UNIVERSITY OF TECHNOLOGY SYDNEY

Competition and training demands of junior Sprint Kayak athletes

A thesis submitted for the degree

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By

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree at the University of Technology Sydney nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me, Thiago Oliveira Borges. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

_____

Signature of Student

_____

Date

Acknowledgements

> "I have a kind of duty, duty of dreaming, always dreaming
>
> as being more than a spectacle of myself,
>
> I have to have the best show I can.
>
> And so, I build myself in gold and silk, in rooms
>
> alleged, I invent a stage, scenery to live my dream
>
> amongst mild lights and invisible music."
>
> Fernando Pessoa

A PhD is a very difficult task to be accomplished in someone's life. It starts as a complex dream and like a puzzle, all the pieces are put in place at their own time and all of a sudden, these pieces are in place and the dream finally come true. However, like any big puzzle, the pieces are put together easier with help, and I am very grateful for everyone that has helped me in any way to complete this PhD. Thank you.

I would like to thank my wife, Dionízia for always being supportive and strong to endure along with me in this endeavour that is life. I love you.

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Finally, to my family and friends, a huge thank you for all of your encouragement, well-wishes, patience and unwavering support.

Preface

This thesis for the degree of Doctor of Philosophy is in the format of published, submitted or ready for submission manuscripts and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology, Sydney; Policies and Directions of the University'. All manuscripts included in this thesis are closely related in subject matter and form a cohesive research narrative.

Based on the research design and data collected by the candidate, two manuscripts have been published, one has been submitted for publication and three are ready to be submitted, in peer-reviewed journals. These papers are initially brought together by an *Introduction*, which provides background information, defines the research problem and the aim of each study. Then, a *Literature Review* provides an overview of previous knowledge that characterizes Sprint Kayak performance, methods for measure training, performance and physiological responses of Sprint Kayak and means to improve those variables. A logical sequence following the development of research ideas in this thesis is presented in manuscript form (*Chapter 3 to Chapter 8*).

Each manuscript outlines and discusses the individual methodology and the findings of each study separately. The *General Discussion* chapter provides an interpretation of the collective findings and practical applications from the series of investigations conducted. Lastly, a final *Summary and Recommendations* chapter summarizes the research hypothesis and conclusions from each project. Future research is suggested on the basis of the findings from the studies. Author-date reference style has been used throughout the document and the reference list is at the end of the thesis.

List of Articles Submitted for Publication

Refereed Journal Publications

- **Oliveira Borges, T.**, Bullock, N. and Coutts, A.J. Pacing characteristics of international Sprint Kayaks athletes. *Int J Perf Analysis in Sports*. 13: 353-364, 2013.

- **Oliveira Borges, T.**, Dascombe, B. J., Bullock, N. and Coutts, A.J. (*Prepared for submission*). Physiological characteristics of well-trained junior Sprint Kayak athletes. *Eur J Sports Sci.*

- **Oliveira Borges, T.**, Bullock, N., Newton, J. and Coutts, A.J. (*under review*). A new field test for assessing and monitoring Sprint Kayak athletes. *J Sports Sci.*

- **Oliveira Borges, T.**, Bullock, N., Duff, C. and Coutts, A.J. Methods for quantifying training in Sprint Kayak. *J Strength Cond Res. Published ahead of print. DOI:10.1519/JSC.0b013e31829b56c4*

- **Oliveira Borges, T.**, Bullock, N., Dascombe, B.J. and Coutts, A.J. (*Prepared for submission*). The acute response of common repeated sprint and high-intensity aerobic training sessions in Sprint Kayak athletes. *J Strength Cond Res.*

- **Oliveira Borges, T.**, Bullock, N., Dascombe, B.J. and Coutts, A.J. (*Prepared for submission*). Comparison of the acute physiological responses of repeated sprint and high-intensity aerobic training sessions in Junior Sprint Kayak athletes. *Int J Sports Phys Perf.*

Conference Proceedings & Abstracts

- **Oliveira Borges, T.**, Bullock, N., Dascombe, B.J. and Coutts, A.J. (2013). *Comparison of high-intensity aerobic and repeated sprint training on performance and physiological variables of junior Sprint Kayak athletes.* Oral communication presented at the European College of Sport Sciences, Barcelona, Spain.

- **Oliveira Borges, T.**, Bullock, N., Dascombe, B.J. and Coutts, A.J. (2013). *Correlates of whole body and muscle oxygen on kinetics, physiological variables and performance in Sprint Kayak.* Mini - oral communication presented at the European College of Sport Sciences, Barcelona, Spain.

Statement of Candidate Contribution

The contribution of each author to the investigations undertaken as part of the thesis is outlined in Table A below.

Table A: Percentage contribution (%) of each author to the investigations conducted during the candidature.

Author	Study 1			Study 2				Study 3			
	Thiago Oliveira Borges	Nicola Bullock	Aaron Coutts	Thiago Oliveira Borges	Nicola Bullock	John Newton	Aaron Coutts	Thiago Oliveira Borges	Ben Dascombe	Nicola Bullock	Aaron Coutts
Research design	80%	10%	10%	70%	10%		20%	70%	5%	5%	20%
Ethics Application				70%	10%		20%	70%		10%	20%
Subject recruitment				30%	20%	50%		90%		10%	
Data collection	100%			70%	10%	20%		90%			10%
Data analysis	60%		40%	80%	10%		10%	80%	10%		10%
Statistical analysis	50%		50%	80%			20%	80%			20%
Manuscript Preparation	100%			100%				100%			
Manuscript Revision		25%	75%		30%		70%		10%	10%	80%

Table A (*cont.*): Percentage contribution (%) of each author to the investigations conducted during the candidature.

Author	Study 4				Study 5				Study 6			
	Thiago Oliveira Borges	Nicola Bullock	Christine Duff	Aaron Coutts	Thiago Oliveira Borges	Nicola Bullock	Ben Dascombe	Aaron Coutts	Thiago Oliveira Borges	Nicola Bullock	Ben Dascombe	Aaron Coutts
Research design	80%	10%		10%	70%	10%	10%	10%	80%	10%		10%
Ethics Application	80%	10%		10%	80%			20%	80%	10%		10%
Subject recruitment	40%	10%	50%		90%	10%			90%	10%		
Data collection	90%		10%		90%			10%	90%	10%		
Data analysis	100%				90%			10%	70%	10%	10%	10%
Statistical analysis	90%			10%	100%				90%			10%
Manuscript Preparation	100%				100%				100%			
Manuscript Revision		25%		75%		10%	20%	70%		15%	15%	70%

Abstract

Introduction: Sprint Kayak is an Olympic sport where women race over 200-m and 500-m and men compete over 200 and 1000-m. In 2009 the 200-m event was included into the Olympic Games' program replacing the men's 500-m events and providing the women with an additional event. Currently, little research is available on the demands of the 200-m event. With the inclusion of this short distance event, the training practices require review, especially in the case of young developing athletes, as this group may begin to specialise their training toward this new format. Therefore, the overall goals of this thesis were to: 1) gain a better understanding of the racing and physiological demands in Sprint Kayak, 2) develop specific methods for monitoring training and performance and 3) compare methods for training well-trained junior Sprint Kayak athletes. The results of four separate studies were reported in six manuscripts.

Study 1: The split –time results from six Sprint Kayak world championships (n_{total} = 486) were pooled and the pacing strategies and performance analysed according to race level (Finals A and B) and boat (K1, K2 and K4). Collectively, the world-class Sprint Kayak athletes present different pacing strategy according to final A and B), boat class (K1, K2 and K4) and from year to year.

Study 2: Examined the relationships between physiological variables, including $\dot{V}O_2max$, maximal aerobic power (MAP), lactate threshold (LT_2), whole body ($\dot{V}O_{2kinetics}$) and muscle oxygen kinetics ($MO_{2kinetics}$), muscle oxygenation parameters and on-water time-trial performances. The results showed physiological variables correlated with performance in both 200-m and 1000-m events. Furthermore, the muscle oxygenation parameters increased the predictive power of these physiological variables highlighting the importance of muscle oxygen extraction for the 200-m time-trial.

Study 3: Tested a specific performance test (SK_{test}) in the laboratory and in the field for validity (as a performance and fitness measure) and reliability (part A). In addition, the test sensitivity was assessed during a normal training period (part B) in a separate group of well-trained junior Sprint Kayak athletes. Part A - Participants (n = 11) completed a standard incremental kayak step test in the laboratory, a SK_{test} consisting of two sets of ten 100-m efforts with 20 s rest between efforts and 1000-m between sets in both laboratory and on-water and on-water time trials over 200 and 1000-m. Part B – Another group of athletes (n = 8) performed weekly trials of the short version of the SK_{test} for four weeks, in their usual training environment. The results showed the SK_{test} to be valid, reliable and sensitive for monitoring fitness and performance changes.

Study 4: Tested the validity of methods for quantifying training load and established the relationships between training loads, physiological variables and on-water performance in well-trained junior Sprint Kayak athletes. The results demonstrated the validity of the session-RPE method for quantifying training loads in Sprint Kayak. Moreover, the inverse relationships between physiological variables, performance and training loads showed that aerobically fitter and faster athletes have lower perceived training loads when external loads are controlled.

Study 5: Compared the power outputs and acute physiological responses (i.e. heart rate [HR], blood lactate [BLa^-], $\dot{V}O_2$, and tissue saturation index [TSI])) of common repeated sprint (RS) and high-intensity aerobic (HIA) interval training sessions in well-trained junior Sprint Kayak athletes. Two different RS training sessions consisting of a shorter 10 s repeat effort session (2 sets of 10 s efforts with 10 s rest between efforts and eight minutes between sets) and a longer 30-s repeat effort session (6 x 30 s efforts with 210 s rest). The HIA sessions included a shorter (2 x 3 min efforts with 3 min rest between efforts, and 5 min between sets) and a longer 2-km (3 x 2 km efforts on a 15

min cycle) interval training sets. The results showed the physiological responses and external loads to the main body the HIA interval sessions were considerably different from RS sessions, with the exception of TSI which was similar for all. Mixed modelling showed significant random variation for the time spent in different training zones for mean power output and $\dot{V}O_2$. The present study highlighted distinct differences in the HR, $\dot{V}O_2$, [BLa$^-$], and perceptual responses to common RS and HIA training, with the shorter RS sessions placing a greater stimulus on glycolytic pathways, and the longer HIA sessions requiring greater energetic demands. Importantly, *large* inter-individual physiological responses were observed across each of the different training sessions. These findings highlight the need to individualise training programs for Sprint Kayak based on the athletes' characteristics and demands of competition.

Study 6: Compared the effects of 5 weeks of RS and HIA interval training on physiological ($\dot{V}O_2$max, MAP, LT$_2$, $\dot{V}O_{2kinetics}$ and MO$_{2kinetics}$) and performance (200 and 1000-m on water time trial) variables in well-trained junior Sprint Kayak athletes using matched-groups randomised design. The groups were matched for physical fitness and on-water kayak performance. In addition to their usual training, the RS training group completed a shorter 10 s repeat effort session (2 sets of 10 s efforts with 10 s rest between efforts and 8 minutes between sets) and longer 30-s repeat effort session (6 x 30 s efforts with 210 s rest), where each session was completed once per week. Similarly, the HIA interval training group completed a three-minute (2 x 3 min efforts with 3 min rest between efforts and 5 min between sets) and longer 2-km aerobic training (3 x 2 km efforts on a 15 min cycle) session once each week during the study in addition to their usual training. Results showed that the RS and HIA interval training interventions elicited *trivial* changes in maximal indicators of aerobic fitness (i.e. $\dot{V}O_2$max and maximal HR) and *trivial* and *small* on-water performance (i.e. time trials

over 200 and 1000-m, respectively) in both groups. In contrast, submaximal physiological responses (i.e. lactate threshold) were *trivial* whereas oxygen kinetics presented *small-to-moderate* improvements after five weeks (~19 training sessions) performed by both RS and HIA groups. This information suggests that physiological and performance characteristics are very stable in well-trained junior Sprint Kayak athletes. It seems that either larger loads of RS or HIA interval training or longer training periods are required to elicit larger changes in specific physiological adaptations in well-trained junior Sprint Kayak athletes.

List of Abbreviations

% HRmax	maximal heart rate percentage
µL	microlitre
AIS	Australian Institute of Sport
ANOVA	analysis of variance
A_p	asymptotic amplitudes for the primary exponential component
A_s	asymptotic amplitude for the slow exponential component
ATP	adenosine triphosphate
$[BLa^-]$	blood lactate concentration
C1	canoe single
C2	canoe double
CI	confidence intervals
CR-10	category-ratio scale
CV	coefficient of variation
EEO_2	end-exercise o_2 value
G_o	total gain
G_p	primary gain
GPS	global positioning system
G_s	slow gain
η^2	partial eta squared
HHb	deoxyhaemoglobin
HR	heart rate
$HR_{exercise}$	exercise heart rate
HRmax	maximal heart rate
HR_{rest}	rest heart rate
ICC	intraclass correlation
ICF	international canoe federation
In	natural logarithm
IRK	internationale repräsentantenschaft kanusport
iTRIMP	individualized training impulse
K1	kayak single
K2	kayak double
K4	kayak four
$L \cdot min^{-1}$	litres per minute
LT_1	aerobic threshold
LT_2	lactate threshold
m	Metre
MAP	maximal aerobic power
min	Minute
$mL \cdot kg^{-1} \cdot min^{-1}$	millilitres per kilogram per minute
mm	millimetre
$mmol \cdot L^{-1}$	mill moles per litre
N	sample size
NIRS	near infrared spectroscopy
O_2Hb	Oxyhaemoglobin
$O_2 (t)$	o_2 at a given time
PCr	phosphocreatine
r	correlation coefficient

r^2	determination coefficient
RPE	ratings of perceived exertion
RSA	repeated sprint ability
RSS	residual sum of squares
s	seconds
SD	standard deviation
SK_{test}	sprint kayak test
session-RPE	ratings of perceived exertion of the training session
SPSS	statistical package for social science
SWT	squared wave submaximal tests
tHb	total haemoglobin
TD_p	time delay for the primary exponential component
TD_s	time delay for the slow exponential component
TE	typical error
TEM	technical error of measurement
TL	training loads
τ^s	time constants for the primary exponential component
TRIMP	training impulse
iTRIMP	individualized training impulse
τ^s	time constants for the slow exponential component
TSI	tissue saturation index
TSS	total sum of squares
TT	time trial
UTS	University of Technology, Sydney
Vmax	highest speed
V_{min}	lowest speed
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_2max$	maximal oxygen uptake
W	Watts
wMRT	weighted mean response time
ΔHR_{ratio}	rate of heart rate elevation

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CHAPTER ONE

Introduction

1. Background

Sprint Kayak has been part of the Olympic program since 1936. Not only has the equipment evolved but also the racing format and the competition rules have changed considerably. The most recent significant rule change occured in 2009 with the inclusion of the 200-m race into the Olympic program for both men and women at the expense of the 500-m racing for men (ICF 2013). The typical individual performance times for men and women have been approximately 35 and 40 s, 100 and 114 s for the 200 and the 500-m, and 210 s for the 1000-m, respectively. Prior to this change, male athletes had been able to compete in both 500 and 1000-m distances at major championships. For example, at both Athens and Beijing Olympic Games, the athlete who won the 500-m also placed third in the 1000-m, which is in part likely attributed to the similar aerobic contribution (~ 82% for the 1000-m and 65% for the 500-m) requirements of these events (Byrnes and Kearney 1997, Bishop 2000, van Someren and Howatson 2008). In contrast, the 200-m event has been shown to require greater anaerobic contribution, and is considered a 'speed-endurance' event rather than an 'endurance' event (Byrnes and Kearney 1997). This shorter event also has distinct technical requirements from both the 500 and 1000-m events. Due to these differences it seems athletes would be required to specialize in either event to be successful at the international level.

