowing potentially important variables or trialling models and methods before attempting on-water data collection.

Intervention studies

There have been many investigations describing the technique of sprint kayaking at race pace (McDonnell et al., 2013a) and now also sub-maximal training intensities (Chapter 7). From a kinematic perspective, the most important variables for achieving a greater average boat velocity were stroke rate, water phase time, aerial phase time, entry sub-phase time and exit sub-phase times. The quality of sports biomechanics research should be judged based on its practical application (Plagenhoef, 1979). The next logical step would be to test the suppositions developed for what may contribute toward enhanced performance using intervention studies.

Kayaking intervention studies aimed to improve performance are limited. The effect of adjusting foot-bar distance and paddle grip widths from a paddler's preferred set-up was studied for three elite paddlers (Ong et al., 2006). The study resulted in varying changes in boat speed; two paddlers were slower with the intervention and one paddler was faster, therefore overall recommendations could not be made. A higher quality intervention study investigated the effect of two strength training programmes for sprint kayaking performance of a larger cohort (Liow & Hopkins, 2003). However, the performance test to judge the usefulness of the weight training intervention was a 15-m sprint in a canoe polo boat and therefore lacked ecological validity for applying the findings to the sport of sprint kayaking. Another study investigated the effect of different warm-up strategies on performance, but was limited to ergometer performance (Bishop, Bonetti, & Dawson, 2001).

This thesis contributed the first known study to investigate the effect of an intervention on time-trial performance on-water. The results confirmed that metronome feedback was effective for inducing an increase in stroke rate, although the target stroke rates were not reached for the duration of 200-m time-trials (Chapter 9). A small increase in stroke rate (4-5 spm) led to a small, but meaningful improvement in 200-m performance time (0.9-1.0%). These findings are limited to 200-m performances in male K1 paddlers. Greater total work would be required to achieve such stroke rate changes in longer distance events, so paddlers of longer events may choose to increase stroke rate (if found effective) by improving the consistency of stroke rate toward the later half of a profile. While it is expected that stroke rates would be higher in team boats (i.e. K2 and K4) for a given race distance due to the higher velocities achieved, individuals varied in their adherence to metronome feedback, so an actue stroke rate increase in team boats may initially impair team synchrony. Further descriptive and experimental research is needed to better understand how stroke rhythm and synchrony affect team boat performance in sprint kayaking.

A higher stroke rate was achieved with small reductions in absolute water and absolute aerial phase times. The change in water phase time was attributed mostly toward a decrease in pull time. The overall implications for coaches were to incorporate more time-trials with metronome feedback in a paddler's training routine with a slight increase in the normal self-selected stroke rate, which may lead to better retention of a faster more efficient and optimal pacing strategy on race-day without feedback. Therefore the next most logical step in kayaking research is the development of training intervention studies. Further research is also needed to investigate the effectiveness of other feedback modes during training (visual, auditory, tactile or multi-modal) and the frequency of feedback needed to retain long-term performance benefits from a stroke rate enhancement without growing dependency.

Summary of an effective paddling stroke

Based on the empirical evidence presented in this thesis, an effective paddling stroke is one where the stroke rate is high, both water and aerial phase times are short, and the entry and exit sub-phase durations are quick. Better paddlers, indicated by a higher average boat velocity of 200-m time-trials, have higher stroke rates as a result of shorter stroke times (Figure 10.1). Stroke time is indirectly proportional to the velocity of the paddle, thus a performance enhancement could be explained by greater drag and lift forces by increasing the paddle velocity, assuming the change in stroke time does not shorten the path of the paddle greatly. However, from submaximal to maximal training intensities, forward reach reduced at the higher intensities, likely influenced by a decrease in stroke time (Chapter 7). This thesis attempted to determine the point where an increase in stroke rate caused a decline in performance by testing a series of time-trials at increasing stroke rates. However, the results indicated, that simply increasing stroke rate would lead to an increase in performance, where the higher the rate change, the better the performance. This observation suggests that experienced paddlers will not alter the mechanics of the stroke so much that boat velocity declines due to a stroke rate increase. If any decline in performance should occur, it is from the attempt of a stroke rate

increase, such that the paddler fails to mentally or physiologically sustain the rate for the race duration.

Summary of theoretical contributions

The following is a summary of the theoretical contributions of the thesis toward understanding what an effective stroke is from assessment of stroke rhythm and kinematics:

- This thesis presented a theory that an effective stroke was one where the entry phase time was small, pull phase time was relatively long, exit phase time was small and aerial phase time was short, with a short aerial time, and high stroke rate. The experimental findings supported this statement with the exception of the duration of the pull phase time.
- This thesis provided additional comments surrounding the effectiveness of a high stroke rate being likely dependent on the blade work during the pull sub-phase.
- Propulsive actions begin more simultaneously with the higher intensity, particularly the actions of the hip and shoulder.
- Propulsive power is driven by the upper body actions in lower training intensities. As intensities and stroke rate increases, propulsive power is driven less by the upper body and more so with rotational movements of the trunk as well as leg extension movements.
- Increasing stroke rate is generally a good intervention because success usually occurs as long as the paddler is able to sustain the higher rating; paddlers should race at the highest sustainable stroke rate possible if specialising in the 200-m sprint race, but their race-plan should be well-developed and rehearsed prior to competition since not all paddlers were able to sustain a higher stroke rate.

Future directions

Kayaking research is limited, and therefore there are numerous possibilities for future research. There has been no descriptive research of kinematic or kinetic variables reported in published kayaking literature for K2 or K4 boats. Adding to the main findings of this thesis, the following research topics would likely be the most useful for coaches and athletes:

- Reliability and validity of the Vaaka Kayak Cadence sensor and Garmin forerunner system.
- Longitudinal (7 week) reliability of 200-m performance times between days to identify the smallest worthwhile changes in performance, allowing for a 6-week training intervention to take place.
- The effect of high vs. low stroke rate training on strength, measures of aerobic fitness, kinematics, and 200-m performance time. A pre-post crossover design of 12 paddlers per group with two testing days before and after each intervention is recommended.
- Development of testing protocols and the effect of increasing stroke rate on 500-m and 1000-m performances and for team-boats.

Thesis limitations

The following are the limitations of the studies presented in this thesis:

Chapter 4:

1. Stroke rate data were gathered from broadcasted video operating at a low frame rate (24 Hz), therefore only one data point for each 8-10 strokes could be plotted leaving gaps in the stroke rate profiles.
2. Stroke rate recommendations were made based on a limited number of paddlers' data (seven male and five female paddlers).

Chapters 5 and 6:

1. Due to the limitations of synchronizing timing devices with GPS data on-water, validity of velocity variables could not be assessed during the validation of the Digitrainer stroke rate.
2. The analysis was limited to a 40-stroke section to assess stroke-to-stroke changes, hence achieving a pace that metabolically and mechanically simulated true race pace was questionable given the lower than expected stroke rates observed for elite paddlers.

Chapter 7:

1. All data were limited to paddling on a Dansprint kayak ergometer.
2. Results were limited to male paddlers; female paddlers dropped out due to injury at the time of the study.

Chapters 8 and 9:

1. This study was limited to time trials performed during training, and not during actual competition. It was not feasible to set-up a biomechanical analysis to this depth at an elite competition.
2. Results were limited to a group of competitive male club paddlers ranging ~40-50 s in performance time, as New Zealand did not have a group of elite 200-m specialists (a new distance on the Olympic programme) and the elite squad was busy with 2012 Olympic preparations at the time of data collection.
3. A minimum sample of 10 female paddlers, to represent a female cohort, was not available during participant recruitment.

Points for resolving limitations and improving the quality of future research

1. The GoPro Hero 3+ cameras (black and silver editions) now offer up to 120 Hz sampling rate options to improve measurement precision of stroke rate or phase times; otherwise using 60 Hz video and digitizing to the nearest half frame and

averaging all strokes of a time-trial provided adequate precision for stroke rhythm assessments.