Regardless of race distance, Sprint Kayak athletes require well-developed levels of specific fitness, specific physical characteristics, as well as good technical and tactical abilities. In fact, indicators of fitness level such as the maximum oxygen uptake ($\dot{V}O_2max$), maximum aerobic power (MAP) and the lactate threshold (LT_2) have *large-*

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to-very large correlations with both 500 and the 1000-m performance (Fry and Morton 1991, Bishop 2000, van Someren and Howatson 2008), though the relationships between these same fitness variables and 200-m performance have shown to be *trivial-to-large* (r from -0.02 to -0.59) (van Someren and Palmer 2003, van Someren and Howatson 2008). These differences in the relationships between these physiological characteristics and race distance suggest that different fitness characteristics may be required for success in each Sprint Kayak event. Moreover, whilst the importance of aerobic characteristics (i.e. MAP, $\dot{V}O_2max$ and LT_2) have been shown to be important for race performance over all distances, it is surprising the importance of oxygen kinetics at whole body ($\dot{V}O_{2kinetics}$) and muscle level ($MO_{2kinetics}$) have yet to be investigated. Therefore, further studies that investigate the specific race demands and physiological requirements of Sprint Kayak events are required. Additionally, whilst there have been several studies in well-developed Sprint Kayak athletes, there have been few studies examining developing junior (i.e. youth) athletes. Studies examining the physiological demands and training responses of developing junior Sprint Kayak athletes are also required as such information may be used to inform and optimize training programs for the next generation of athletes. Such information may be used to guide coaches and sport scientist on appropriate programs to develop elite kayak athletes in each of the specific Sprint Kayak events.

Whilst many studies have examined the importance of aerobic ($\dot{V}O_2max$, MAP and LT_2) and anaerobic (accumulated oxygen deficit and 30 s maximal effort) fitness variables in open-age Sprint Kayak athletes, it is surprising that to date no studies have examined the importance of whole body oxygen kinetics and muscle oxygen kinetics for these athletes. It is well known that at the beginning of the exercise, there is an

oxygen deficit as the metabolic machinery adjusts to the new levels of intensity. At the same time, the aerobic contribution to ATP replenishment acts so that the muscles have sufficient energy to maintain muscle contractions (Burnley and Jones 2007, Poole, Barstow et al. 2008). It has been shown that the faster these adjustments occur, the better the athletes reach the optimal level of oxygen consumption. Moreover, these adjustments are correlated with levels of fitness and performance in both recreationally and trained athletes (Carter, Jones et al. 2000, Berger, Tolfrey et al. 2006, Ingham, Carter et al. 2007). Furthermore, studies have shown oxygen kinetics is related with aerobic (Burnley and Jones 2007) and anaerobic fitness (Dupont, Millet et al. 2005). Collectively, it seems that Sprint Kayak athletes could benefit from an investigation of whole body and muscle oxygen kinetics. This information would help to clarify the relationships between oxygen kinetics, and Sprint Kayak performance.

With a wide range of metabolic demands between race distances, it seems logical that Sprint Kayak athletes require a specific, well-designed training program to provide the athletes with the best preparation to succeed in competition. One important aspect of any training program is applying appropriate training doses so that the athlete receive sufficient stimulus to improve their physical characteristics, whilst avoiding excessive training and reduce the risks of overtraining (Kenttä, Hassmén et al. 2006, Coutts, Reaburn et al. 2007). It has been suggested that careful monitoring of training can be used to gauge how the athletes are coping with training (Borrensen and Lambert 2009). However, to objectively monitor training, first there is the need for valid methods that can be applied to quantify the training loads. Whilst, several methods for quantifying training loads are available (Banister, Calvert et al. 1975, Foster, Hector et al. 1995, Borrensen and Lambert 2009), none have been validated in Sprint Kayak training.

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It has been suggested that the training outcome can be gauged by both the internal training and the external training load (Impellizzeri, Rampinini et al. 2005), with each of these constructs of training load providing different information about the training program. The external training load provides information about the nature of the training completed in a particular session such as distance covered, power output or velocity, whilst the internal loads represent how the athletes responded to the imposed external load. In Sprint Kayak, the external loads can be measured through training distances and speeds, whilst the internal training load is commonly assessed through heart rate response or an athlete's perception of effort. To date however, no studies have examined the validity of methods for quantifying the internal training loads in Sprint Kayak training. Such information is important so that coaches and scientists can monitor the training applied to their athletes during training and make informed decisions about the training process of their athletes.

The monitoring process may also involve routine laboratory testing such as $\dot{V}O_2$max, MAP and lactate threshold assessments (Bullock, Woolford et al. 2013). Whilst such procedures may offer precise and objective measures of changes in an athlete's physiological status, they can often burden the athlete as their scheduling may disrupt training routines, have financial cost and the results may have limited ecological validity to race performance. Therefore, valid and reliable field tests of Sprint Kayak fitness and performance are appealing for coaches and athletes as they can be implemented as a standard training session and be completed in the typical training environment (Coutts, Reaburn et al. 2007, Coutts, Slattery et al. 2007, Wallace, Slattery et al. 2009). To date however, whilst several field-based tests for other sports have been

developed, there are no known valid and reliable field tests for monitoring changes in Sprint Kayak fitness and performance. Such tests could be useful and regularly used in conjunction with other monitoring tools (training load and fatigue measures) to follow and control an athletes' progression during training. Nevertheless, such approach in Sprint Kayak yet requires investigations to clarify if valid and reliable field tests can be developed for Sprint Kayak.

2. Research Problem

Compared to many other sports there is a relatively little research that has examined the training and competition demands of Sprint Kayak athletes. Indeed, there have been no field-based studies that have examined the race demands in competitions of top-level Sprint Kayak athletes. Moreover, the laboratory-based research in Sprint Kayak mostly investigates the requirements of the 500 and 1000-m events, with relatively few studies examining the demands of the new 200-m Olympic event. Additionally, most previous studies have only reported on the relationships of generic fitness measures such as $\dot{V}O_2max$, MAP and lactate threshold, and Sprint Kayak race performance. As consequence, the understanding of other variables such as whole body and muscle oxygen kinetics and Sprint Kayak on-water performance are limited. Information about the relationships of such variables with Sprint Kayak race performance (both 200 and 1000-m events) may assist scientists and coaches to better understand the physiological factors for targeting in training. Moreover, there is also little information on the best methods for training to improve these physiological characteristics in Sprint Kayak athletes. Such information may assist athletes to appropriately focus their training so that performance outcomes can be maximised. There is presently also little information

available on the physiological characteristics of developing Sprint Kayak athletes – the group that will form the basis of future open age athletes. Therefore studies that examine the racing characteristics, physiological determinants of performance, and the acute and chronic physiological responses to different training methods in Sprint Kayakers are required. Additionally, tools for monitoring training and assessing performance changes in the field are also needed so that the process of training in can be carefully monitored and controlled. Such information would provide new insights into 1) the competition demands of the Sprint Kayak events, 2) optimal methods for training for the Sprint Kayak, and 3) provide new practical scientific tools that can be used to monitor and control the training process in Sprint Kayak. Indeed, the overall aims of this thesis are to provide new information to assist coaches and sport scientists better prepare junior Sprint Kayak athletes for competition.

3. Study Objectives

This thesis consisted of a number of applied studies that addressed various problems that improved our understanding of the physiological and racing demands of Sprint Kayak competition, methods for training for improved Sprint Kayak performance and methods for monitoring and controlling Sprint Kayak training.

An applied research approach was used to examine the racing characteristics, the determinants of performance, optimal approaches to training and a valid monitoring training system for assessing fitness and performance adaptations in junior Sprint Kayak athletes. Additionally, a method for quantifying training load for Sprint Kayak was validated and a new practical field test for assessing physiological and performance

changes in well-trained young Sprint Kayak athletes was also developed. A series of six

related studies were conducted.

Study 1: Pacing characteristics of international Sprint Kayak athletes (Chapter 3)

Aims

To profile the pacing strategies used by world-class kayakers during world championships events; to verify the pacing profile of different competition levels (A and B-finals), competitive seasons and different boats (K1, K2 and K4).

Hypothesis

World-class Sprint Kayak athletes would present pacing strategies according to their performance level, the boat crew and competitive season.

Significance

Previous studies have described the different pacing approaches and strategies to improve performance based on pacing manipulation (Bishop, Bonetti et al. 2002, Ansley, Schabort et al. 2004, Abbiss and Laursen 2008). Although these investigations are important to understanding pacing, they were conducted under laboratory or controlled conditions. Whilst a few field-based studies conducted in the field to describe competition pacing have been conducted with rowing (Garland 2005, Brown, Delau et al. 2010), no studies have examined the pacing strategies adopted by well-trained Sprint Kayakers. Therefore, Study 1 described the pacing strategies adopted by world class Sprint Kayakers. This new information could be used to better understand the racing demands in the field in Sprint Kayak and guide training practices.

Study 2: Physiological characteristics of well-trained junior Sprint Kayak athletes (Chapter 4)

Aims

To profile the physiological characteristics of developing junior Sprint Kayak athletes, and to establish the relationship between these physiological variables ($\dot{V}O_{2kinetics}$, $M_{O2kinetics}$, paddling efficiency and performance in the longer (1000-m) and shorter (200-m) Sprint Kayak time trials.

Hypothesis

The physiological variables would correlate with performance, particularly the variables related to oxygen kinetics and muscle oxygenation parameters.

Significance

Previous research has shown the predictive power of $\dot{V}O_2max$, MAP and LT_2 for 1000, 500 and 200-m performance in adult Sprint Kayak athletes from national to international level (Fry and Morton 1991, Bishop 2000, van Someren and Howatson 2008). However, the relationship of other fitness variables such as the oxygen kinetics and muscle oxygenation parameters and 200 and 1000-m Sprint Kayak performance in junior well-trained athletes has yet to be explored.

Study 3: Field test for assessing and monitoring Sprint Kayak athletes (Chapter 5)

Aim

To develop a valid, reliable and sensitive field-based test for Sprint Kayak athletes that could be applied to athletes on a regular basis.

Hypothesis

The Sprint Kayak test (SK_{test}) would be a valid, reliable and sensitive test of Sprint Kayak performance.

Significance

Regular testing of high performance athletes can provide important information on the effectiveness of the training program and how the athletes are coping/adapting to training. However, laboratory tests can be difficult to implement regularly during the training season as they disturb the training routines, can be expensive and may lack of ecological validity for the sports (Kenttä, Hassmén et al. 2006, Coutts, Slattery et al. 2007, Borrensen and Lambert 2009). Therefore, a valid and reliable practical test that allows the assessment of a squad within a training session is appealing to be implemented in Sprint Kayak programs.

Study 4: Methods for quantifying training in Sprint Kayak (Chapter 6)

Aim

To determine the validity of the session-RPE method using the three different scales of perceived exertion compared to common measures of training load. A secondary aim was to verify the relationship between the training loads, fitness and performance in Sprint Kayak athletes.

Hypothesis

It was hypothesized that session rating of perceived exertion methods would have good construct validity for monitoring training loads in Sprint Kayak and

individuals' session-RPE training loads are related to physiological variables and performance.

Significance

A training program with either excessive or insufficient training load may impair the training-induced adaptations. In order to monitor the athletes, there is the need first to objectively quantify the training loads with proper and valid methods (Impellizzeri, Rampinini et al. 2005, Borrensen and Lambert 2009). However, to date, no studies have validated any methods for quantifying training in Sprint Kayak. It is anticipated that the results from this investigation will provide coaches and sport scientists with a tool to objectively quantify the training loads.

Study 5: Comparison of the acute physiological responses of repeated sprint and high-intensity aerobic training sessions in Sprint Kayak athletes. (Chapter 7)

Aim

To describe the power outputs and acute physiological responses to common repeat sprint (RS) and high-intensity aerobic (HIA) interval training sessions in well-trained young Sprint Kayak athletes.

Hypothesis

It was hypothesized that RS training bouts would provide a greater anaerobic training stimulus, whilst the HIA training bouts would provide a greater aerobic training stimulus. We also hypothesized that there would be *large* intra-individual

variability in the responses across training sessions. Finally, it was also expected that there would be *large* inter-individual responses to each of the training bouts.

Significance

Training programs for athletes are typically designed as a structured and organized sequence of training loads to induce adaptations that eventually lead to performance enhancements (Siff and Verkhoshansky 1999, Smith 2003, Issurin 2008). Theoretically, each training session is planned to provide a specific stimulus, and training programs are sequenced so that training is periodised as such the athletes adapt specifically to their meet their training goal. However, there are no studies that have assessed the acute physiological responses to typical Sprint Kayak training sessions – RS training and HIA interval training. It is intended that this study will provide new information of the acute physiological responses to these different Sprint Kayak training sessions so that the potential mechanisms of training adaptation in junior Sprint Kayak athletes is better understood.

Study 6: The effects of repeated sprint and high-intensity aerobic training on physiological variables and performance in junior Sprint Kayak athletes (Chapter 8)

Aim

To examine the effects of RS compared with HIA interval training on physiological variables and performance indicators in well-trained junior Sprint Kayak athletes.

Hypothesis

RS training would improve muscle oxygenation, anaerobic glycolytic responses and 200-m time trial performance, whilst the HIA training would have a greater increase upon maximal aerobic power, $\dot{V}O_2max$, lactate threshold, whole body oxygen kinetics and 1000-m performance.

Significance

To the authors' best knowledge, no studies have investigated the effects of different training strategies in well-trained junior Sprint Kayak athletes. Moreover, no studies have examined the effects of different training approached on 200-m Sprint Kayak performance - the new event in the Olympic Games' program. It is intended that this study will provide new information on the optimal training approach for training for the 200 and 1000-m Sprint Kayak events.