2. The GoPro app (http://gopro.com/software-app/gopro-app, accessed 4th November, 2013) now allows remote control access from a smartphone or tablet, reducing the need for a coach or research to ask the paddler to stop paddling to press record. This would make data collection more efficient and reduce unwanted video footage, and could reduce the time-cost of video analysis. The application also allows a coach to review and play back recorded footage immediately which could assist coaches with quicker more objective qualitative analysis on the water.

3. The Vaaka Kayak Cadence sensor synchronizes stroke rate with gps-devices utilizing ANT+ wireless technology, eliminating the first limitation of Chapters 5 and 6. Further research should explore this technology given the significant savings in analysis time this device provides.

4. Averaging stroke-to-stroke variables throughout a full time trial (when feasible) provides better ecological validity of performance determinants than sampling a small or large section of strokes.

5. K1 200-m time-trials should be limited to four tests in one day for research purposes when testing the effect of an acute outcome.

Conclusions

Stroke rate is an important determinant of sprint kayaking performance. Stroke rates of 144-168 spm for the men's K1 200-m event and stroke rates of 131-147 spm for the women's K1 200-m event are required to achieve medal winning times. The typical self-selected stroke rates of New Zealand elite paddlers at race pace for repeated 300-m sprints averaged ~101 spm, and averaged 98 spm at L5 training pace (~94-100% VO_2max) lasting four minutes. However, it was best to assess stroke rates using time-trials. The typical self-selected stroke rates of New Zealand sub-elite paddlers were 122 ±11 spm during K1 200-m time-trials. Sub-elite paddlers responded moderately well to stroke rate feedback via a metronome. Increasing stroke rate by 4-5 spm (2.9-4.2%) led to a small but meaningful improvement in performance time (0.9-1.0%) for an acute intervention in sub-elite paddlers. Faster paddlers tended to have a better response to stroke rate feedback, therefore the findings should be transferable to elite level paddlers. An effective stroke may be one where the entry phase time is small, pull phase time is relatively long for a given stroke rate, exit phase time is small and aerial phase time is small at the highest sustainable stroke rate for a given race distance. The experimental findings support this theory with the exception of pull phase time. The effectiveness of a high stroke rate is likely dependent on the blade work during the pull sub-phase, however further research is needed.

References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine, 38*, 239-252.

Ackland, T. R., Ong, K. B., Kerr, D. A., & Ridge, B. (2003). Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science and Medicine in Sport, 6*, 285-294.

Aitken, D. A., & Jenkins, D. G. (1998). Anthropometric-based selection and sprint kayak training in children. *Journal of Sports Sciences, 16*, 539-543.

Aitken, D. A., & Neal, R. J. (1992). An on-water analysis system for quantifying stroke force characteristics during kayak events. *Journal of Applied Biomechanics, 8*, 165-173.

Akca, F., & Muniroglu, S. (2008). Anthropometric-somatotype and strength profiles and on-water performance in turkish elite kayakers. *International Journal of Applied Sports Sciences, 20*, 22-34.

Baker, J., Rath, D., Sanders, R., & Kelly, B. (1999). A three-dimensional analysis of male and female elite sprint kayak paddlers. In R. H. Sanders & B. J. Gibson (Eds.), *Scientific Proceedings of the XVIIth International Society of Biomechanics in Sports Conference* (pp. 53-56). Perth, Australia: Edith Cowan University.

Batterham, A. M., & Hopkins, W. G. (2005). Making meaningful inferences about magnitudes. *Sportscience, 9*, 6-13.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*, 50-57.

Baudouin, A., & Hawkins, D. (2002). A biomechanical review of factors affecting rowing performance. *British Journal of Sports Medicine, 36*, 396-402.

Baudouin, A., & Hawkins, D. (2004). Investigation of biomechanical factors affecting rowing performance. *Journal of Biomechanics, 37*, 969-976.

Begon, M., Colloud, F., & Sardain, P. (2010). Lower limb contribution in kayak performance: modelling, simulation and analysis. *Multibody System Dynamics, 23*, 387-400.

Begon, M., Lacouture, P., & Colloud, F. (2008). 3D kinematic comparison between on-water and on ergometer kayaking. In Y. H. Kwon, J. Shim, J. K. Shim & I. S. Shin (Eds.), *Scientific Proceedings of the XXVIth International Society of Biomechanics in Sports Conference* (pp. 502-505). Seoul, Korea: Seoul National University.

Bishop, D., Bonetti, D., & Dawson, B. (2001). The effect of three different warm-up intensities on kayak ergometer performance. *Medicine and Science in Sports and Exercise, 33*, 1026-1032.

Bishop, D., Bonetti, D., & Dawson, B. (2002). The influence of pacing strategy on VO_2 and supramaximal kayak performance. *Medicine and Science in Sports and Exercise, 34*, 1041-1047.

Bonetti, D., & Hopkins, W. (2010). Variation in performance times of elite flat-water canoeists from race to race. *International Journal of Sports Physiology and Performance, 5*, 210-217.

Bonetti, D., Hopkins, W., & Kilding, A. (2006). High-intensity kayak performance after adaptation to intermittent hypoxia. *International Journal of Sports Physiology and Performance, 1*, 246-260.

Bourgois, J., Van Renterghem, B., Janssens, M., Vrijens, J., & De Blieck, C. (1998). Comparative study of specific ergometry and field tests in kayaking. *Journal of Sports Sciences, 16*, 430-431.

Bradshaw, E., Hume, P., Calton, M., & Aisbett, B. (2010). Reliability and variability of day-to-day vault training measures in artistic gymnastics. *Sports Biomechanics, 9*, 79-97.

Brown, M. B., Lauder, M., & Dyson, R. (2010). Activation and contribution of trunk and leg musculature to force production during on-water sprint kayak performance. In R. Jensen, W. Ebben, E. Petushek, C. Richter & K. Roemer (Eds.), *Scientific Proceedings of the XXVIIIth International Society of Biomechanics in Sports Conference*. Marquette, Michigan: Northern Michigan University.

Brown, M. B., Lauder, M., & Dyson, R. (2011). Notational analysis of sprint kayaking: Differentiating between ability levels. *International Journal of Performance Analysis in Sport, 11*, 171-183.

Chow, J. W., & Knudson, D. V. (2011). Use of deterministic models in sports and exercise biomechanics research. *Sports Biomechanics, 10*, 219-233.

Coker, J. (2010). *Using a boat instrumentation system to measure and improve elite on-water sculling performance.* Unpublished doctoral thesis, Auckland University of Technology, Auckland, New Zealand.

Cox, R. (1992). *The science of canoeing: A guide for competitors and coaches to understanding and improving performance in sprint and marathon kayaking.* Frodsham, Cheshire: Coxburn Press.

Dai, X. W., Ho, W. H., Chang, L. C., & Liu, D. Z. (2004). The analysis of muscular strength and EMG in kayak stroke. In M. Lamontagne, D. G. E. Robertson & H. Sveistrup (Eds.), *Scientific Proceedings of the XXIInd International Society of Biomechanics in Sports Conference* (pp. 610). Ottawa, Canada: University of Ottawa.

Doody, S. G., Bird, A. M., & Ross, D. (1985). The effect of auditory and visual models on acquisition of a timing task. *Human Movement Science, 4*, 271-281.

Endicott, W. T. (1992). *The Barton Mold: A study in sprint kayaking.* Charlotte, NC: USA Canoe/Kayak.

Espinosa-Sanchez, M. (2005). Three-dimensional kinematic study of the paddle stroke in individual flatwater kayaking. In Q. Wang (Ed.), *Scientific Proceedings of the XXIIIrd International Symposium of Biomechanics in Sports* (pp. 889). Beijing, China: China Institute of Sport Science.