CHAPTER TWO

Literature Review

Oliveira Borges, T., Bullock, N. and Coutts, A.J. (*Prepared for submission*). Physiology and monitoring training strategies in Sprint Kayak. *Sports Med*.

Abstract

Kayaking and canoeing are activities that have been implemented as work, leisure or competition (Shephard 1987). Within the sport of canoe and kayak there are several modalities such as canoe marathon, wild water canoe, canoe polo, canoe sailing, dragon boat, freestyle, ocean racing, canoe slalom and canoe sprint constitute the International Canoe Federation (ICF) with Canoe Slalom and Canoe Sprint being Olympic disciplines. Canoe Sprint has been part of the Olympic program since 1936 whereas Canoe Slalom was introduced in 1992 (ICF 2013). In addition, there are marked differences between the boats where a canoe is an open decked craft and the athlete uses a single bladed paddle, assuming a kneeling position. The kayak, on the other hand, the athlete uses a double bladed paddle and paddle from a seated position. Even though ICF uses Canoe Sprint to name the sport, the term used in this thesis will be Sprint Kayak as all studies are related to kayak and not canoe.

The recreational and leisure appeal of canoe and kayak may be due to versatility as the boats are usually lightweight, easy to transport and a variety of lakes, rivers and the sea suits the practice of this activity. Moreover, there are a range of boats from stable touring canoe and kayaks to the fast Olympic sprint boats. However, despite the popularity of canoe and kayak, the scientific literature regarding this sport is lacking. The literature currently available has focused on a range of fields of study (Table 2.1). When keywords related to canoe and kayak sport were searched in the PubMed, they returned 504 results, being 133 for "kayak", 173 for "canoe", 97 for "kayaking", 76 for "canoeing" and 207 for "paddling". For comparative purposes, the search of "rowing" returned 876 papers, whilst "cycling" returned 33,806 and "running" 43,850 papers. The

aim of this review is to summarize the research related to Sprint Kayak and provide directions for future scientific investigation.

Literature Search Strategy

The Internet was the main resource to gather the literature for this review. Both Pubmed (www.pubmed.com) and Scielo (http://www.scielo.org) were used as the primary search engines for the literature search. In addition the ICF website (www.canoeicf.com) and 'grey papers' from the reference list of the primary sources were used to assure that all relevant information relating to the science of Sprint Kayak Racing was located. The keywords used in the search were: "kayak, canoe, kayaking, canoeing and paddling". The terms "rowing", "cycling" and "running" were also used for comparison purposes. The term rowing returned two papers in Sprint Kayak field of study. The search in Pubmed returned 504 papers while the search in Scielo provided 12 papers, however, not all were related to Sprint Kayak. The inclusion criteria were that the studies must have been in Sprint Kayak (or canoeing flat-water) in a population of athletes. The papers were excluded if the population were non-athletes or the studies were conducted in any other canoe and kayak discipline other than Sprint Kayak. These studies were also assessed for quality, where scientific reporting quality, external validity, bias, confounders and power were taken into account (Downs and Black 1998). The checklist was modified to assess the methodological quality of the studies included in this review (See Appendix 1).

Table 2.1: Published studies relevant for training in Sprint Kayak.

Author	Discipline	Boats	Subjects level	Subject's Gender	Field of study
Tesch, Piehl et al. 1976	Sprint Kayak	-	Elite	Male	Exercise physiology
Tesch 1983	Sprint Kayak	-	Elite	Male	Exercise physiology
Tesch and Karlsson 1984	Sprint Kayak	-	Elite	Male	Exercise physiology
Tesch and Lindeberg 1984	Sprint Kayak	-	International	Male and female	Exercise physiology
Pendergast, Bushnell et al. 1989	White water, slalom and Sprint Kayak	Canoe slalom K1	National	Male and female	Exercise physiology
Fry and Morton 1991	Sprint Kayak	Canoe Sprint K1	International	Male	Kinanthropometrics
Misigoj-Durakovi and Heimer 1992	Sprint Kayak	C. Sprint K1/C. Sprint C1	Universiade	Male	Anthropometry
Kendal and Sanders 1992	Sprint Kayak	Canoe Sprint K1	National	Male	Biomechanics
Mackinnon, Ginn et al. 1993	Sprint Kayak	-	International	-	Biochemistry
Clingeleffer, McNaughton et al. 1994	Sprint Kayak	Kayak ergometer	Elite	Male	Exercise physiology
Clingeleffer, Mc Naughton et al. 1994	Sprint Kayak	Kayak ergometer	State and National	Male	Exercise physiology
Jackson 1995	Sprint Kayak	-	-	-	Engineering

Table 2.1(cont.): Published studies relevant for training in Sprint Kayak.

Author	Discipline	Boats	Subjects level	Subject's Gender	Field of study
Gray, Matheson et al. 1995	Sprint Kayak	Canoe Sprint K1	Elite	Male	Exercise physiology
Billat, Faina et al. 1996	Sprint Kayak	Arm cranking	National class	Male	Exercise physiology
Aitken and Jenkins 1998	Sprint Kayak	C. Sprint K1/K. ergometer	Elite/ Children	Male and female	Talent identification and training
Barnes and Adams 1998	Kayak ergometer	Kayak ergometer	Experienced	-	Exercise physiology
Garbutt and Robinson 1998	Sprint Kayak	Canoe Sprint K1	Three Star ability	Male	Exercise physiology
Romer, Godfrey et al. 1998	-	Kayak ergometer	National and international	Male and female	Exercise physiology
Perez-Landaluce, Rodriguez-Alonso et al. 1998	Sprint Kayak	Canoe sprint K1	International level	Male	Exercise physiology
Zamparo, Capelli et al. 1999	Sprint Kayak	Canoe Sprint K1	Middle to high class	Male and female	Exercise physiology
Bishop 2000	Sprint Kayak	Canoe Sprint K1	National to International	Female	Exercise physiology
van Someren, Phillips et al. 2000	Sprint Kayak	C. Sprint K1/K. ergometer	Club to national level	Male	Exercise physiology
Kearney and Mckenzie 2000	-	-	-	-	Review
Bishop, Bonetti et al. 2001	Sprint Kayak	Kayak ergometer	National level	Male and female	Exercise physiology

Table 2.1(cont.): Published studies relevant for training in Sprint Kayak.

Author	Discipline	Boats	Subjects level	Subject's Gender	Field of Study
van Someren and Oliver 2002	Sprint Kayak	C. Sprint K1/K. ergometer	Well trained	Male	Exercise physiology
Robinson, Holt et al. 2002	-	-	-	-	Review
Sperlich and Baker 2002	Sprint Kayak	-	-	-	Biomechanics
Ackland, Ong et al. 2003	Sprint Kayak	Canoe Sprint boats	Elite	Male and female	Anthropometry
Liow and Hopkins 2003	Slalom; White Water; Canoe-Polo;Down-River and Sprint Kayak	Canoe Polo	National	Male and female	Resistance training
van Someren and Palmer 2003	Sprint Kayak	C. Sprint K1/K. ergometer	National and international	Male	Exercise physiology
Sumner, Sprigings et al. 2003	-	-	-	-	Physics
Nakamura, Borges et al. 2004	Sprint Kayak	Canoe Sprint K1	National	Male	Exercise physiology
Fontes, Nakamura et al. 2005	Sprint Kayak	Canoe Sprint K1	National	Male	Exercise physiology
Bonetti, Hopkins et al. 2006	Sprint Kayak	Kayak ergometer	Subelite	-	Exercise physiology

Table 2.1(cont.): Published studies relevant for training in Sprint Kayak.

Author	Discipline	Boats	Subjects level	Subject's Gender	Field of study
Kenttä, Hassmén et al. 2006	Sprint Kayak	Canoe sprint K1	Elite	Male and female	Psychological monitoring
Nakamura, Cyrino et al. 2006	Sprint Kayak	Canoe Sprint K1	National	Male	Training
Ong, Elliott et al. 2006	Sprint Kayak	Canoe Sprint K1	Elite	Male and female	Biomechanics
Sprigings, McNair et al. 2006	Sprint Kayak	Kayak ergometer	Elite	Male	Biomechanics
Wozniak, Wozniak et al. 2007	Sprint Kayak	-	Olympian	-	Recovery - Biochemistry
van Someren and Howatson 2008	Sprint Kayak	Canoe Sprint K1	Club to international	Male	Exercise physiology
Michael, Rooney et al. 2008	-	-	-	-	Review
Nakamura, Perandini et al. 2009	Sprint Kayak	Canoe Sprint K1	National to International	Male	Exercise physiology
García-Pallarés, Carrasco et al. 2009	Sprint Kayak	Canoe Sprint K1	World class/ Olympic	Male	Training
Garcia-Pallares, Sanchez-Medina et al. 2009	Sprint Kayak	Kayak ergometer	World Class/ Olympic	Male	Training
García-Pallarés, Carrasco et al. 2009	Sprint Kayak	Kayak ergometer	World Class/ Olympic	Male	Training
Michael, Smith et al. 2009	-	-	-	-	Review
Garcia-Pallares, Garcia-Fernandez et al. 2010	Sprint Kayak	Canoe Sprint K1/K.Ergo	Elite	Male	Training
Janssen and Sachlikidis 2010	Sprint Kayak	Canoe Sprint K1	Active paddler	Male	Biomechanics
McKean and Burkett 2010	Sprint Kayak	-	Sub-elite	Male and female	Physiotherapy
Buglione, Lazzer et al. 2011	Sprint Kayak	Canoe Sprint boats	National	Male and female	Exercise physiology

Plan of Development

This review consists of three main sections where the first section describes a brief history of kayaking. Secondly, the studies that have described the racing characteristics and physiological and morphological profile of Sprint Kayak athletes will be described. Additionally, other possible physiological factors impacting performance will be explored. Finally, the research investigating the current factors influencing performance and training in Sprint Kayak and the methods for monitoring training and performance are reviewed.

Brief history of canoeing and kayaking

Originating in North America, the earliest kayaks are believed to have been around for over 4000 years. The kayak was invented and first used by the native hunters in sub-Arctic regions of north-eastern Asia, North America and Greenland. Both kayaks and canoes were first used by the Native Americans for trade, transportation and war. However, soon after arrival in North America, the early settlers began using these crafts for both commerce and leisure, although the commercial role of canoes ended when the North American transcontinental railroads were built, their use was continued for sport and leisure (Shephard 1987, Kearney and Mckenzie 2000).

The sport of canoeing and kayaking emerged from the North American middle class in the 19th century (ICF 2013) where two common crafts had been used: a decked canoe, propelled by a double blade paddle (kayak) and an open canoe, propelled by a single blade paddle (Shephard 1987, ICF 2013) and these constitutes the main

differences between a canoe and a kayak. As a consequence of the popularity of this water-based pastime, the American Canoe Association was founded in 1880.

The early increase in the popularity of the sport of kayak has been credited to Scottish barrister John Macgregor after describing his adventures in a double-blade wooden kayak in his book "A Thousand Miles in the Rob Roy Canoe" (Kearney and Mckenzie 2000). The increased popularity of kayak lead to the formation of the International Canoe and Kayak Federation (Internationale Repräsentantenschaft Kanusport, IRK) in 1924, which was responsible for organizing canoe and kayak competitions. Later in 1946, the name of the IRK was changed to the International Canoe Federation (ICF) which remains the governing body for international canoe and kayak competition.

Racing Characteristics

Canoe Sprint Racing is the official name provided by the International Canoeing Federation to describe canoe and kayak races of 200, 500 and 1000-m contested in a straight and non-obstructed lane. However, this thesis will use the term Sprint Kayak instead of Canoe, since its focus is on kayaks. Both kayaks (where the athletes assume a seated position and propel the craft with a double-bladed paddle) and canoes (with a single-bladed paddle and athletes paddle in a kneeling position) are involved in the discipline of Canoe Sprint racing.

Sprint Kayak has been part of the Olympic Games program since 1924 (as a demonstration) and 1936 (officially), where the men competed over 1000-m and 10000-

m in single and double canoes and kayaks. Women first competed in 1948 London Olympics, over the 500-m distance. Presently, at the international level, Sprint Kayak athletes compete over distances of 200-m (male and female), 500-m (female only) and 1000-m (male only). Moreover, in addition to the changes in race distances in the last century, there have been remarkable changes in kayak racing equipment (boats and paddles). The kayak paddles originally used a flat blade (Figure 2.1), but this has had undergone several design evolutions with most international competitors now using a 'tear-drop' blade (Robinson, Holt et al. 2002). Currently, Germany and Hungary are the two dominant countries in Sprint Kayak taking 26 and 21 medals in the last four Olympic Games, respectively. In addition, Australia has won an Olympic medal at every Olympic Games since 1988 (Roto Sports 2011).

Changes in technology and rules have also lead to changes in boat design (See Figure 2.2). One of the recent most profound changes in boat design has been the removal of the minimum boat width. Since the relaxing of this rule in 2003, there have been significant changes in the design and composition of the boat hull and deck. These changes in equipment and laws have been suggested to influence paddling technique and boat speed (Jackson 1995, Robinson, Holt et al. 2002, Michael, Smith et al. 2009).
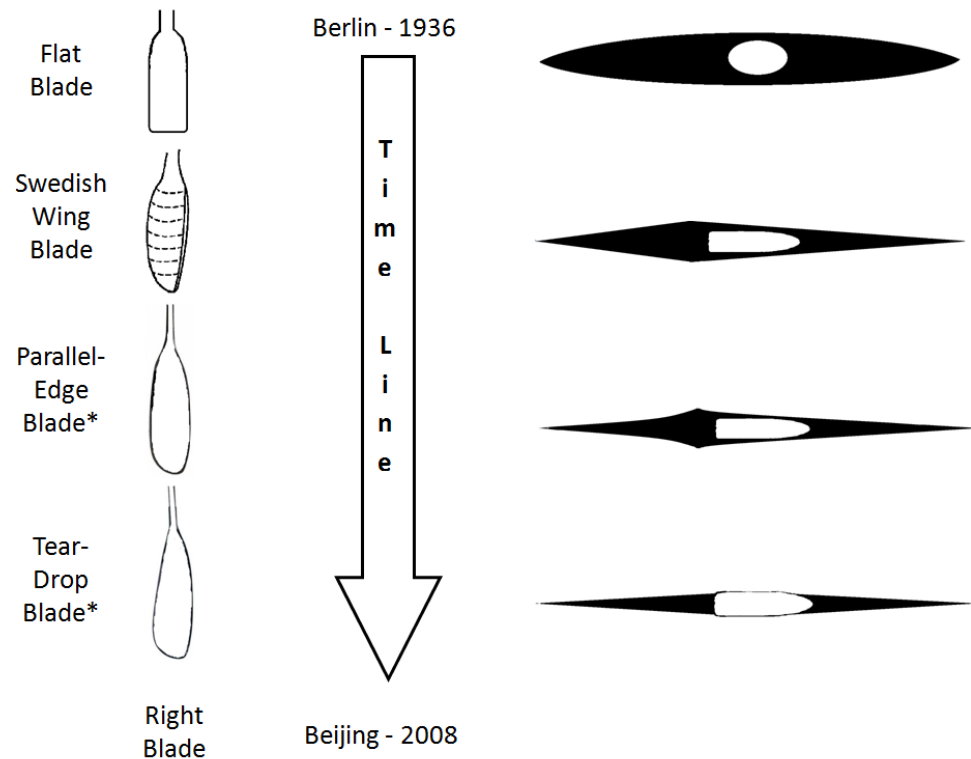
Figure 2.1: Examples of paddles and boats evolution (from Berlin Olympic Games – 1936 to Beijing Olympic Games – 2008) * - Most recently used blades.