Fleming, N., Donne, B., Fletcher, D., & Mahony, N. (2012). A biomechanical assessment of ergometer task specificity in elite flatwater kayakers. *Journal of Sports Science and Medicine, 11*, 16-25.

Forbes, S., Fuller, D. L., Krentz, J. R., Little, J. P., & Chilibeck, P. D. (2009). Anthropometric and physiological predictors of flat-water 1000 m kayak performance in young adolescents

and the effectiveness of a high volume training camp. *International Journal of Exercise Science, 2*, 106-114.

Fry, R., & Morton, A. (1991). Physiological and kinanthropometric attributes of elite flatwater kayakists. *Medicine and Science in Sports and Exercise, 23*, 1297-1301.

Garcia-Palleres, J., Sanchez-Medina, L., Carrasco, L., Diaz, A., & Izquierdo, M. (2009). Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *European Journal of Applied Physiology, 106*, 629-638.

Gibson, A. S. C., Lambert, E. V., Rauch, L. H. G., Tucker, R., Baden, D. A., Foster, C., et al. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine, 36*, 705-722.

Hay, J. G., & Reid, J. G. (1988). *Anatomy, mechanics and human motion* (2nd ed.). Englewood Cliff, NJ: Prentice-Hall.

Hay, J. G., & Yanai, T. (1996). *Evaluating the techniques of elite U.S. kayakers. A report to U.S. Olympic Committee and U.S. Canoe and Kayak Team.* Iowa City, IA: University of Iowa.

Helmer, R. J. N., Farouil, A., Baker, J., & Blanchonette, I. (2011). Instrumentation of a kayak paddle to investigate blade/water interactions. *Procedia Engineering, 13*, 501-506.

Hildebrand, F., & Drenk, V. (2006). How is propulsion produced on the paddle? In H. Schwameder, G. Strutzenberger, V. Fastenbauer, S. Lindinger & E. Müller (Eds.), *Scientific Proceedings of the XXIVth International Society of Biomechanics in Sports Conference* (pp. 1). Salzburg, Austria

Hopkins, W. G. (2000a). Measures of reliability in sports medicine and science. *Sports Medicine, 30*, 1-15.

Hopkins, W. G. (2000b). Quantitative research design. *Sportscience, 4*, 1-8.

Hopkins, W. G. (2002). *A new view of statistics*. Retrieved 2nd April, 2011, from http://www.sportsci.org/resource/stats/effectmag.html

Hopkins, W. G., Hawley, J. A., & Burke, L. M. (1999). Design and analysis of research on sport performance enhancement. *Medicine and Science in Sports and Exercise, 31*, 472-485.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*, 3-12.

Hopkins, W. G., Schabort, E. J., & Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine, 31*, 211-234.

Issourin, V. (1990). Biomechanical aspects of kayak related to strength. In J. Vrijens, J. Verswtnyft & D. deClerq (Eds.), *International Seminar on Kayak-Canoe Coaching and Sciences* (pp. 83-91). Budapest, Hungary: International Canoe Federation.

Jackson, P. S. (1995). Performance prediction for Olympic kayaks. *Journal of Sports Sciences, 13*, 239-245.

Janssen, I., & Sachlikidis, A. (2010). Validity and reliability of intra-stroke kayak velocity and acceleration using a GPS-based accelerometer. *Sports Biomechanics, 9*, 47-56.

Kendal, S. J., & Sanders, R. H. (1992). The technique of elite flatwater kayak paddlers using the wing paddle. *International Journal of Sport Biomechanics, 8*, 233-250.

Kleshnev, V. (1999). *Estimation of biomechanical parameters and propulsive efficiency in rowing (pp. 1-17)*: Australian Institute of Sport, Biomechanics Department.

Knudson, D. V. (2007). Qualitative biomechanical principles for application in coaching. *Sports Biomechanics, 6*, 109-118.

Knudson, D. V., & Morrison, C. S. (2002). *Qualitative analysis of human movement* (2nd ed.). Champaign, IL: Human Kinetics.

Kraemer, W. J. (2005). The body of knowledge: Use and professionalism. *Strength and Conditioning Journal, 27*, 33-35.

Liow, D., & Hopkins, W. (2003). Velocity specificity of weight training for kayak sprint performance. *Medicine and Science in Sports and Exercise, 35*, 1232-1237.

Logan, S. M., & Holt, L. E. (1985). The flatwater kayak stroke. *National Strength & Conditioning Association Journal, 7*, 4-11.

Mann, R. V., & Kearney, J. (1980). A biomechanical analysis of the Olympic-style flatwater kayak stroke. *Medicine and Science in Sports and Exercise, 12*, 183-188.

Mann, R. V., & Kearney, J. T. (1983). Biomechanics of canoeing and kayaking. In J. Terauds (Ed.), *Scientific Proceedings of the Ist International Society of Biomechanics in Sports Conference* (pp. 145-151). San Diego, California: Point Loma College.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2012a). An observational model for biomechanical assessment of sprint kayaking technique. *Sports Biomechanics, 11*, 507-523.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2012b). Sprint kayaking stroke rate reliability, variability and validity of the digitrainer accelerometer compared to GoPro video measurement. In E. J. Bradshaw, A. Burnett & P. A. Hume (Eds.), *Scientific Proceedings of the XXXth Conference of the International Society of Biomechanics in Sports* (pp. 316-319). Melbourne: Australian Catholic University.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013a). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sports Biomechanics, 12*, 205-220.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013b). Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition. *International Journal of Performance Analysis in Sport, 13*, 38-50.

McKean, M., & Burkett, B. (2010). The relationship between joint range of motion, muscular strength, and race time for sub-elite flat water kayakers. *Journal of Science and Medicine in Sport, 13*, 537-542.

Michael, J. S., Rooney, K. B., & Smith, R. M. (2012). The dynamics of elite paddling on a kayak simulator. *Journal of Sports Sciences, 30*, 661-668.

Michael, J. S., Smith, R., & Rooney, K. B. (2009). Determinants of kayak paddling performance. *Sports Biomechanics, 8*, 167-179.

Mononen, H. V., & Viitasalo, J. T. (1995). *Stroke parameters and kayak speed during 200 m kayaking.* Paper presented at the XVth Congress of the International Society of Biomechanics, Jyvaskyla, Finland. from

Nolte, V. (2005). *Rowing Faster*. Champagne, IL: Human Kinetics.

Ong, K., Ackland, T. R., Hume, P. A., Ridge, B., Broad, E., & Kerr, D. A. (2005). Equipment set-up among Olympic sprint and slalom kayak paddlers. *Sports Biomechanics, 4*, 47-58.

Ong, K., Elliott, B., Ackland, T., & Lyttle, A. (2006). Performance tolerance and boat set-up in elite sprint kayaking. *Sports Biomechanics, 5*, 77-94.

Plagenhoef, S. (1979). Biomechanical analysis of Olympic flatwater kayaking and canoeing. *Research Quarterly, 50*, 443-459.

Plagenhoef, S. (1987). The tempo of the universe related to performance in sports. In *Scientific Proceedings of the Vth Conference of the International Society of Biomechanics in Sports* (pp. 44-56).

Qiu, Y., Wei, W., Liu, A., & Cao, J. (2005). Comparative research on the stroke rhythm of men and women kayakers in the international competition. In Q. Wang (Ed.), *Scientific Proceedings of the XXIIIrd International Symposium on Biomechanics in Sports* (pp. 943-946). Beijing, China: China Institute of Sport Science.

Robinson, M. G., Holt, L. E., Pelham, T. W., & Furneaux, K. (2011). Accelerometry measurements of sprint kayaks: The coaches' new tool. *International Journal of Coaching Science, 5*, 45-56.