Up to and including the 2008 Beijing Olympic Games, men competed in the single kayak (K1) and double kayak (K2) over the distances of 500 and 1000-m whereas the four kayak (K4) only raced over 1000-m. In the canoe events, men competed in the single (C1) and double canoe (C2) over 500 and 1000-m. In contrast, women only raced in kayaks (K1, K2 and K4) over 500-m. At the World Championships and World Cup events canoeists and kayakists competed over 200-m (van Someren and Palmer 2003, ICF 2013). This competitive format with 1000 and 500-m for men started in 1976 and allowed ~27 athletes to win medals in either distances (Roto Sports 2011). In 2010 the Canoe Sprint rules for the Olympic program were modified so both men and women competed over 200-m while the 500-m were excluded from men's program (see Figure 2.2)

	1000m	500m	200m
Men's kayak	K1	K1 ⟶	K1
	K2	K2 ⟶	K2
	K4		
Women's kayak		K1	K1
		K2	
		K4	
Men's canoe	C1	C1 ⟶	C1
	C2	C2	

⟶ Re-arrangement of the Olympic program to London 2012 (ICF, 2009)
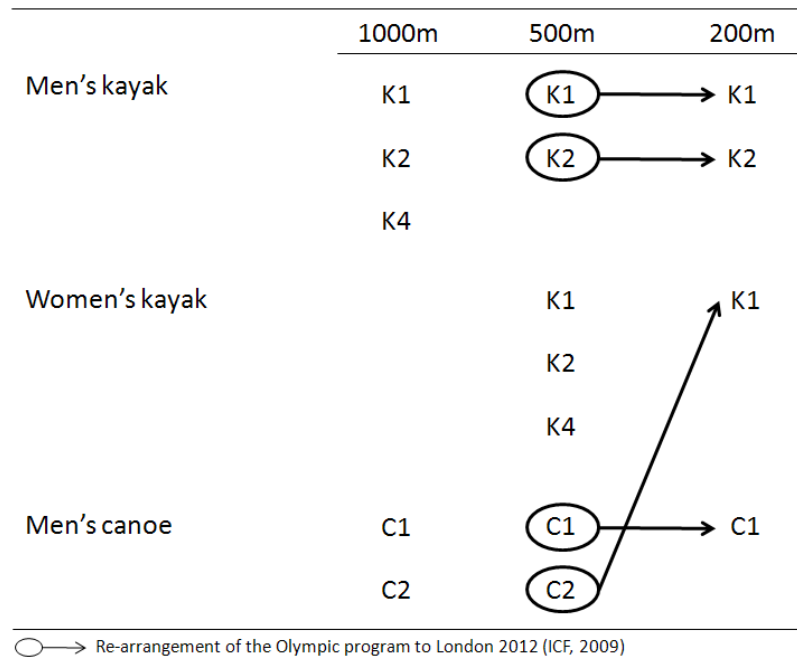
Figure 2.2: Re-arrangement of the Olympic Program for Canoe Sprint Racing for London 2012.

The Olympic events are usually the priority for most elite athletes, with training designed to develop the athletes and peak performance at the Olympics. Therefore, with the removal of the 500-m event from the Olympic program and inclusion of the 200-m, the physiological, anthropometrical and technical characteristics required for the Olympic events have changed. This modification to the race program caused athletes to specialise for either the 200-m or 1000-m events. At present there is relatively little known about the specific physiological demands or optimal training practices of the Olympic Sprint Kayak events. Further studies are required to assist coaches to design training programs for these events.

Physiological Attributes and Factors Affecting Performance in Sprint Kayak Athletes

At the elite level, the men's individual Sprint Kayak race durations are approximately 35 and 204 s for the 200 and 1000-m, respectively. Further, for women's the 200-m lasts 39 to 40 s and K1 500 m performances range from 107 to 120 s for the winners (ICF 2013). Additionally, men and women also have crew competitions with faster performances in K2 and K4 crafts for all these distances (200, 500 and 1000-m) (Bishop 2000, van Someren and Howatson 2008, ICF 2013). It is likely that training for this wide range of performance times induce specific adaptations that lead the athletes to succeed in competition.

It is well established that an athlete's body shape can determine how well an athlete performs in a particular sport. Therefore, it is not surprising that there are distinct anthropometrical attributes in higher-level kayak athletes (Fry and Morton 1991, Aitken and Jenkins 1998, Ackland, Ong et al. 2003). For example, Ackland et al. (2003) reported that elite Sprint Kayakers had well-developed upper body musculature, increased stature, narrow hips (for males), low skinfold values, increased sitting height and bi-acromial diameter in comparison to their sub elite counterparts. Moreover, others have shown that higher-level Sprint Kayak athletes typically have increased thigh, forearm and upper arm length and lower skinfolds compared to both active university students and general population (Aitken and Jenkins 1998, Ackland, Ong et al. 2003). Elite Sprint Kayak athletes tend to be taller (Cohen's d: male 1.11; female 0.74) and heavier (Cohen's d: male 0.96; female 1.20) than their sub elite level counterparts (Fry and Morton 1991, Aitken and Jenkins 1998, Ackland, Ong et al. 2003). Collectively, these attributes seem to allow Sprint Kayak athletes of higher level to be more efficient

paddlers, permitting the optimal balance between stroke length and stroke rate, increasing the efficiency of movement on the water. Nonetheless, it is important to point out that Sprint Kayak does not cause the successful athletes to develop these attributes. Rather, the sport provides the ideal conditions for those with these innate characteristics to improve them (Ford, De Ste Croix et al. 2011, Tucker and Collins 2012).

In addition to morphological adaptations, specific physiological capacities may also be suited to Sprint Kayak performance. Surprisingly however, few studies have examined the energetic demands of each of the Sprint Kayak events. Nonetheless, it has been estimated ~82 and ~62% of energy for the 1000 and 500-m events is derived from aerobic pathways, respectively (Byrnes and Kearney 1997). In contrast, the 200-m race has greater reliance on anaerobically-derived with ~37% of energy estimated from aerobic sources (Byrnes and Kearney 1997). These findings demonstrate that longer races require a larger aerobic contribution compared to the shorter events. Further research is required to accurately describe the on-water physiological demands in Sprint Kayak.

It has been shown that Sprint Kayak racing is demanding, as the athletes compete above their lactate threshold for more than 80 s in the longer races (Bishop 2000). Therefore, the training undertaken to prepare for such arduous activity is expected to develop several components of fitness, including maximum oxygen uptake ($\dot{V}O_2max$). The $\dot{V}O_2max$ is a common indicator for aerobic fitness and higher levels allow athletes to maintain higher power outputs and speed during racing. For example, investigations with athletes from national to elite international level have presented *large-to-very large* inverse correlations between $\dot{V}O_2max$ and performance over 500 and 1000-m on-water

performance (Fry and Morton 1991, Bishop 2000). In contrast, van Someren and Howatson (2008) have recently reported only *trivial-to-small* associations between $\dot{V}O_2$max and performance for each of the three race distances.

An athletes' $\dot{V}O_2$max has been related to the amount of muscle mass involved in the effort. Since Sprint Kayak predominantly requires upper body muscles to propel the craft, Sprint Kayak athletes typically exhibit lower $\dot{V}O_2$max than sports such as cycling and running due to a smaller active muscle mass (Shephard 1987, Bunc and Heller 1994, Impellizzeri and Marcora 2007). Sprint Kayak athletes have presented scores for absolute $\dot{V}O_2$max of 3.9 ±0.7 (2.9−5.0) L·min^{-1} and relative 56.9 ±8.5 (44.6−68.6) mL·kg^{-1}·min^{-1} (Tesch 1983, Fry and Morton 1991, Bunc and Heller 1994, Billat, Faina et al. 1996, Perez-Landaluce, Rodriguez-Alonso et al. 1998, Zamparo, Capelli et al. 1999, Bishop 2000, Bishop, Bonetti et al. 2002, van Someren and Oliver 2002, Bishop 2004, Bishop and Spencer 2004, Bonetti, Hopkins et al. 2006, van Someren and Howatson 2008, Garcia-Pallares, Sanchez-Medina et al. 2009, Garcia-Pallares, Garcia-Fernandez et al. 2010). Unfortunately, accurate comparison between studies is difficult as various exercise protocols, exercise modes and equipment have been used to measure these capacities. Nonetheless, based on current evidence, it seems that Sprint Kayak athletes would benefit from a well-developed aerobic system as the longer races are contested close to $\dot{V}O_2$max (Byrnes and Kearney 1997, Bishop 2000).

In addition to a *large* contribution of the aerobic system, Sprint Kayak athletes, also benefit from higher anaerobic capacities. Indeed, Sprint Kayak intensities are typically contested above lactate threshold, showing that energy is also provided from non-oxidative sources. Moreover, several studies have shown that anaerobic capacities such

as peak power, total work and peak lactate concentration in a 30-s "all-out" effort on kayak ergometer all have *large-to-very large* correlations with 200, 500 and 1000-m on-water performance (van Someren and Palmer 2003, van Someren and Howatson 2008). Taken collectively, these findings suggest that both aerobic and anaerobic systems as well as morphological characteristics are important for enhanced Sprint Kayak performance. However, it is reasonable to assume that other factors also contribute to Sprint Kayak performance.

Sprint Kayak time trials require a fast metabolic adjustment from rest to race pace as the athlete moves the boat from a stationary position. Due to these requirements, it is likely that an athlete's oxygen kinetics ($\dot{V}O_{2kinetics}$) characteristics might contribute to performance. Surprisingly, the role of $\dot{V}O_{2kinetics}$ has not yet been investigated as an important physiological factor related to race Sprint Kayak performance. Indeed, $\dot{V}O_{2kinetics}$ describes how fast an individual can adjust from rest to exercise at different intensities. Typically, $\dot{V}O_{2kinetics}$ are assessed in three main domains of exercise intensity: moderate, heavy and severe. The *moderate* domain corresponds to exercise intensities below lactate threshold (Burnley and Jones 2007). In this domain the lactate concentration remains stable and a plateau is evidenced since $\dot{V}O_2$ reaches steady state following the primary $\dot{V}O_2$ response. In the *heavy* domain, the lactate production starts to exceed its removal with a sustained production of lactate throughout the effort. Finally, in the *severe* domain neither the $\dot{V}O_2$ nor lactate stabilise over time, leading to exhaustion (Hopkins 2006, Burnley and Jones 2007). The $\dot{V}O_{2kinetics}$ takes into account the whole body adjustment to exercise intensity although there seems to be a delay between O_2 delivery and $\dot{V}O_2$. It has been suggested that this delay may be due to the

measurements being made away from the working muscles (Grassi, Poole et al. 1996, Vollaard, Constantin-Teodosiu et al. 2009, Oliveira Borges, Dascombe et al. 2013).

More recently, the possibility of obtaining a non-invasive insight into the muscle has been made available using near infrared spectroscopy (NIRS). This technology measures the balance between oxygen delivery and $\dot{V}O_2$ in the muscle of interest (Grassi, Pogliaghi et al. 2003). The NIRS applies the modified Beer-Lambert law using a 2-wavelength continuous wave, which spatially resolves spectroscopy methods simultaneously measuring changes in total haemoglobin ([tHb]), tissue oxyhaemoglobin ([O_2Hb]) and deoxyhaemoglobin ([HHb]). The difference between the [HHb] and [HbO_2] represents the average saturation to calculate the tissue saturation index (TSI) (Grassi, Poole et al. 1996, Grassi, Pogliaghi et al. 2003). Not only can NIRS provide information on the muscle oxygen kinetics, it can also provide the muscle oxygenation parameters that may be used as parameters to increase the understanding of muscle metabolism.

Faster $\dot{V}O_{2kinetics}$ and $MO_{2kinetics}$ indicates more economical exercise as aerobic metabolism is present relatively sooner in the exercise bout. Moreover, studies have shown that higher level athletes possess faster kinetics than their lower level counterparts in rowing (Ingham, Carter et al. 2007), cycling (Bouchard, Sarzynski et al. 2011) and soccer (Rampinini, Sassi et al. 2009). Furthermore, training background has been shown to influence the $\dot{V}O_{2kinetics.}$ For instance, aerobic trained subjects showed faster kinetics when compared to sprint trained counterparts (Bouchard 2012, Ufland, Ahmaidi et al. 2013). Finally, studies have also demonstrated that muscle fibre characteristics (Gaesser and Poole 1996, Buchheit, Mendez-Villanueva et al. 2010) and upper and lower body segments (Calbet, Holmberg et al. 2005, Buchheit, Mendez-

Villanueva et al. 2010) differentiate the speed of kinetics. Collectively, these results show that the kinetics relies on a series of parameters and may account for the variations unexplained for Sprint Kayak performance. Unfortunately, to date there are no studies investigating the relationships between $\dot{V}O_{2kinetics}$, $MO_{2kinetics}$, muscle oxygenation parameters and Sprint Kayak performance.

The major international kayak competitions typically require athletes to compete in many races during qualifying and finals. Some athletes can also participate in more than one event in a championship such as K1 and K4, creating a busy racing schedule during a regatta. For example, prior to the finals, athletes would often race heats and semi-finals of a certain boat class on the same day (ICF 2013). The world class athletes maybe regulate or pace their effort during the earlier rounds, to ensure that they qualify for the finals but also to allow them to peak at the end of the regatta but for many athletes each race will be a maximal effort. The regulation of effort within a race has been described as pacing (Abbiss and Laursen 2008, Sealey, Spinks et al. 2010). In a recent review, Abbiss and Laursen (2008) showed that there are six main pacing profiles during races in different sport disciplines. Based on anecdotal information and the pacing profiles described in this review, it seems that the optimal strategy is the reverse J-shaped, with a fast start followed by a small decrease in velocity, increasing towards the end of the effort. This pacing profile has been observed in rowing (Garland 2005) and outrigger canoeing (Sealey, Spinks et al. 2010), although no studies have examined the pacing profiles of elite level Sprint Kayak athletes. A better understanding of profiling pacing of elite athletes can help coaches and sport scientists develop effective race strategies during regattas – as this may be an effective teaching tool for junior athletes .

A pacing strategy allows the athlete to adjust the effort according to racing demands particularly because as the race starts it only takes few moments to adapt to the race demand. Moreover, by regulating the effort the athlete ensures to successfully perform. It is surprising, however that there has only been one published study that has examined the influence of pacing on Sprint Kayak performance. In this previous laboratory study, it was demonstrated that a fast start followed by an even pace strategy during two-min kayak ergometer performance increased total power output on a kayak ergometer (Bishop, Bonetti et al. 2002). Unfortunately however, this study has limited ecological validity and thus the results may not demonstrate pacing behaviour in real competition. Moreover, it is not known whether during actual competition athletes from different levels adopt different pacing strategies. Additionally, athletes may adopt a different pacing strategy according to the boat they are competing in (K1, K2 or K4) and it is not known if different boats influence pacing profile as well. As a result, more studies investigating pacing under competitive conditions are required to clarify all the issues regarding pacing in Sprint Kayak.

Training and Monitoring Training

Competitive level athletes and coaches aim to improve competitive performance, and a thoroughly planned long-term training program plays an important role to attain this goal. However, athletes often have specific events that are prioritized within the training season, which they may focus to peak at these times. In order to prepare for these competitions and properly perform at the race day or competition period, coaches design a training program that prepare the athletes to reach their optimal performance at the chosen event (Rowbottom 2000). Nevertheless, the accuracy of such system relies on the fine control of the training process.

The control of training refers to the manipulation of training contents and the amount of stress these impose to the athletes. This particular psycho-physiological stress is considered as the internal training load and the scores from its quantification can provide feedback to coaches, scientists and athletes on how athletes are responding to the prescribed training. Studies have shown that internal training loads can be quantified using valid methods, based on heart rate and the ratings of perceived exertion (RPE) (Borg 1998), or other physiological variables (e.g. blood lactate). The external training load refers to the session content (type of exercise), distance travelled, weight lifted, power generated or average speed maintained during a period of time. The internal training load describes the internal stress imposed in the athletes by the external training loads (Impellizzeri, Rampinini et al. 2005, Scott, Black et al. 2013).

Methods for Quantifying Internal Training Loads Based on Heart Rate Responses

Advances in technology and easy access has made the use of heart rate monitors and methods to quantify training loads based on heart rate relatively simple to implement. The need for a simple method for describing the training load led to the development of methods that integrate the components of training into a single unit of measurement. For example, Banister (1991) first described the training impulse (TRIMP) as the unit dose of physical stress for a particular session. The TRIMP was calculated using equation one, using training session duration, maximal heart rate, resting heart rate and average heart rate scores.

$$\text{TRIMP (w)} = \text{duration of training session (min)} \cdot \Delta HR_{ratio} \cdot Y \qquad \text{(equation 1)}$$

Where $\Delta HR_{ratio} = (HR_{exercise} - HR_{rest})/(HR_{max} - HR_{rest}); Y = 0.64e^{1.92x}$ for males and $Y = 0.86e^{1.67x}$ for females; $e = 2.71$ and $x = \Delta HRratio$

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The TRIMP method weights higher intensity sessions using a typical lactate profile relative to exercise intensity of men and women (Y in equation 1). This ensures that disproportionate importance to low intensity, long duration training sessions compared to higher intensity and shorter duration training sessions does not occur. One criticism the TRIMP method has received is the use of general population weighting factors, which may not accurately reflect well-trained athletes responses to exercise and training. An attempt to overcome this limitation is applying individual weighting factors from individual lactate profiles. For example, research have presented that the individualized TRIMP (iTRIMP) is valid tool for tracking fitness and performance in long distance runners (Manzi, Iellamo et al. 2009). It may be logical that this method applies to Sprint Kayak, considering the cyclic nature and considerable participation of endurance training loads in both sports.

Other methods for quantifying training load using heart rate have also been proposed, based on intensity zones and specific weighting factors for time spent in each zone (Edwards 1993, Lucia, Hoyos et al. 2003). For example, the method of Edwards (1993) assumes five training zones, based on percentages of heart rate whereas Lucia's (2003) method uses three intensities' training zones determined by the ventilatory thresholds. However, these methods have received criticism due to the possible influence of extreme scores within each intensity zone. These values may interfere with the accuracy of the method (Borrensen and Lambert 2009). Finally, the heart rate methods for quantifying training are enticing for coaches and athletes as it provides objective measures of training stress. Unfortunately however, these approaches require significant technical and scientific expertise to calculate. Additionally, they are also

dependent upon athletes having access to, and being able to wear heart rate recording devices during training and competition.

Methods for Quantifying Training Loads Based on Ratings of Perceived Exertion

Despite the appeal of the heart rate-based methods as an objective measure of stress, their drawbacks such as increased chance of losing data due to technical difficulties, the need for technical and scientific expertise to calculate the training loads and limited accuracy to measure high-intensity efforts dictate that other methods that overcome these issues be developed. In an attempt to address some of the limitations associated with heart rate-based methods, the session-RPE method for quantifying training load (session-RPE) was proposed (Foster, Hector et al. 1995, Foster, Daines et al. 1996, Foster, Florhaug et al. 2001). This method quantifies the training dose as the product of training duration and intensity, where intensity is measured using the athlete's rating of perceived exertion (RPE).

The justification for the use of perceived exertion is that it corresponds to the integration information sent from peripheral (muscles and joints), central cardiovascular and respiratory functions during exercise to central nervous system (Borg 1982, Borg 1998). The rating of perceived exertion scales, developed using psychophysics principles, gauges the perceived exertion information. These scales were developed as level-anchored, semi-ratio scales that combine the advantages of a ratio scale with those of a labelled category scale according to the Borg's Range Model (Borg 1998, Borg and Borg 2001, Costa, Breitenfeld et al. 2012). This model asserts that the subjective range of intensity (from minimal to maximal) is equal between individuals, and there is

significant empirical support for this theory (Borg 1998, Hubal, Gordish-Dressman et al. 2005, Costa, Breitenfeld et al. 2012).

The perception of effort can be quantified using the RPE scales. However, each scale has particular theory behind its construction and, as such, the responses to each scale are expected to be different. For example, the most known perceived exertion scale is the Borg's (1970) RPE 6-20 15-point category-scale where perceptual ratings of exertion increases linearly with heart rate increments and power output on a cycle ergometer. However, this linearity seems to detriment the assessment of non-linear physiological variables such as the lactate. Indeed, Borg (1970) showed that when blood lactate was plotted against the 15-point scale scores, the increase in blood lactate concentration for each point increment was about three times greater at the top end of the scale compared to the bottom. Accordingly to evaluate perception of effort linked to non-linear physical responses such as lactate metabolism, Borg (1982) developed a category-ratio perceived exertion scale, the CR-10. This category scale with ratio scale properties increased in a positively accelerating fashion. Nevertheless, a limitation of this scale is that correlations between heart rate and CR-10 are slightly lower than the RPE 6-20 scale due to non-linearity and smaller numerical range for the most common intensities.

At competition level, small differences can separate the champion from athletes in the tenth or lower ranking. For example, Bonetti and Hopkins (Bonetti and Hopkins 2010) found a smallest worthwhile changes in Sprint Kayak performance of approximately 0.3-0.6%. Therefore, it seems reasonable to assume that small effects should be taken into account in training as well. The CR-10 scale is the base of the

session-RPE methods for quantifying training load. However, with the few numerical anchor points (0-10), it still may not be sufficiently sensitive to show small changes in effort perception. Due to this limitation, the centimax CR-100 perception of effort scale was recently developed. One of the few research studies comparing the CR-100 with the CR-10 showed that the participants tended to rate the effort at the exact location of the anchor point in the CR-10 compared to the CR-100 (Borg and Kaijser 2006). This result suggests the CR-100 may be more sensitive to small changes in perceived exertion. Although the CR-100 has been shown to be a valid measure to quantify training loads in Australian Football (Scott, Black et al. 2013) there is still the need to expand the responses of the CR-100 and compare the responses in a variety of sports.

Training and Monitoring Training in Sprint Kayak

The few studies that have investigated the training process in Sprint Kayak have described the training content (external training loads) and the possible impact in physiological and performance adaptations. For example, Aitken and Jenkins (1998) examined the effect of 12 weeks of training in a group of 13-14 year old boys and girls on morphological, mechanical work, physiological and 500-m time-trial performance. Moreover, Garcia-Pallares et al. (2009) described the training induced adaptation responses in world-class Sprint Kayak athletes. Although there was no manipulation of the training loads to investigate the effects of different approaches to training this study, provides valuable insights, particularly for higher level Sprint Kayak athletes. Furthermore, Garcia-Pallares et al. (2010) investigated in a crossover design the difference between two periodization models, being the traditional model for a period of 12 weeks and the block training model throughout 5 weeks, after a 5-week wash out period. The main findings were that the block training elicited more efficient training

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adaptation compared to the traditional model. Both models showed similar increases in $\dot{V}O_2max$ and $LT_2\dot{V}_{O2}$ after intervention with larger gains in peak speed and power at $\dot{V}O_2max$ level in the block training model periodization. Despite these results, this study did not investigate the interaction of internal and external training loads to increase the understanding of the mechanisms that underpin training induced adaptations. Indeed, the interactions of training loads, adaptation and performance are complex. Furthermore, as these studies only present external training load data, which limits the assessment of these training approaches (Mujika 2013).

Sprint Kayak athletes often undertake high training loads, with higher level athletes requiring even larger amounts of training to generate positive adaptation. For instance, Garcia-Pallares et al. (2009) showed that world class Sprint Kayak athletes presented ~10.2 $h \cdot week^{-1}$ of endurance and ~3.6 $h \cdot week^{-1}$ of weight training over a 12-week period. As a consequence of these high training loads, the risks of overreaching or overtraining are increased (Linnarsson 1974, Bouchard, An et al. 1999, Verbeke and Molenberghs 2009), therefore it is important to monitor how the athletes are coping with training. The use of psychological tools to monitor the athlete's response to training is appealing for this purpose as these tools are usually non-invasive, simple to implement, and usually well accepted by athletes. Moreover, it has previously been shown that perceptions of training effort and stress disturbances are sensitive to both short, mid and long-term training load (Berglund and Safstrom 1994, Kenttä, Hassmén et al. 2006). As such, Sprint Kayak training could be monitored by valid perceptual tools and this information may be used to objectively guide coaches to understand how athletes are responding to training.

Practical Performance Tests

The most common approach to monitor athletes is throughout periodical physical and physiological testing. This approach allows coaches to assess the efficacy of their training programs and to determine whether the athletes are responding to training as planned. Indeed, it has been reported that the frequent assessment of important physical and physiological characteristics can provide coaches with information that can be used to optimise the training process (Coutts, Slattery et al. 2007). At the elite level, however, athletes do not have much time available to spend reporting to laboratories or the capacity to complete regular maximal exercise tests (Lamberts, Swart et al. 2009). In this way an appealing alternative approach has been the application of field tests, which can be easily implemented to the training routine as a standard training session under controlled conditions. Moreover, such approach should be time efficient and possess the ability to assess preferably part or the whole squad at the same time, requiring minimal resources.

A potentially useful tool for monitoring training in Sprint Kayak athletes is a regular on-water standardised training set from which physiological and performance measures can be easily obtained. Such a test could easily be implemented into the training program of Sprint Kayak athletes. Repeated sprint ability (RSA) has been researched within team sport athletes, based on its similarity to sport-specificity demands (Glaister 2005, Spencer, Bishop et al. 2005). A characteristic of RSA is that it demands a strong contribution from both aerobic and anaerobic metabolism (Gastin 2001, Tomlin and Wenger 2001, Glaister 2005). Studies have suggested that although the anaerobic metabolism predominantly contributes to the performance the sprints, the aerobic metabolism plays an important role in sprint performance and recovery, which implies

overall performance (McMahon and Wenger 1998, Tomlin and Wenger 2001, Dupont, Millet et al. 2005). During repeated sprints, the significant reduction in anaerobic ATP turnover seems to be partly compensated by an increase in $\dot{V}O_2$ in subsequent sprints (Gastin 2001). Additionally, whilst the aerobic contribution for one single sprint is negligible, a faster adjustment of the $\dot{V}O_2$ at the beginning of the exercise increases the contribution of the aerobic energy system (Dupont, Millet et al. 2005). Moreover, aerobic metabolism is important during repeated sprints as it assist with the reloading of myoglobin and haemoglobin with O_2 increasing resynthesis of phosphocreatine (PCr) between sprint efforts (Dupont, Millet et al. 2005). In fact, PCr resynthesis and recovery of power output were both related to aerobic fitness (Bogdanis, Nevill et al. 1996). Due to the contribution of both the aerobic and anaerobic energy system contributions during repeated sprints tests, a test involving these characteristics may be useful for assessing training-induced adaptations to both fitness and performance in Sprint Kayak athletes.

Summary of Literature Review

Sprint kayak is an Olympic sport that is competed over 200, 500 or 1000-m in K1, K2 and K4. Despite its status as an Olympic sport, there have been relatively few scientific studies investigating the training and competitive demands. Sprint Kayak predominantly requires the upper body segments to propel the crafts while the lower limbs play an important role in technique (Ong, Elliott et al. 2006). Elite paddlers are taller (Shephard 1987), heavier and with wider bi-acromial diameter (Fry and Morton 1991, Aitken and Jenkins 1998) than both the sub elite and normal population (Aitken and Jenkins 1998, Ackland, Ong et al. 2003). Elite level paddlers have a lactate threshold ~80% $\dot{V}O_2$max and a high $\dot{V}O_2$max. In addition, the contribution of the

aerobic system to the energy production has been estimated as ~37, 65 and 84% for 200, 500 and 1000-m respectively. Moreover, other physiological indicators such as the $\dot{V}O_{2kinetics}$, muscle oxygen kinetics and muscle oxygenation parameters have been suggested to explain important mechanisms of the physiological adjustments to exercise. It is unfortunate, however, that these indicators have not been investigated in Sprint Kayak.