Schmidt, R. A. (2003). Motor schema theory after 27 years: Reflections and implications for a new theory. *Research Quarterly for Exercise and Sport, 74*, 366-375.

Seiler, S., & Tønnessen, E. (2009). Intervals, thresholds, and long slow distance: the role of intensity and duration in endurance training. *Sportscience, 13*, 35-53.

Sherwood, D. E., & Lee, T. D. (2003). Schema theory: Critical review and implications for the role of cognition in a new theory of motor learning. . *Research Quarterly for Exercise and Sport, 74*, 376-382.

Sitkowski, D. (2008). Anaerobic threshold in canoeists during specific physical exertion on water or canoe ergometer. *Polish Journal of Sport and Tourism, 15*, 166-173.

Smith, R. M., & Loschner, C. (2002). Biomechanics feedback for rowing. *Journal of Sports Sciences, 20*, 783-791.

Smith, S. W. (2003). *Digital Signal Processing: A Practical Guide for Engineers and Scientist*: Newnes Books.

Sousa, F., Roriz, P., & Goncalves, C. (1996). Kinematics analysis of stroke cycle to an international athlete on canoeing - K1. In J. M. C. S. Abrantes (Ed.), *Scientific Proceedings of the XIVth International Symposium on Biomechanics in Sports* (pp. 401-403). Funchal, Madeira: Universidade Tecnica de Lisboa.

Stothart, J. P., Reardon, F. D., & Thoden, J. S. (1986). Paddling ergometer kinematics of elite kayakers. In J. Terauds, B. A. Gowitzke & L. E. Holt (Eds.), *Scientific Proceedings of the IVth International Society of Biomechanics in Sports Conference* (pp. 125-128). Halifax, Canada: Dalhousie University.

Sumner, D., Sprigings, E. J., Bugg, J. D., & Heseltine, J. L. (2003). Fluid forces on kayak paddle blades of different design. *Sports Engineering, 6*, 11-19.

Szanto, C. (2004). *Racing Canoeing* (2nd ed.). Buenos Aires: International Canoe Federation.

Thompson, K. G., MacLaren, D. P. M., Lees, A., & Atkinson, G. (2002). Accuracy of pacing during breaststroke swimming using a novel pacing device, the Aquapacer™. *Journal of Sports Sciences, 20*, 537-546.

Timofeev, V., Gorodetsky, K., Sokolov, A., & Shklyaruk, S. (1996). Energetic, biomechanical, and electromyographic characteristics of elite kayakers and canoeists. In V. A. Rogozkin & R. Maughan (Eds.), *Current Research in Sports Sciences: An International Perspective* (pp. 191-196). New York: Plenum Press.

Trevithick, B., Ginn, K., Halaki, M., & Balnave, R. (2007). Shoulder muscle recruitment patterns during a kayak stroke performed on a paddling ergometer. *Journal of Electromyography and Kinesiology, 17*, 74-79.

Tucker, R., & Noakes, T. D. (2009). The physiological regulation of pacing strategy during exercise: a critical review. *British Journal of Sports Medicine, 43*, 1-9.

Van Someren, K. A., & Howatson, G. (2008). Prediction of flatwater kayaking performance. *International Journal of Sports Physiology & Performance, 3*, 207-218.

Van Someren, K. A., & Oliver, J. E. (2002). The efficacy of ergometry determined heart rates for flatwater kayak training. *International Journal of Sports Medicine, 23*, 28-32.

Van Someren, K. A., & Palmer, G. S. (2003). Prediction of 200-m sprint kayaking performance. *Canadian Journal of Applied Physiology, 28*, 505-517.

Van Someren, K. A., Phillips, G. R. W., & Palmer, G. S. (2000). Comparison of physiological responses to open water kayaking and kayak ergometry. *International Journal of Sports Medicine, 21*, 200-204.

Appendix 1: Abstracts of conference presentations

Auckland University of Technology Postgraduate Symposium

20 min. oral presentation, 24th September 2010

RELIABILITY AND VARIABILITY OF VELOCITY AND STROKE RATE VARIABLES IN FLAT-WATER SPRINT KAYAKING

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Background: Stroke rate (SR) and timing variables may play an important role in improving flat-water kayaking performance; however their reliability and variability are unknown. **Aim:** To assess within-trial and between-trial reliability/variability of flat-water kayaking velocity and SR variables. **Methods:** Six elite NZ kayakers (three males, three females) performed three trials of 300-m at race pace in a K1 mounted with a lightweight GPS and high-speed video camera. The first 40 strokes from 200 m were analyzed. Within-trial consistency, within-subject reliability/variability, and grouped-subject reliability/variability between trials (2-1 and 3-2) were determined using coefficient of variation (CV), mean difference (Mdiff), Cohen's effect size (ES), typical error (TE), and intra-class correlation coefficients (ICCr). All results were calculated using individual stroke data (n=40) and five-point moving averages (n=36). **Results:** There was lower variability across all variables for most kayakers using five-point moving averages. Using this method, the CV remained under 2% for velocity and video-derived SR during trials two and three, while the GPS-based SR CV averaged up to 2.4%. There was good reliability (Mdiff ≤5% and ES ≤0.6) and moderate variability (TE <10% or ICCr ≥0.67) for video and GPS-based SR between both pairs of trials, and moderate reliability (Mdiff ≤5% and ES >0.6) and small variability (TE <10% and ICCr ≥0.67) to moderate variability for velocity between both pairs of trials. Propulsive time and aerial time varied less (CV <5%) than entry, pull, and exit time (CV >5%). All stroke timing variables except entry time, displayed good average reliability and moderate variability within-subjects between trials 3-2. Entry time displayed moderate reliability. Most variables showed less reliability and greater variability with grouped-subject analysis. **Discussion:** Investigating within-subject data over five-point moving averages for trials two and three proved to be the best method for increasing reliability and reducing variability of all variables.

New Zealand Sports Medicine and Science Conference

15 min. oral presentation, 18-20th November 2010

Measuring biomechanical performance variables in flat-water sprint kayaking

[1]McDonnell, L.K., [1]Hume, P.A., [2]Nolte, V.
[1]Sport Performance Research Institute New Zealand, AUT University, Auckland, New Zealand
[2]University of Western Ontario, Canada

Background: Kayaking research has attempted to determine the relationship between stroke rate and boat velocity,[(Kendal & Sanders, 1992)] however has focused on between-subject comparisons of small sample size. Reliability of variables, and methods for measuring variables, have not been investigated.

Aim: To determine the best method for assessing within-trial and between-trial reliability and variability of flat-water sprint kayaking velocity, GPS-based stroke rate, video-based stroke rate, and time in each of the kayaking stroke phases were measured.

Methods: Six elite New Zealand kayakers (three males, three females) performed three trials of 300-m sprints in a K1 mounted with a GPS/accelerometer device and a lightweight high-speed video camera. Within-trial consistency was evaluated using the mean, SD, and coefficient of variation (CV) for all variables from the first 40 strokes from 200 m. Within-subject reliability (mean difference=Mdiff; Cohen's effect size=ES) and variability (typical error=TE; intra-class correlation coefficient=ICCr) between trials were evaluated between pairs of trials (2-1 and 3-2) for all variables. Grouped-subject reliability (Mdiff and ES) and variability (TE and ICCr) between trials were calculated from grouped individual means. All results were calculated using individual stroke data (n=40) and five-point moving averages (n=36).

Results: There was lower variability across all variables for most kayakers using the five-point moving average analysis. Using this method, CVs remained under 2% for velocity and video-derived stroke rate during trials two and three, while the GPS-based stroke rate CV averaged up to 2.4%. There was good reliability (Mdiff ≤5% and ES ≤0.6) and moderate variability (TE <10% or ICCr ≥0.67) for video and GPS-based stroke rate between both pairs of trials, and moderate reliability (Mdiff ≤5% and ES >0.6) and small variability (TE <10% and ICCr ≥0.67) to moderate variability for velocity between both pairs of trials. Propulsive time and aerial time varied less (CV <5%) than entry, pull, and exit time (CV >5%). All stroke timing variables except entry time, displayed good average reliability and moderate variability within-subjects between trials 3-2, while entry time showed moderate reliability. Most variables showed less reliability and greater variability with grouped-subject analysis.

Discussion: The lower variability from the five-point moving average and higher reliability between trials 3-2, and treating trial one as a familiarization trial, supported using these methods for future investigation. Lower reliability across most variables for grouped data suggests these variables are largely dependent on the individual. Poor technique[(Plagenhoef, 1979)] and self-selected stroke rates may have affected the reliability of stroke timing variables of some individuals.

Conclusion: Using within-subject data over five-point moving averages for trials two and three proved to be the best method when analyzing velocity, stroke rate, and stroke timing variables during short duration sprints among New Zealand flat-water kayakers.

Appendix 2: Abstract of publication in Sports Medicine

The initial PhD topic that led to the continued funding with sprint kayaking resulted in the following manuscript originally published by Wolters Kluwer: McDonnell, L. K., Hume, P. A., & Nolte, V. (2011). Rib stress fractures among rowers: Definition, epidemiology, mechanisms, risk factors and effectiveness of injury prevention strategies. *Sports Medicine, 41*(11), 883-901. Sports Medicine is an Adis Journal, and the current publisher is Springer Science+Business Media; The abstract was provided with kind permission from Springer Science+Business Media B.V.

Rib stress fractures (RSFs) can have serious effects on rowing training and performance and accordingly represent an important topic for sports medicine practitioners. Therefore, the aim of this review is to outline the definition, epidemiology, mechanisms, intrinsic and extrinsic risk factors, injury management and injury prevention strategies for RSF in rowers. To this end, nine relevant books, 140 journal articles, the proceedings of five conferences and two unpublished presentations were reviewed after searches of electronic databases using the keywords 'rowing', 'rib', 'stress fracture', 'injury', 'mechanics' and 'kinetics'. The review showed that RSF is an incomplete fracture occurring from an imbalance between the rate of bone resorption and the rate of bone formation. RSF occurs in 8.1–16.4% of elite rowers, 2% of university rowers and 1% of junior elite rowers. Approximately 86% of rowing RSF cases with known locations occur in ribs four to eight, mostly along the anterolateral/lateral rib cage. Elite rowers are more likely to experience RSF than nonelite rowers. Injury occurrence is equal among sweep rowers and scullers, but the regional location of the injury differs. The mechanism of injury is multifactorial with numerous intrinsic and extrinsic risk factors contributing. Posterior-directed resultant forces arising from the forward directed force vector through the arms to the oar handle in combination with the force vector induced by the scapula retractors during mid-drive, or repetitive stress from the external obliques and rectus abdominis in the 'finish' position, may be responsible for RSF. Joint hypomobility, vertebral malalignment or low bone mineral density may be associated with RSF. Case studies have shown increased risk associated with amenorrhoea, low bone density or poor technique, in combination with increases in training volume. Training volume alone may have less effect on injury than other factors. Large differences in seat and handle velocity, sequential movement patterns, higher elbow-flexion to knee-extension strength ratios, higher seat-to-handle velocity during the initial drive, or higher shoulder angle excursion may result in RSF. Gearing may indirectly affect rib loading. Increased risk may be due to low calcium, low vitamin D, eating disorders, low testosterone or use of depot medroxyprogesterone injections. Injury management involves 1–2 weeks cessation of rowing with analgesic modalities followed by a slow return to rowing with low-impact intensity and modified pain-free training. Some evidence shows injury prevention strategies should focus on strengthening the serratus anterior, strengthening leg extensors, stretching the lumbar spine, increasing hip joint flexibility, reducing excessive protraction, training with ergometers on slides or floating-head ergometers, and calcium and vitamin D supplementation. Future research should focus on the epidemiology of RSF over 4-year Olympic cycles in elite rowers, the aetiology of the condition, and the effectiveness of RSF prevention strategies for injury incidence and performance in rowing.

Participant Information Sheet

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

23rd October 2009

Project Title

Reliability and validity of video, Garmin, and Digitrainer on-water training systems: Measuring performance variables.

An Invitation

Hi, my name is Lisa McDonnell and I am a PhD student at AUT University. Along with my supervisors Prof. Patria Hume and Dr Volker Nolte and my PhD sport advisors Wayne Maher and Simon Pearson, I am inviting you to help with a project that looks at the reliability and validity of video, Garmin, and Digitrainer on-water training systems for use in flat-water kayaking.

You should decide whether or not you would like to be involved. You don't have to be involved, and you can stop being involved in the study at any time without adverse consequences.

What is the purpose of this research?

This study will analyse and summarise Canoe Racing New Zealand's video, Garmin, and Digitrainer data in order to provide coaches with data that will determine the best data feedback system for stroke frequencies, boat velocity, and race time.

How was I chosen for this invitation?

The top six female and six male kayakers (affiliated with CRNZ) available to participate in the North Shore area were chosen. Criteria include being fit, currently training as a sprint kayaker, and healthy. All recruited participants that meet these criteria will be able to participate.

What will happen in this research?

Lightweight data collection equipment will be mounted to your boat during three trials of 300 m time trials during one of your training sessions. You will not see any direct feedback from this equipment during the trial, but you may use your standard Garmin watches as normal to perform the trials. After your trials, data will be analyzed. No additional time is required from you, just your permission for me to mount a lightweight video camera to your boat prior to data collection and to use the data.

What are the discomforts and risks?

You will not experience any risk or discomfort above that normally occurring in a training session of similar intensity.

How will these discomforts and risks be alleviated?

Water will be offered if you feel dizzy during training.

What are the benefits?

You will benefit from this study in the future by the enhanced understanding of the equipment and the measures that it gives. This will enable better feedback sessions with a more detailed understanding and knowledge of expected and desirable values.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation (ACC) providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Only the project supervisors/advisors: Professor Patria Hume, Dr. Volker Nolte, Wayne Maher, Simon Pearson, and Lisa McDonnell will be able to access the raw data. A confidentiality document has been signed by these researchers to ensure your privacy. Your coach may know whether or not you are participating in this project, but will not know your results unless you agree to this. Due to the small, distinct population used, if gender and boat type are discussed there is the possibility that external parties may be able to form an educated guess as to who the participants may be, but no names will be attached to the data. All information related to you will be coded in order to ensure that you cannot be identified. The information will remain in locked storage and will only be accessible to the researchers of the project. No-one should be able to identify you from any of the summary findings for the report of the project.

What are the costs of participating in this research?

The only cost to you is that of time. The consent form should not take more than 5 minutes and the on-water data collection is incorporated into your normal training time period.

What opportunity do I have to consider this invitation?

After consideration you may withdraw your participation at any time.

How do I agree to participate in this research?

If you agree to participate please fill in the attached consent form and return to myself.

Will I receive feedback on the results of this research?

The level of group results feedback you receive will be at your coach's discretion. You can request an individual report of your own individual data if you want it at any time.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

Professor Patria Hume, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7306, patria.hume@aut.ac.nz

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Lisa McDonnell, Rowing New Zealand, Cambridge PO BOX 765,
Phone: 021 0240 4858
Lisa.mcdonnell@aut.ac.nz

Project Supervisor Contact Details:

Professor Patria Hume, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7306, patria.hume@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 29/01/10, AUTEC Reference number 09/275.

Participant
Information Sheet

AUT
U N I V E R S I T Y
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

12th September 2010.

Project Title

Power profiles and performance predictors in sprint kayakers.