There have been few studies that have investigated the training responses in elite level kayakers. Nonetheless, it does seem that they typically undertake high training loads which might place them at risk of non-functional overreaching or overtraining. Due to this, there is a need for the development of valid and reliable tools that can be used to monitoring the training process. A few studies have suggested the use of psychological monitoring to describe fatigue and recovery, tools more related to psychobiological responses can be useful for this purpose (Berglund and Safstrom 1994, Kenttä, Hassmén et al. 2006). However, other studies from cycling have shown that methods for monitoring training based on heart rate responses are more appropriate for detecting training adaptations (Banister 1991, Busso and Thomas 2006, Borrensen and Lambert 2009). In addition, athlete perceived exertion has been suggested to be a valid tool for to monitoring endurance training (Foster, Hector et al. 1995, Foster, Florhaug et al. 2001, Coutts, Slattery et al. 2007). However, the best tools for monitoring training in Sprint Kayak athletes have not been established.

At present there are no commonly accepted on-water tests for assessing performance or training adaptations in Sprint Kayak athletes. It is possible that a RSA test could provide important information on adaptations in both fitness and performance. Future

work is required to determine the efficacy of an on-water monitoring test in Sprint Kayak. Furthermore, future studies are also required to investigate the race and training demands of elite level Sprint Kayak, and in particular the 200-m event. Additionally, to improve the training process in Sprint Kayak, there is a need for the development of valid and reliable tools for quantifying training and training-induced adaptations.

CHAPTER THREE

Pacing characteristics of international Sprint Kayak

Abstract

This study aimed to profile pacing strategies and pacing profile of world-class kayakers during world championships. Data were from publically available websites of eight international competitive seasons (2004 - 2011). Data represent percentage average race pace. Mixed ANOVA was used to compare pacing (250 m splits) and race level (A and B-finals) and crew boats. Effect size was calculated converting F-values into r-values ($P < 0.05$). There were significant interactions between splits and season ($F_{7.99, 255.7}=13.08$, $P <0.001$, $r=0.05$), splits and boat crew ($F_{5.33, 255.7}=4.82$, $P <0.001$, $r=0.02$), race level, the split speed and the competitive season ($F_{8.49, 271.5}=2.07$, $P =0.035$, $r=0.01$) and the race level, the split speed and the boat crews ($F_{5.66, 271.5}=2.28$, $P =0.04$, $r=0.01$) for the 1000 m. There was a significant interaction between race level, split speed and boat crew ($F_{1, 80}=4.35$, $P =0.004$, $r=0.05$) in the 500 m. Performances of A and B-finals were significantly different. In conclusion, pacing of sprint kayakers can vary according to race level (A or B-finals, elite or sub-elite respectively), crew (K1, K2 and K4), split distances (250 m splits) and competitive seasons. Additionally, our data suggests there may be specific crew boat dynamics and, therefore, specific race demands.

Key words: Canoe Sprint, Pacing and Performance

Introduction

Canoe Sprint has been an Olympic sport since 1936 and comprises of two distinct disciplines - kayak and canoe. Kayak athletes assume a seated position in the craft and use a double-blade paddle whereas canoe athletes paddle in a kneeling position and use a single blade paddle. Competitions for both kayak and canoeing are over the distances of 200 m, 500 m and 1000 m in several different boats (i.e. K1, K2 and K4). The main international events in Canoe Sprint are the World Cup series, The World Championship and the Olympic Games. The Olympic Games and World Championships are the most prestigious events in the calendar. International competitions require athletes to participate in heats and semi-finals prior to competing in the finals. Heats and semi-finals are often 3-4 hours apart with the final the following day (http://www.canoeicf.com). Many athletes compete in several events over multiple distances, which places significant demands on the athletes. Accordingly, it can be challenging for coaches and sport scientists, working in canoe sprint, to establish competition strategies that allow athletes to regulate effort so that best performances are achieved. Little is known about the competition demands and racing profile of international Canoe Sprint racing.

Whilst relatively little is known about pacing in competitive Canoe Sprint, there have now been many studies that have examined racing strategies in an array of events ranging from few a minutes to several hours (Garland 2005, Gosztyla, Edwards et al. 2006, Abbiss and Laursen 2008, Brown, Delau et al. 2010, Muehlbauer, Schindler et al. 2010). The effort regulation during races, commonly known as pacing, has been used by athletes to minimise/control fatigue and to maximise performance (Hanon and Gajer 2009, Tucker and Noakes 2009). While several models of pacing have been suggested

(Abbiss and Laursen 2008), there have been no reports of pacing in different Sprint Canoe events during competition. However, Bishop et al. (2002) demonstrated in a laboratory setting that compared to an even pace strategy, a deliberate fast start pacing strategy provides a higher mean power output during a 2-min kayak ergometer effort. At present, the pacing strategies used by world-class kayakers during competition are not well understood.

The pacing profile of different sports and exercise modes, may be used by coaches, athletes and sport scientists to improve both racing strategy and training approaches to prepare the athletes for competition. Therefore, the aims of this study were to 1) profile the pacing strategies used by world-class kayakers during world championships events; 2) verify the pacing profile of different competition levels (A and B-finals), competitive seasons and different boats (K1, K2 and K4). It was hypothesized that athletes present pacing strategies according to their performance level, the boat crew and competitive season.

Methods

Study design

Race results were obtained from eight international competitive seasons (2004-2011) from the men 500 m and 1000 m races at the Canoe Sprint World Championships. The competitive results from all A-finals and B-finals for single, double and quad boats were pooled for the analysis and classified according to the race condition as elite (A-final) and sub-elite (B-final). All races were divided into 250 m split distances (four splits for the 1000 m races and two splits for the 500 m races) with

each split speed normalized according to the average race speed so that comparisons could be made between different boat crews, competitive seasons and race conditions (Garland 2005, Brown, Delau et al. 2010). All data were downloaded from public competition websites and the International Canoe Federation (http://www.canoeicf.com). Therefore, it was not necessary to obtain informed consent from athletes for use of their data.

Data reduction

Data obtained from the 2004 and 2008 Olympic Games years' were excluded due to the absence of B-finals. For the 1000 m races, the data from the 2007 season were excluded because there were no split times provided for the K1 B-final whilst the 2010 season data were excluded because there were too many outliers for the K2 and K4 events. Outliers were determined as values that were below and/or above 1.5 times interquartile range. The outliers were later found to be due to irregular cross wind in the race course. The data of the 500 m from the 2009 season were excluded from the analysis as there was not a B-final in the K2 event. Therefore, the final analysed data set was derived from the race results obtained from the 2005, 2006, 2007, 2009, 2010 and 2011 World Championships. These data were analysed according to event distance ($n_{1000\ m}$=216; n_{K1}=72, n_{K2}=72, n_{K4}=72; $n_{500\ m}$=270; n_{K1}=135, n_{K2}=135; n_{Total}=486). In addition, total race time was computed to verify possible differences between A or B-finals and competitive season.

Statistical analyses

All data were tested for normality by Shapiro-Wilk's test and homogeneity of variance by Levene's test and in case of these assumptions being violated, all data were

log transformed. Mauchly's test of sphericity was conducted, and in case of sphericity assumption being violated, the Greenhouse-Geisser correction was applied. A mixed analysis of variance (ANOVA) was performed on the dependent variable (split speed). The independent variables (within-subjects) were split distances (250, 500, 750 and 1000 m) with four levels, race condition (A or B-final) with two levels, crew (between-subjects) with three levels (K1, K2 and K4) and competitive season (five levels for the 500 m; and four levels for the 1000 m races). Effect sizes were calculated by converting the *F*-values into r-values using procedures described elsewhere (Cooper and Hedges 1994, Field, Miles et al. 2012) having reference values of 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1 as *trivial, small, moderate, large, very large, nearly perfect* and *perfect*, respectively (Hopkins 2002) Two-way factorial ANOVA was performed on the total time (dependent variable) of each race condition and competitive season (independent variable). All data were presented as mean ± standard deviation for the pacing treatment and final time (performance). The statistical significance was set at *P* <0.05. All statistical analyses were performed using the software PASW Statistics 18 (SPSS Inc., Chicago, IL, USA).

Results

Figure 3.1 shows the pacing profile of world class 1000 m Sprint Kayak races. There were significant interactions between splits and season ($F_{7.99, 255.7}$=13.08, *P* <0.001, r=0.05), splits and boat crew ($F_{5.33, 255.7}$=4.82, *P* <0.001, r=0.02), race level, the split speed and the competitive season ($F_{8.49, 271.5}$=2.07, *P* =0.035, r=0.01) and the race level, the split speed and the boat crews ($F_{5.66, 271.5}$=2.28, *P* =0.04, r=0.01).
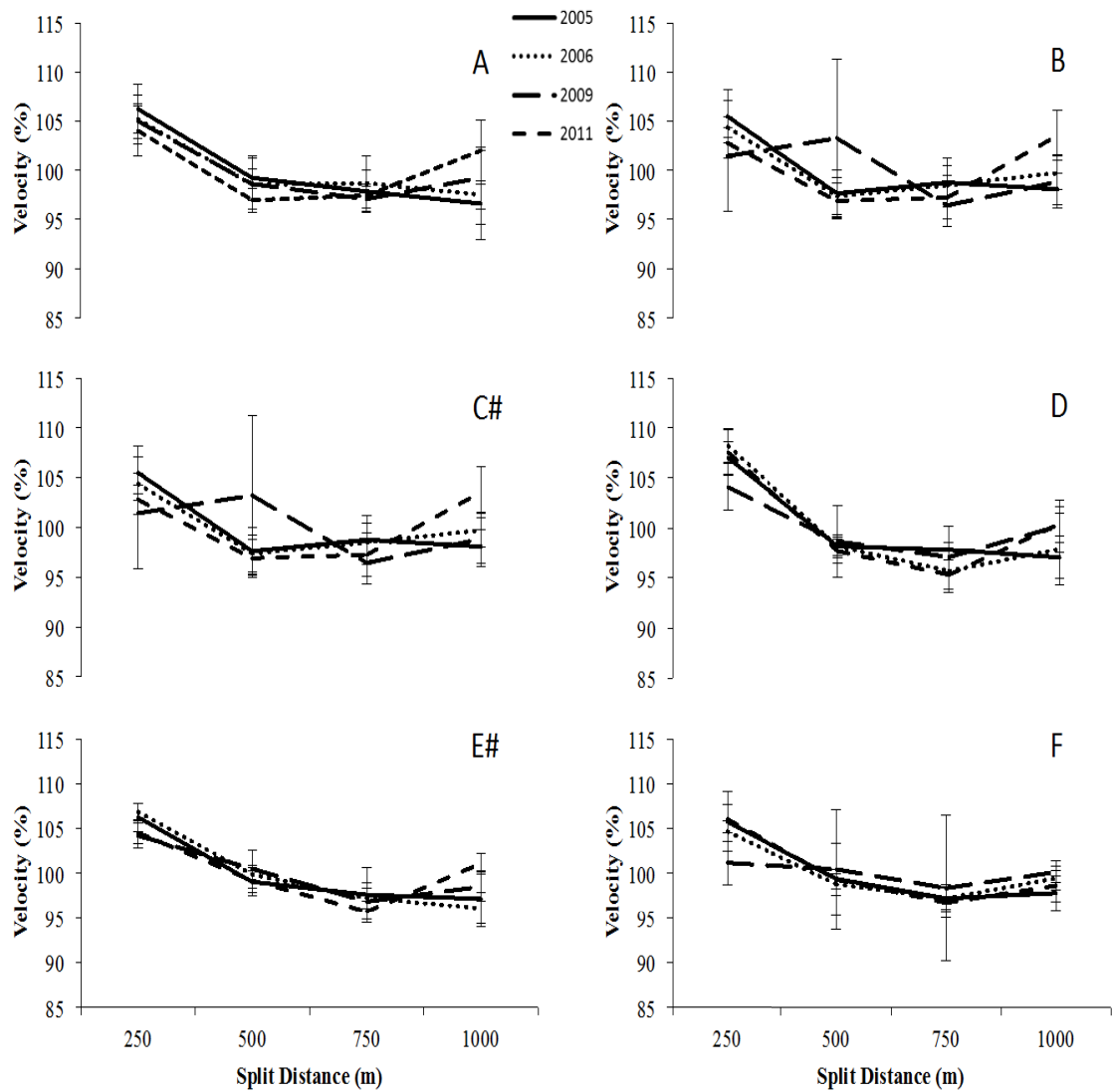
Figure 3.1: Pacing profile (% of mean velocity) of World Class 1000-m Sprint Kayak races in 250 m splits. A – K1 A final; B – K1 B final; C – K2 A final; D – K2 B final; E – K4 A final; F – K4 B final.

Figure 3.2 presents the pacing profile of world class 500 m Sprint Kayak events. There was a significant interaction between race level, split speed and boat crew ($F_{1,80}$=4.35, P =0.004, r=0.05).
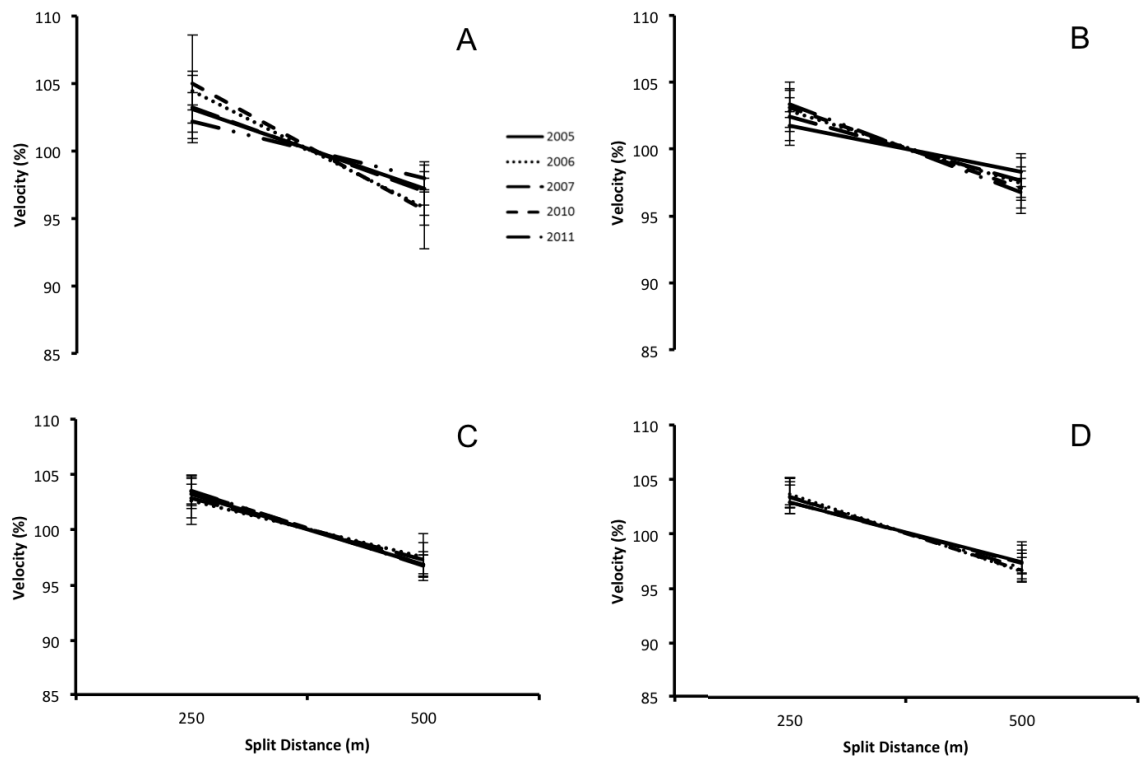
Figure 3.2: Pacing profile (% of mean velocity) of World Class 500-m Sprint Kayak races in 250 m splits. A – K1 A final; B – K1 B final; C – K2 A final; D – K2 B final.