An Invitation

Hi, my name is Joe McQuillan and I am a PhD student at AUT University. Along with my supervisors Assoc. Prof. Andrew Kilding and Assoc. Prof Paul Laursen I am inviting you to help with a project that looks at the relationship of three off- water kayak performance.

You should decide whether or not you would like to be involved. You don't have to be involved, and you can stop being involved in the study at any time.

What is the purpose of this research?

The purpose of the research is to establish a performance profile of kayak athletes and compare a number of off-water assessments. By doing this we will be able to evaluate the sensitivity of off-water lab based physiology and performance assessments.

How was I chosen for this invitation?

You have been suggested as being at the level of a national kayak paddler.

What will happen in this research?

You will come to the University lab at the Millennium Institute for Sport and Health in Mairangi Bay on a total of nine occasions across four weeks. The first week will comprise of three visits during which time you will be familiarised with the equipment we will be using to measure your performance and with the three types of assessments you will be completing in the three following weeks. During this first week you will have your body dimensions measured using skinfold callipers and a tape measure and also be familiarised with the body markers which will be applied in order to measure your stroke biomechanics. The three assessments you will be shown during the first three visits are:

1. Power Profile during across five time durations on the kayak ergometer - 5, 30, 60 120 and 240 seconds. These trials will simply require you to paddle as hard as possible for the specified duration. During each trial we will measure your peak power and average power output.

2. Incremental kayak step test to measure kayak economy, technique, peak aerobic power and VO_2max. This test involves paddling on the kayak ergometer in stages of 4 minutes with a one minute rest between stages. Each stage will increase in intensity (wattage) until you can no longer maintain the required power output. During the incremental test we will measure VO_2 using a metabolic cart, blood lactate using a lactate pro, heart rate using a heart rate monitor, and technique using reflective markers and high speed video cameras. These measures will help us define your kayak economy, kayak technique and current level of fitness.

3. Three-minute critical power assessment to measure average power output, average stroke rate and contribution of aerobic and anaerobic energy contribution to the three-minute all-out effort. This will feel similar in intensity to a kayak race.

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During weeks two, three and four you will complete each assessment twice within a week. The testing sessions will be separated by at least two days of rest i.e. if you complete the first assessment on Tuesday the second assessment will not be carried out until at least Friday of that same week. You should rest on the day of the test and in the afternoon of the day prior to the assessment. Aside from these rest periods you should compete and train as written in your training program during the four weeks over the time of the assessments.

What are the discomforts and risks?

You may experience some temporary discomfort (exertion) during the power profile assessment, incremental maximal aerobic test and three-minute all out test. This will be similar to what you feel during hard training and racing (heavy breathing, tired muscles). However, if you experience any excessive discomfort you will be able to stop the test at anytime.

How will these discomforts and risks be alleviated?

The research student is a qualified first aid responder and a medical clinic is located within the building where the lab testing will take place. Cool water will be offered at the end of the assessments and adequate measures will be taken if you feel at all dizzy during the assessments. You will have sufficient time to warm-up prior to starting the assessments.

What are the benefits?

You will benefit from this study by understanding how a period of training effects both competition and off-water performance. You will also establish markers of fitness and technique at this current period in your kayaking career.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All information related to you will be coded in order to ensure that you cannot be identified. The information will remain in locked storage and will only be accessible to the people of the kayak assessment project. No-one will be able to identify you from any of the summary findings for the report of the project.

What are the costs of participating in this research?

The only cost to you is that of time. Each of the two x power profile assessments and incremental kayak step-tests will involve 60 minutes of your time. Prior to these assessments you will have reflective markers for technique analysis attached which will take 15 minutes of your time. The two x three minute all-out assessment will involve 40 minutes of your time as we will need to measure base-line breathing prior to the assessment. During the first week the anthropometry measures will take approximately 20 mins. We will provide you with a $20 petrol voucher to help cover costs of transport to the testing sessions.

What opportunity do I have to consider this invitation?

- You may take the time you need and decide whether or not you would like to be involved
- You can stop being involved in the project at any point

How do I agree to participate in this research?

If you agree to participate please fill in the attached consent form and return to myself.

Will I receive feedback on the results of this research?

Yes, feedback will be provided to you, if you request it.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor:

Assoc. Prof. Andrew Kilding, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7056, andrew.kilding@aut.ac.nz

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, Ph 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Joe McQuillan, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Auckland 0637, Ph 921 9999 ext. 7119, joe.mcquillan@aut.ac.nz

Project Supervisor Contact Details:
Assoc. Prof. Andrew Kilding, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7056, andrew.kilding@aut.ac.nz

Participant Information Sheet

Date Information Sheet Produced:

7th April 2011

Project Title

Optimising stroke rate in developing paddlers.

An Invitation

Hi, my name is Lisa McDonnell and I am a PhD student at AUT University. Along with my supervisors Prof. Patria Hume and Dr Volker Nolte and my PhD sport advisors Dr Simon Pearson and Paula Kearns, I am inviting you to help with a project that aims to individually optimise stroke rate in developing 200-m paddlers towards achieving peak performance.

You should decide whether or not you would like to be involved. You don't have to be involved, and you can stop being involved in the study at any time without adverse consequences.

What is the purpose of this research?

This research will determine the short-term and long-term consistency of self-selected preferred stroke rates chosen in 200-m time trials and performance times, and then how stroke rates can be optimised using immediate stroke rate feedback using a metronome. We also aim to determine body size/shape characteristics of individuals that may play a role in optimising stroke rate selection for peak performance (such as the effect of long or short limbs).

How was I chosen for this invitation?

The best 12 male and 12 female sub-elite kayak paddlers based on previous 2011 regatta results (CRNZ National Championships) or by professional opinion from an experienced coach (for those who did not compete in the 2011 CRNZ National Championships), who are available for the testing sessions in Auckland, were chosen to be invited to participate in this study.

Due to the restrictions of data collection equipment, only the best 12 male and 12 female kayak paddlers will be able to participate. If recruited participants cannot participate for any reason, and drop-out rate exceeds two paddlers for each gender, the next best available participants will be recruited as replacements and the same study design will be carried out to ensure that we have enough data for analysis.

What will happen in this research?

You will be asked to perform five 200-m time trials (separated by one hour rest/recovery when other paddlers will be racing) for one testing session, and to perform four testing sessions (total of 20 time trials) for the study duration (see Table 1). The first two

sessions will occur one week apart. During the week following the second session, you will be given a familiarisation session with a stroke rate feedback device (metronome) and you will have one to two weeks to become comfortable using the device and controlling your stroke rates. During sessions three and four, you will be asked to perform one trial approximately four strokes per minute (using single strokes, not double strokes) slower than your self-selected stroke rate, one trial at your self-selected stroke rate, and three trials above your self-selected stroke rate (approximately four, eight, and twelve strokes per minute higher). Session four will occur three weeks after session three, and session five will occur one week after session four. Within a week of sessions four or five, your anthropometric (body size/shape) characteristics will be measured by a qualified anthropometrist. Your anthropometric profile will only be taken once.

Table 1. Testing timeline.

Week	Test
1	5 x 200-m time trials session one
2	5 x 200-m time trials session two
3	Familiarisation of stroke rate feedback
4	Familiarisation of stroke rate feedback
5	5 x 200-m time trials (with stroke rate feedback) session three / Anthro testing.
6	5 x 200-m time trials (with stroke rate feedback) session four / Anthro testing.
7	Alternative data collection
8	Alternative data collection

What are the discomforts and risks?

The North Shore Canoe Club coach's (Gavin Elmiger's) involvement is a potential risk as a conflict of interest. If you participate in this research, you will be videotaped during the 200-m trials, which is a risk with regard to privacy. Given you should be accustomed to repeat 200-m tests throughout a day, there are no other moral, physical, psychological or emotional risks that exceed that of your normal participation in training with your kayak club. It is possible that you may lose balance and fall out of the boat during a trial, which would be a risk that would not exceed the risk of your normal participation in training.