Performance

The mixed ANOVA revealed significant main effects for race level with differences between A and B-final performances. Post hoc analysis showed that the performance after the Olympic Games years were generally faster (table 3.1). Table 3.2 shows that the performance times of world class 500 m Sprint Kayak races were different for seasons and A and B-final performances.

Table 3.1: Mean (±SD) of performance times of world-class 1000-m canoe sprint athletes.

Year	N	K1 $_{1000}$		K2 $_{1000}$		K4 $_{1000}$	
		A Final	**B Final**	**A Final**	**B Final**	**A Final**	**B Final**
2005	54	213.5 ± 3.8	217.3 ± 2.1[*]	200.2 ± 1.7[b,d]	201.6 ± 2.1[b,d, *]	179.1 ± 2.0	183.7 ± 2.6[*]
2006	54	223.0 ± 5.2	229.0 ± 3.6[*]	201.9 ± 3.8	204.2 ± 2.3[*]	180.5 ± 3.8	185.4 ± 3.8[*]
2009	54	213.6 ± 3.1[b,d]	218.4 ± 2.7[b,d, *]	197.3 ± 1.6[b,d]	201.7 ± 2.2[b,d, *]	179.6 ± 1.7	183.2 ± 3.1[*]
2011	54	222.1 ± 3.6	229.9 ± 3.4[*]	203.2 ± 2.5	205.2 ± 2.2[*]	170.4 ± 1.9[a,b,c]	173.6 ± 2.2[a,b,c, *]
Main effects		Level $F_{1, 64}$=45.4, p<0.001		Level $F_{1, 64}$=20.5, p<0.001		Level $F_{1, 64}$=39.5, p<0.01	
		Year $F_{3, 64}$=51.5, p<0.001		Year $F_{3, 64}$=14.4, p<0.001		Year $F_{3, 64}$=62.5, p<0.001	
Effect Size		Level=0.42; Year = 0.45		Level=0.24; Year = 0.18		Level=0.38; Year = 0.49	

[a] – significantly different to 2005, [b] – significantly different to 2006, [c] – significantly different to 2009, [d] – significantly different to 2011, * – significantly different to A final.

Table 3.2: Mean (±SD) of performance times of world-class 500-m canoe sprint athletes

Year	N	K1$_{500}$ A Final			K1$_{500}$ B Final			K2$_{500}$ A Final			K2$_{500}$ B Final		
2005	36	98.1	±	1.5^{c,d}	102	±	1.7^{c,d,*}	90.3	±	1.4	93.4	±	0.7*
2006	36	100.8	±	1.7^{c}	99.8	±	1.5^{c,*}	90.0	±	1.4	92.0	±	1.2*
2007	36	97.4	±	0.9^{d,e}	98.5	±	1.0^{d,e,*}	89.9	±	1.3^{d}	90.7	±	0.8^{d,*}
2010	36	101.7	±	4.2^{e}	102.4	±	2.0^{e,*}	91.0	±	1.0	94.2	±	4.2*
2011	36	99.4	±	2.2	100.6	±	1.2*	89.7	±	1.2	94.2	±	4.2*

Main effects — Level $F_{1, 80}$=8.66, p=0.004 (K1$_{500}$); Level $F_{1, 80}$=35.33, p<0.001 (K2$_{500}$)

Year $F_{4, 80}$=9.06, p<0.001 (K1$_{500}$); Year $F_{4, 80}$=2.96, p=0.025 (K2$_{500}$)

Effect size — Level=0.10; Year = 0.10 (K1$_{500}$); Level=0.31; Year = 0.04 (K2$_{500}$)

[a] – significantly different to 2005, [b] – significantly different to 2006, [c] – significantly different to 2007, [d] – significantly different to 2010, [e] – significantly different to 2011, * – significantly different to A final.

Discussion

The aims of the present study were to profile the pacing strategies adopted by world-class kayak athletes over different distance races (500 m and 1000 m), boats (K1; K2 and K4) and levels (A and B-finals) over an 8-year period. The main findings demonstrated that 1000 m races all displayed a reverse J-shaped pacing profile (Abbiss and Laursen 2008), with the first 250 m split being the fastest and an increase in speed during the final 250 m split; a fast starting strategy was apparent in both the 1000 and 500–m events; and the pacing profiles in the 1000 m races were different for K1 and K4 boats and race level (A and B-finals).

The reversed J-shaped pacing profile found in sprint kayak is comparable to those reported in other sports, including rowing, running, cycling and speed skating (de Koning, Bobbert et al. 1999, Kennedy and Bell 2003, Garland 2005, Brown, Delau et al. 2010, Muehlbauer, Schindler et al. 2010). In this study the first 250 m splits were faster for all races, regardless of race level, boat crew and competitive season. These findings suggest that sprint kayak athletes and coaches consider positions at the front of the group early in the race to be tactically advantageous and are similar to previous work with rowers that reported that a fast start may afford leading boats with a better view of opponents and also assist them to avoid the wash from competitors boats (Garland 2005, Brown, Delau et al. 2010, Muehlbauer, Schindler et al. 2010, Sealey, Spinks et al. 2010). However since the leading athletes in sprint kayak are unable to see the other boats in the race, it is likely that a fast start strategy might assist kayak performance by allowing athletes to avoid the wash of other boats and control the race from the front position and react to challenges later in races.

In addition to tactical advantages, the fast start strategy may also provide physiological advantages such as improving the energy production through the aerobic pathway. It has recently been proposed that a fast start provides a greater rate of muscle ATP hydrolysis, increases signalling for oxygen supply which speeds oxygen kinetics and spares the non-oxidative energy contribution that may be used later in the end spurt (Abbiss and Laursen 2008, Jones, Wilkerson et al. 2008, Bailey, Vanhatalo et al. 2010). Unfortunately, since no physiological measures were taken in the present study, we are unable to confirm if there are physiological advantages associated with the fast starts.

Similar to the earlier laboratory-based kayak research (Bishop, Bonetti et al. 2002), the 500 m races in the present study showed a significant decrease in speed during the second half of the race (Figure 3.2). Fast start approaches have previously been shown to be beneficial for both shorter duration races <120 s in running, cycling and speed skating (van Ingen Schenau, de Koning et al. 1994), and longer races of 120-190 s duration (Foster, Snyder et al. 1993, de Koning, Bobbert et al. 1999, Garland 2005). For example, in rowing, athletes generally assume a fast start strategy regardless of their finishing position or sex (Garland 2005). Taken collectively, these results show that a fast start strategy should be trained for best performances in both 1000 m and 500 m kayak events.

Another consistent characteristic observed in the 1000 m race for K1 and K2 was the end spurt with an increased speed in the last 250 m of the race. Unfortunately, we were only able to obtain the mid-point split during the 500 m races and we are unable to determine if the end spurt occurs during these shorter races. Nonetheless, the end spurt is a common phenomenon in many time-trial events (Abbiss and Laursen 2008) and is

most likely a consequence of an effort to improve the position at the finish line. Previous researchers have reported that world-class athletes are well aware of the total distance of the race, which allows them to assume a more aggressive strategy applying the end spurt (Swart, Lamberts et al. 2009, Brown, Delau et al. 2010). Indeed, Swart et al., (2009) showed that the more the athletes were aware of the endpoint of their effort, the higher were their perceived exertion ratings and power output. World-class athletes, such as those examined in the present study, typically have a high level of experience and knowledge of their competitive distances, which may therefore help to explain such an approach to the races.

The significant interaction observed between splits and crew boats in both the 1000 m and 500 m kayak events, showed that the K4 races were comparable with the K1's at the first 250 m split. However, the reversed J-shaped curve pacing profile did not hold true for the K4 boats as their velocity was closer to the total average performance while the K1 1000 m boats showed greater end spurt. In contrast, the K1 boats in the 500 m races had faster first 250 m split and slower second split, compared to the K2 crew boat. These differences in pacing profiles may be partly explained by the complex interaction between the drag created between the hulls and water and the physiological cost required from the kayakers to maintain boat speed. For example, the friction drag of the larger boats (i.e. K2 and K4) are ~2−3 times higher than the smaller K1 and these increases in drag act to reduce boat speed (Jackson 1995). Therefore, small increases in boat speed require relatively large increases in power output (Jackson 1995). Consequently, it is metabolically more demanding for team boat athletes (K2 and K4) to overcome drag in order to lift the average boat velocity. These observations may help to explain why coaches and crew of larger boats (K2 and K4) often report difficulty in

increasing boat speed after it has decreased. They may also explain the reduced or lack of end spurt in the larger crew boat races compared to the small K1 events.

A new finding from the present study was the different pacing strategies between A and B-finals. The athletes from the B-finals were slower in the middle section of the race compared to the A-final for the 1000 m, whilst there was a more heterogeneous pacing profile from the B-finals in both the 500 m and 1000 m races. This finding agrees with other research that has demonstrated that athletes from A-finals had lower performance variability than their B-finalists counterparts in cycling, track and field, swimming and sprint kayak athletes (Pyne, Trewin et al. 2004, Hopkins 2005, Paton and Hopkins 2006, Bonetti and Hopkins 2010). As it is typical that talented but developing athletes qualify for the B-finals, it may be that factors such as fitness, race experience and confidence explain the different pacing profiles between the finals. The athletes from A-finals are likely to have higher fitness level and paddling skills, which was confirmed by faster performance time for this group (Table 3.1 and Table 3.2). In fact athletes of higher performance level have been reported to show more aggressive pacing strategies during running and rowing (Baden, McLean et al. 2005, Garland 2005, Abbiss and Laursen 2008, Hanon and Gajer 2009, Swart, Lamberts et al. 2009, Brown, Delau et al. 2010) compared to their lower level counterparts. Indeed, Brown et al. (2010) suggested that higher level athletes rely on a consistent greater anaerobic contribution throughout the entire race whereas lower level athletes use anaerobic energy predominantly at the beginning and end of the races. This may be due to increased task knowledge and confidence from the A-final athletes.

In spite of valuable information, most studies present few limitations. Limitations of this study are that only official split and total times were used for the current analysis. Unfortunately, the relatively crude data (i.e. 250 m time splits) did not allow us to describe precisely the actual pacing strategy adopted. Nevertheless, the present study provide information on real competition without any experimental manipulation of the pacing or racing condition (Muehlbauer, Schindler et al. 2010). Moreover, the less consistent pacing strategy in the B final may be due to lower motivation and heterogeneity of the athletes. Finally, confounding factors such as environmental conditions may have also affected the pacing results. Nonetheless, this is valuable information for coaches, athletes and sport scientists interested in real pacing strategies at world-class level in the three different boats and race condition (A and B-finals). As the athletes develop to higher levels their pacing strategies evolve and both coaches and athletes could take advantage of the results presented here to guide their career development. Nonetheless, future studies should expand the current study to describe the pacing strategies more precisely and include the 200 m event. Indeed, the introduction of fast sampling GPS may assist scientists in such analyses.

Conclusion

In conclusion, the present investigation showed that, the pacing strategy of sprint kayakers can vary according to race level (A or B-finals, elite or sub-elite respectively), crew (K1, K2 and K4), split distances (250 m splits) and competitive seasons. These alterations in pacing may be influenced by an athlete's physiological capacity, motivation, tactical approach or racing experience (Jackson 1995, Ansley, Schabort et al. 2004, Micklewright, Papadopoulou et al. 2009). We also provided evidence that

there may be specific crew boats dynamics (Jackson 1995, Michael, Smith et al. 2009) and therefore, specific racing demands. Further research is needed to determine the impact on the physiological, biomechanical, technical and tactical factors on athletes when paddling K1, K2 and K4 over different competitive distances. The current results provide information on how pacing develops in Sprint Kayak in the small and larger boats. The practical applications of this study are that coaches and kayakers could use this profile as a reference when organizing their training programme or when defining racing strategies. The K4 in particular requires a well-planned pacing strategy, as it presented a different profile presented by the K1. Such strategy would include practicing even pace strategies at targeted race performance. Moreover, the team boats may receive different training approach including fast starts, even pacing and perhaps the end spurt in order to distribute the effort over 1000 m and 500 m better.

CHAPTER FOUR

Physiological characteristics of well-trained junior Sprint Kayak

athletes

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Abstract

The aims of this study were to profile the physiological characteristics of well-trained junior Sprint Kayak athletes, and to establish the relationship between these physiological variables (i.e. $\dot{V}O_{2kinetics}$, muscle $O_{2kinetics}$, paddling efficiency) and performance in the longer (1000-m) and shorter (200-m) Sprint Kayak time trials. The National Sprint Kayak Incremental step test was performed on a kayak ergometer in the laboratory to determine $\dot{V}O_2max$, MAP, power:weight ratio, paddling efficiency and $\dot{V}O_2$ at lactate threshold ($\dot{V}O_{2LT2}$). A series of square wave tests determined whole body and muscle on kinetics. On-water time trials were completed over 200 and 1000-m. There were *large-to-nearly* perfect (-0.5 to -0.9) inverse relationships between maximal physiological outcomes and on-water time trial performance in both 200 and 1000-m performance. Submaximal physiological variables including paddling efficiency and lactate threshold were *moderate-to-very large* correlated (-0.4 to -0.7) with 200 and 1000-m. Moreover, *trivial-to-large* correlations (0.11 to -0.5) were observed between muscle oxygenation parameters, muscle and whole body oxygen kinetics. Results from multiple regression showed that 88% of the unadjusted variance for the 200-m time trial performance was explained by $\dot{V}O_2max$, deoxyhaemoglobin (HHb), and mean maximal aerobic power (MAP) ($F_{3, 17} = 40.6$, p<0.001). The coefficient estimates for this model were -7.89 (90% CI: -10.16 to -5.62), 0.08 (90% CI: 0.03 to 0.14) and -0.25 (90% CI: -0.35 to -0.14) for absolute $\dot{V}O_2max$, MAP and HHb, respectively. Similarly, multiple regression showed that 85% of the unadjusted variance in 1000-m Sprint Kayak time trial performance was explained by $\dot{V}O_2max$ and HHb ($F_{3, 17} = 34.8$, p<0.001). The coefficient estimates for absolute $\dot{V}O_2max$ were -27.40 (90% CI: -39.50 to -15.30); MAP, 0.05 (90% CI: -0.24 to 0.35), and; HHb, -0.78 (90% CI: -1.35 to -0.21). In conclusion, the present findings showed that well-trained junior Sprint Kayak athletes

have high levels of relative aerobic fitness. Furthermore, the current data supports the relationship between maximal aerobic capacities and performance, and the importance of the ΔHHb for performance during 200-m Sprint Kayak.