How will these discomforts and risks be alleviated?

The researcher (independently from the coach) will recruit and ask paddlers to participate in this research. The coach will not be around while informed consent is being signed to allow any questions or concerns to be addressed between the researcher and you. Participation in this research will not be an advantage or disadvantage to you with regard to your status on the team in the present or future. Your results will be kept confidential and provided only to you.

The video collected is only for a data collection tool (to calculate race times accurately) and will not be distributed to any paddler, coach, or organisation. The video will be kept in locked storage with the data and destroyed after 10 years.

If you do not feel comfortable balancing in a K1 kayak, you should not participate in this study. In the rare event that you should fall out of the kayak, standard club safety protocols will be followed. The club K1 kayaks will float if they are rolled upside down, and you may use the kayak as a flotation device while kicking or swimming to shore. The furthest lane in the 200-m course will not be further than 50-m from the shore, but is expected to be within 20-m from the shore.

What are the benefits?

Race times (200-m time trials) will be posted on the day of data collection (similar to a regatta). Findings of the effects of the intervention and their anthropometric profile will be

given to you in the form of a three to four page summary report as an electronic pdf document (mostly graphs and figures) for a friendly explanation of results and recommendations upon completion of the study. A final written report will be distributed to Canoe Racing New Zealand to benefit the development of a national 200-m development programme in the future or from which information sheets on kayak performance may be generated, but no individual's results will be identified in the final report to Canoe Racing New Zealand. You will also gain experience racing and be provided with training feedback on stroke rate.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation (ACC) providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Only project researchers Lisa McDonnell, Professor Patria Hume, Dr. Volker Nolte and Dr Simon Pearson will be able to access the raw data. Your individual results will be distributed only to you via an electronic pdf document, and it will be up to you to distribute this information to your coach or others if you want to. This ensures that no identifiable data is passed to third parties. Identifiable data will remain confidential and only non-identifiable results will be displayed in reports, summaries, or other research outputs resulting from this study. All information related to you will be coded in order to ensure that you cannot be identified. The information will remain in locked storage and will only be accessible to the researchers of the project. No-one should be able to identify you from any of the summary findings for the report of the project.

What are the costs of participating in this research?

The only cost to you is that of time. It is expected that you will need a 30 minute to one hour pre-race warm-up preceding each data collection session (typical morning regatta race preparation warm-up). You will also be provided as much familiarisation time with the metronome feedback as you would like over a two week span when no testing will occur, however at least one training session up to 30 minutes is requested with the researcher. A one hour team meeting will be provided to the participants to explain the details of the study (15 minutes) with the remaining time available for questions (optional). Fifteen hours will be required from four separate sessions of five by 200-m (up to one minute) time trials with one hour rest between (four hours each session not including warm-up), so most of this is rest time in which you are permitted to do whatever you wish as long as you feel rested and recovered. We estimate that this study may require a total of 24 hours of your time over a period of 6-8 weeks (refer to Table 1 for approximate timeline).

What opportunity do I have to consider this invitation?

After consideration you may withdraw your participation at any time.

How do I agree to participate in this research?

If you agree to participate please fill in the attached consent form and return to Lisa McDonnell.

Will I receive feedback on the results of this research?

Yes, findings of the effects of the intervention and your anthropometric profile will be given to you in the form of a two page summary report as an electronic pdf document (mostly graphs and figures) for a friendly explanation of results and recommendations. You will receive feedback upon completion of the study.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the primary project supervisor,

Professor Patria Hume, Sport Performance Research Institute New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7306, patria.hume@aut.ac.nz

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Lisa McDonnell, Sport Performance Research Institute New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7205, Mobile: 021 02 404 858, lisa.mcdonnell@aut.ac.nz

Project Supervisor Contact Details:

Professor Patria Hume, Institute of Sport & Recreation Research New Zealand, School of Sport and Recreation, AUT University, Private Bag 92006, Auckland 1020, Ph 921 9999 ext. 7306, patria.hume@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 30 May 2011, AUTEC Reference number 11/102.

Appendix 4: Consent forms

Consent to Participation in Research

Title of Project: **"Reliability and validity of video, Garmin, and Digitrainer on-water training systems: Measuring performance variables."**

| Project Supervisor: | **Professor Patria Hume** |
| Researcher: | **Lisa McDonnell** |

- I have read and understood the information provided about this research project (Information Sheet dated 23rd October 2009).   Yes/No

- I have had an opportunity to ask questions and to have them answered.   Yes/No

- I am not suffering from any injury or illness which may impair my physical performance   Yes/No

- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.   Yes/No

- If I withdraw, I understand that all relevant information will be destroyed.   Yes/No

- I understand that the video collected will be used for academic/feedback purposes only and will not be published in any form outside of this project without my written permission.   Yes/No

- I give permission for my results to be shared with my coach   Yes/No

- I agree to take part in this research.   Yes/No

- I wish to receive a copy of the report from the research: tick one: Yes O   No O

Participant signature: ....……………………..

Participant name: …………………………………………………………

Date: …………………………………………………………

Participant's Contact Details:

……………………………………………………………………………………….

……………………………………………………………………………………….

Project Supervisor Contact Details:
Professor Patria Hume
Institute of Sport & Recreation Research New Zealand
School of Sport and Recreation
Auckland University of Technology
Private Bag 92006
Auckland 1020
Ph 921 9999 ext. 7306
patria.hume@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on ***29/01/10*** AUTEC
Reference number 09/275.

Consent to Participation in Research

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Title of Project: **"Power profiles and performance predictors in sprint kayakers"**

Project Supervisor: **Associate Professor Andrew Kilding**
Researcher: **Joe McQuillan**

- I have read and understood the information provided about this research project
(Information Sheet dated 12th September 2010)   Yes/No

- I have had an opportunity to ask questions and to have them answered   Yes/No

- I am not suffering from any injury or illness which may impair my physical
performance   Yes/No

- I understand that I may withdraw myself or any information that I have provided for
this project at any time prior to completion of data collection, without being
disadvantaged in any way   Yes/No

- If I withdraw, I understand that all relevant information will be destroyed   Yes/No

- I consent to my data being shared with my coach   Yes/No

- I understand that the information collected will be used for academic/feedback
purposes only and will not be published in any form outside of this project without
my written permission   Yes/No

- I agree to take part in this research   Yes/No

- I understand that I can request to have any blood/biological fluid taken returned to
me   Yes/No

- I wish to receive a copy of the report from the research: *tick one:* Yes   O   No   O

Participant signature: ....

Participant name: ....

Date: ....

Participant's Contact Details:

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Project Supervisor Contact Details:
Associate Professor Andrew Kilding
Institute of Sport & Recreation Research New Zealand
School of Sport and Recreation
Auckland University of Technology
Private Bag 92006
Auckland 1020
Ph 921 9999 ext. 7056
Andrew.kilding@aut.ac.nz
Approved by the Auckland University of Technology Ethics Committee Date 3rd
September, 2010.

Consent to Participation in Research

Title of Project: **"Optimising stroke rate in developing paddlers."**

Project Supervisor: **Professor Patria Hume**

Researcher: **Lisa McDonnell**

- I have read and understood the information provided about this research project (Information Sheet dated 7th April 2011).   Yes/No

- I have had an opportunity to ask questions and to have them answered.   Yes/No

- I am not suffering from any injury or illness which may impair my physical performance   Yes/No

- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.   Yes/No

- If I withdraw, I understand that all relevant information will be destroyed.   Yes/No

- I understand that the copyright of videos is owned by the researchers and will not be distributed to anyone. Video is only intended as a data collection tool. Yes/No

- I agree to take part in this research.   Yes/No

- I wish to receive a copy of the report from the research: tick one: Yes O   No O

Participant signature: ....……………………..

Participant name: ……………………………………………………………

Date: …………………………………………………………………

Participant's contact details:

…………………………………………………………………………..

…………………………………………………………………………..

Project Supervisor Contact Details:
Professor Patria Hume
Sport Performance Research Institute New Zealand
School of Sport and Recreation
Auckland University of Technology
Private Bag 92006
Auckland 1020
Ph 921 9999 ext. 7306
patria.hume@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *30 May 2011,* **AUTEC Reference number 11/102.**

Appendix 5: Ethics approval

MEMORANDUM
Auckland University of Technology Ethics Committee (AUTEC)

To:	Patria Hume
From:	**Madeline Banda** Executive Secretary, AUTEC
Date:	29 January 2010
Subject:	Ethics Application Number 09/275 **Reliability and validity of video, Garmin, and Digitrainer on-water training systems: Measuring performance variables.**

Dear Patria

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 14 December 2009 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 8 February 2010.

Your ethics application is approved for a period of three years until 29 January 2013.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/research/research-ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 January 2013;

- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/research-ethics*. This report is to be submitted either when the approval expires on 29 January 2013 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Lisa McDonnell lisa.mcdonnell@aut.ac.nz

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Andrew Kilding
From: **Charles Grinter** Ethics Coordinator
Date: 3 September 2010
Subject: Ethics Application Number 10/57 **Power profiles and performance predictors in elite sprint kayakers.**

Tena koe Andrew

I am pleased to advise that I have approved a minor amendment to your ethics application allowing an additional data capture using videotape. This delegated approval is made in accordance with section 5.3.2 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 11 October 2010.

Your ethics application is approved for a period of three years until 15 June 2013.

I remind you that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 15 June 2013;

- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 15 June 2013 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

On behalf of Madeline Banda, Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Joe McQuillan joe.mcquillan@aut.ac.nz, Paul Laursen

M E M O R A N D U M

Auckland University of Technology Ethics Committee (AUTEC)

To:	Patria Hume
From:	**Dr Rosemary Godbold and Madeline Banda** Executive Secretary, AUTEC
Date:	3 June 2011
Subject:	Ethics Application Number 11/102 **Optimising stroke rate in developing paddlers.**

Dear Patria

Thank you for providing written evidence as requested. We are pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 9 May 2011 and that on 30 May 2011, we approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 27 June 2011.

Your ethics application is approved for a period of three years until 30 May 2014.

We advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 May 2014;

- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 30 May 2014 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC and ourselves, we wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold and Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Lisa McDonnell lisa.mcdonnell@aut.ac.nz

Appendix 6: Copyright permissions

Sports Biomechanics copyright permission

The copyright agreements signed for the following *Sports Biomechanics* manuscripts explicitly state that the authors retain the "right to include an article in a thesis or dissertation that is not to be published commercially, provided that acknowledgement to prior publication in the relevant Taylor & Francis journal is made explicit":

McDonnell, L. K., Hume, P. A., & Nolte, V. (2012). An observational model for biomechanical assessment of sprint kayaking technique. *Sports Biomechanics, 11*, 507-523.

McDonnell, L. K., Hume, P. A., & Nolte, V. (2013). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sports Biomechanics, 12,* 205-220.

International Journal of Performance Analysis in Sport copyright permission

From: O'Donoghue, Peter [mailto:PODonoghue@cardiffmet.ac.uk]

Sent: Wednesday, 5 June 2013 8:42 p.m.

To: Patria Hume

Subject: RE: IJPAS paper

Hi Patria

It can be included in the print copy but not the electronic copy

POD

From: Patria Hume [patria.hume@aut.ac.nz]

Sent: 05 June 2013 03:51

To: O'Donoghue, Peter

Subject: FW: IJPAS paper

Hi Peter

Lisa is wanting to submit her thesis tomorrow, and has only just realised that she did not get the required copyright permission form completed.

If you are able to send an email stating that the IJPAS gives permission for the text version to appear in Lisa's thesis, with reference to the journal at the start of the thesis chapter, that would be appreciated. This is the standard format that we use for PhD theses.

Regards
Patria.

Patria Hume PhD FISBS Professor Human Performance

Director, AUT Millennium Sports Performance Research Institute New Zealand www.sprinz.ac.nz
Room SA207, AUT Millennium Campus, 17 Antares Place, Mairangi Bay, North Shore City 0632, Auckland.
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| Auckland 1020 | PHONE +64 9 921 9999 ext 7306 | FAX +64 9 921 9960 | SKYPE patria1|
Associate Dean Research, Faculty of Health and Environmental Sciences
Room AG105, AUT North Shore Campus, Akoranga Drive.
AUT HEALTH + ENVIRONMENTAL SCIENCES

Dear Peter O'Donoghue,

I am the author of "**Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition**" ("the Work") which was published by **University of Wales Institute, Cardiff** in **International Journal of Performance Analysis in Sport** and for which the copyright was assigned to **University of Wales Institute, Cardiff** by an agreement dated **April 2013 (published in volume 13, number 1, pages 38-50)**.

I am a doctoral student at Auckland University of Technology and would like to include the Work in my doctoral thesis '**The effect of stroke rate on performance in flat-water sprint kayaking**'. The Work would be fully and correctly referenced in this thesis. A print copy of this thesis when completed will be deposited in the Auckland University of Technology Library, and a digital copy will also be made available online via the University's digital repository, ScholarlyCommons@AUT http://autresearchgateway.ac.nz/ . This is a not-for-profit research repository for scholarly work which is intended to make research undertaken in the University available to as wide an audience as possible. I would be grateful if you, or the company you represent, could grant me permission to include the Work in my thesis and to use the Work, as set out above, royalty free in perpetuity.

If you agree, I should be very grateful if you would sign the form (attached) and return a copy to me. If you do not agree, would you please notify me of this. I can most quickly be reached by email at lisa.mcdonnell@aut.ac.nz. Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,
Lisa Kelly McDonnell

Sports Medicine copyright permission

From: Permissions Europe/NL [mailto:Permissions.Dordrecht@springer.com]
Sent: Thursday, 6 June 2013 1:08 a.m.
To: Lisa McDonnell
Subject: RE: Copyright permission for Sports Medicine Manuscript in a Doctoral Thesis Appendix

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Kind regards,
Maaike Duine

Dear Jenny Thomspon, Sports Medicine Publication Manager,

I am the author of "**Rib stress fractures among rowers: Definition, epidemiology, mechanisms, risk factors and effectiveness of injury prevention strategies**" ("the Work") which was published by **Adis, a Wolters Kluwer business** in **Sports Medicine** and for which the copyright was assigned to **Adis, a Wolters Kluwer business** by an agreement dated **28th of September 2011 (published in volume 41, issue 11, pages 883-901)**.

I am a doctoral student at Auckland University of Technology and would like to include the Work as an appendix to my doctoral thesis '**The effect of stroke rate on performance in flat-water sprint kayaking'** given my PhD scholarship was originally awarded for my work in rowing rib stress fractures. The Work would be fully and correctly referenced in this thesis. A print copy of this thesis when completed will be deposited in the Auckland University of Technology Library, and a digital copy will also be made available online via the University's digital repository, ScholarlyCommons@AUT http://autresearchgateway.ac.nz/. This is a not-for-profit research repository for scholarly work which is intended to make research undertaken in the University available to as wide an audience as possible. I would be grateful if you, or the company you represent, could grant me permission to include the Work in my thesis and to use the Work, as set out above, royalty free in perpetuity.

If you agree, I should be very grateful if you would sign the form (attached) and return a copy to me. If you do not agree, would you please notify me of this. I can most quickly be reached by email at lisa.mcdonnell@aut.ac.nz. Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,
Lisa Kelly McDonnell

**Note: *Sports Medicine* is an Adis Journal, now published by Springer Science+Business Media.