Introduction

The current Olympic Sprint Kayak program consists of three racing distances - one longer (1000-m men, race time range [205-215 s]) and two shorter (500-m women [115-120 s]; 200-m men [34-35 s] and women [39-40 s]) distance races. While the 1000 and the 500-m are the traditional Sprint Kayak race distances, the 200-m races are a recent addition into the Olympic program (ICF 2013). This variety of performance distances suggests that distinct physiological attributes may be required for success within each specific race duration. For example, it has been estimated that the 1000-m event requires ~82% of total energy to be provided through oxidative pathways, whereas only ~37% is required for a maximal 200-m race (Byrnes and Kearney 1997). However, in the recent past, few athletes had been able to perform in both 1000-m and 500-m, with the later requiring an estimate of around 65% of the aerobic pathway. Therefore, it seems that this smaller metabolic difference between the 1000 and the 500-m distances has not been enough to prevent the athletes to perform well in two distances.

Aerobic metabolism has been reported to play an important role in Sprint Kayak racing (Fry and Morton 1991, Bishop 2000). Past studies have reported *large-to-very large* correlations between maximum oxygen uptake ($\dot{V}O_2max$) with 1000 and 500-m Sprint Kayak performance (Fry and Morton 1991, Bishop 2000), while only *trivial-to-moderate* relationships have been observed with 200-m efforts (van Someren and Palmer 2003, van Someren and Howatson 2008). Many authors have shown that other aerobic characteristics, such as maximal power output at $\dot{V}Omax$ level and anaerobic traits like power produced during 30 s and 2-min and the accumulated oxygen deficit (Bishop 2000, van Someren and Palmer 2003, van Someren and Howatson 2008) relate

to Sprint Kayak performance, highlighting the importance of developing both metabolic pathways for competitive success.

While the role of the aerobic metabolism in Sprint Kayak has been well documented, other important variables of oxidative metabolism such as whole body oxygen kinetics ($\dot{V}O_{2kinetics}$), muscle oxygen kinetics ($M_{O2kinetics}$) and muscle oxygenation parameters have yet to be reported in Sprint Kayak athletes. The $\dot{V}O_{2kinetics}$ represent the rate of metabolic adaptation to exercise (Burnley and Jones 2007) and have been shown to be faster in higher level athletes when compared to their lower level counterparts in similar racing sports such as rowing (Ingham, Carter et al. 2007) and cycling (Koppo, Bouckaert et al. 2004, Koppo, Whipp et al. 2004). Together, this information suggests that athletes who can rapidly adjust to increases in exercise intensity may benefit from the efficient supply of energy from the aerobic system and a reduced energy contribution from anaerobic pathways. Moreover, faster $\dot{V}O_{2kinetics}$ appears to share the benefit from aerobic and anaerobic qualities as it has been shown that athletes with faster $\dot{V}O_{2kinetics}$ also possess better repeated-sprint performance (Dupont, Millet et al. 2005). Nonetheless, there is still need to improve the understanding of the physiological factors that may contribute to Sprint Kayak performance.

Profiling the physiological demands of Sprint Kayak athletes of all ages, levels and events provide insight into important aspects to direct training activities. Whilst, several studies have described physiological and anthropometrical characteristics of high performance female (Bishop 2000), youth (Aitken and Jenkins 1998), lower level open age (Fry and Morton 1991) and national to international adult (van Someren and Palmer

2003, van Someren and Howatson 2008) athletes that competed over longer race distances, few have examined the physiological factors associated with 200-m performance. Surprisingly no studies have profiled the physiological characteristics of well-trained junior Sprint Kayak athletes to date, particularly since this group forms the basis talent programs that develop into elite performers.

At present, there is a relatively poor understanding of the physiological characteristics of developing junior Sprint Kayak athletes, and their relationships with performance. Therefore, the aims of this study were 1) to profile the physiological characteristics of well-trained junior Sprint Kayak athletes, and 2) to establish the relationship between these physiological variables (i.e. $\dot{V}O_{2kinetics}$, $M_{O2kinetics}$, paddling efficiency and performance in the longer (1000-m) and shorter (200-m) Sprint Kayak time trials.

Methods

Experimental design

Anthropometric, physiological and performance characteristics of well-trained junior Sprint Kayak athletes were assessed during a 7-day period in the laboratory setting. The athletes had anthropometric characteristics measured, aerobic fitness parameters such as $\dot{V}O_2max$, mean maximal aerobic power (MAP) and lactate threshold (LT$_2$)), oxygen uptake on-kinetics (phase II fast kinetics – τ^p), $M_{O2kinetics}$ (phase II muscle fast kinetics – τ^p), muscle oxygenation parameters including oxyhaemoglobin ([O$_2$Hb]), de-oxyhaemoglobin ([HHb]), total haemoglobin ([tHb]) and tissue

desaturation index (TSI) and gross efficiency assessed in a laboratory. Separately, each athlete's on-water 200 and 1000-m time trial performance was also determined.

Participants

Twenty-one (13 males, 8 females,) well-trained junior Sprint Kayak athletes (17.0 ±1.2 years, Σ_7 skinfolds 83.3 ±31.3 mm, body mass 72.4 ±8.3 kg, stature 176.1 ±8.8 cm, training experience 2.7 ±1.2 years, training volume 11.3 ±3.0 h·wk^{-1}) took part in this study. Prior to commencement of the study, all procedures, aims and any risk related to the study were explained to the athletes and their parents and written informed consent was provided. Local University's Ethics committee had approved the study (UTS HREC REF No. 2011-159A).

Performance and Physiological Assessments

Aerobic fitness.

Several measures of aerobic fitness ($\dot{V}O_2$max, MAP and LT_2) were determined using an incremental Kayak step test (Bullock, Woolford et al. 2013). Briefly, five four-minute submaximal stages were performed at fixed intensities depending upon the gender, age and performance ability of the athlete. The technical errors of this protocol stands at ±3 W for power output, ±0.6 L □ min^{-1} for absolute $\dot{V}O_2$max, ±1.0 ml □ kg □ min^{-1} for relative $\dot{V}O_2$max, ± 2 bpm for heart rate, and ±0.6 mmol □ L^{-1} for maximal lactate concentration. The last four-minute stage was performed maximally at perceived time-trial intensity. A 60 s period was allowed between each workload for sampling blood lactate concentration ([BLa⁻]) and recording average power, average stroke rate and ratings of perceived of exertion (RPE). The gas exchange was measured continuously via breath-by-breath using a MedGraphics System (CPX Ultima,

MedGraphics Corporation, Minnesota, USA) with the highest consecutive one minute reported as the maximum value ($\dot{V}O_2$max). The system was calibrated before each test session using known O_2 and CO_2 concentrations, according to the manufacturer specifications. The flow meter was calibrated using a 3 L syringe.

The LT_2 was determined by the D-max method (ICC 0.77-0.93, $p<0.01$) as described elsewhere (Zhou and Weston 1999). All laboratory tests were performed on a dynamically calibrated WEBA kayak ergometer (Weba Sport und Med. - Artikel GmbH, Vienna, Austria) where the power output varied according to the tension applied throughout each stroke, mimicking the actual movement of the on-water stroke (typical error of estimate – 7.2% W).

Near-infrared spectroscopy (NIRS).

Blood flow and muscle oxygenation of the latissumus dorsi were made using a portable NIRS device (Portamon, Artinis Medical Systems, Zetten, the Netherlands) during each testing session. A 2-wavelength continuous wave system that uses the modified Beer-Lambert law and spatially resolved spectroscopy methods simultaneously measured changes in tissue oxyhaemoglobin ($[O_2Hb]$), deoxyhaemoglobin ($[HHb]$) and total haemoglobin ($[tHb]$) by using their chromophoric properties at 750 and 860 nm. The difference between the $[HHb]$ and $[HbO_2]$ representing the average saturation of the latissimus dorsi was calculated as the tissue saturation index (TSI). An arbitrary value of 3.83 was used for the differential path length factor (Buchheit, Laursen et al. 2009).

The NIRS device was placed at the midpoint between the inferior border of the scapula and posterior axillar fold and orientated parallel to the muscle fibre orientation. A translucid waterproof adhesive (OpSite Flexgrid, Smith&Nephew, Australia) was fixed between the NIRS device and the skin to prevent the sweat to cause any issue with light transmission/absorption. The device was fixed to the skin by a dark adhesive tape and covered with a black sport crop top to ensure no ambient light to penetrate. The crop top also helped to keep the device on site as it exerted light pressure against the skin. The NIRS data was continuously recorded at a 10 Hz rate and the data was later averaged to 1 s values using bespoke software (LabVIEW, National Instruments, USA), to allow synchronization with $\dot{V}O_2$ data. The NIRS-derived data were averaged at the last minute of each submaximal stage of the step test and are reported as either changes in micro molar units ($[\Delta O_2 Hb]$, $[\Delta HHb]$, $[\Delta tHb]$) or percentage (TSI). Similar to the $\dot{V}O_{2max}$ test protocol, the two consecutive maximal 30 s values for each parameter were averaged and considered as maximal effort.

Oxygen kinetics assessment.

A series of three square-wave transitions from rest to exercise were performed on the kayak ergometer across a single visit to the laboratory. The athletes paddled for two minutes at a very low intensity (20 W) followed by a rapid increase to a pre-determined paddling intensity for six minutes. The intensities corresponded to power outputs: 1) their individual LT_2 (~80 % of $\dot{V}O_2$ - moderate domain), 2) the intensity mid-way between the individual LT_2 and $\dot{V}O_{2max}$ (50%Δ, heavy domain); and, 3) the intensity at 80% of the difference between LT_2 to $\dot{V}O_{2max}$ (80%Δ, severe domain). According to previous methods, a 6-min rest was allowed between the moderate and heavy domain, whilst a 10-min break was provided between the heavy and severe domain to ensure

metabolic rate to return to resting levels (Burnley, Jones et al. 2000, Ingham, Carter et al. 2007).

Modelling of O$_2$ kinetics and muscle oxygenation data.

After a thorough examination of the $\dot{V}O_2$ data, any data point found more than four standard deviations away from the mean response was deleted. The breath-by-breath data was interpolated to second-by-second values, and the response of the $\dot{V}O_2$ for each domain was time aligned and averaged. For the $M_{O2kinetics}$, the main parameter of choice was the tissue saturation index (TSI). The raw data recorded at 10 Hz was initially averaged to one second samples and then time aligned. A non-linear least squares regression technique was used to model the time course of the $\dot{V}O_2$ response and TSI. A single (Eq. 1 and 2) component exponential equation was used to model the moderate response whilst for the heavy and severe domains, a double (Eq. 3 and 4) component equation was applied (Koppo, Bouckaert et al. 2004, Burnley and Jones 2007). The Solver function within Microsoft Excel (Microsoft Corporation™, USA) was used to determine the best fit of the parameters.

$\dot{V}O_2$ Moderate Domain - $\dot{V}O_2$ (t) = $\dot{V}O_2$ (b) + A$_p$ · [1-e$^{-(t-TDp)/}$ $\tau$$_P$] (Eq. 1)

TSI Moderate Domain - TSI (t) = TSI (b) - A$_p$ · [1-e$^{-(t-TDp)/}$ $\tau$$_P$] (Eq. 2)

$\dot{V}O_2$ Heavy and Severe Domain - $\dot{V}O_2$ (t) = $\dot{V}O_2$ (b) + A$_p$ · [1-e$^{-(t-TDp)/}$ τ^{P}] + A$_s$ · [1-e$^{-(t-TDs)/}$ τ^{s}] (Eq. 3)

TSI Heavy and Severe Domain - TSI (t) = TSI (b) + A$_p$ · [1-e$^{-(t-TDp)/}$ τ^{P}] + A$_s$ · [1-e$^{-(t-TDs)/}$ τ^{s}] (Eq. 4)

Where, $\dot{V}O_2$ (t) and TSI (t) are the $\dot{V}O_2$ and TSI at a given time; $\dot{V}O_2$ (b) and TSI (b) are the baseline value across the last 2 minutes of 'unloaded' paddling; A$_p$ and A$_s$ are the asymptotic amplitudes for the primary and slow exponential component; $\tau$$_p$ and $\tau$$_s$ are the time constants for each component; and TD$_p$ and TD$_s$ are the time delays for the primary and slow components.

Even though a two-component model was used to fit both the heavy and severe-intensity $\dot{V}O_2$ and TSI responses, only the time constant for the fast component of the $\dot{V}O_2$ and TSI kinetics was reported.

Energy expenditure and Gross efficiency.

Energy expenditure during the maximal stage of the incremental step test was calculated as the sum of the net $\dot{V}O_{2max}$ (represented by the gain of the $\dot{V}O_{2max}$ minus rest $\dot{V}O_2$) and net [La] (calculated from the $[La]_{max}$ gain minus rest [La] (assumed 1 $mmol\cdot L^{-1}$)). The net [La] was then converted into O_2 equivalent using energy equivalent for $\dot{V}O_2$ as 20.9 $kJ\cdot L^{-1}$ (Gomes, Mourão et al. 2012). The paddling gross efficiency was calculated as the ratio between power output and energy expenditure. The power output was converted into energy assuming the energy equivalent for $\dot{V}O_2$ as 20.9 $kJ\cdot L^{-1}$ (Di Prampero 1981, Di Prampero 1986, Zamparo, Capelli et al. 1999, Gomes, Mourão et al. 2012).

Anthropometry

A calibrated skinfold calliper (Harpenden, Baty International, UK) with a 0.2 mm precision was used for skinfolds measurements. The triceps, subscapular, biceps, supraspinale, abdominal, thigh and calf skinfolds were measured according to the International Society for the Advancement of Kinanthropometry standards (ISAK) (Marfell-Jones, Stewart et al. 2006). The body mass was determined by a Tanita digital scale (BC-590BT, Tanita, USA) and the stature by a wooden stadiometer with a 0.1 cm precision.

Sprint Kayak Performance

The on-water Sprint Kayak performance was determined during time trials at the lake where the athletes usually trained. The athletes used their own standard kayak (520 cm long, 12 kg) and were assessed individually, to avoid any of pacing or wash influence from other paddlers (Perez-Landaluce, Rodriguez-Alonso et al. 1998). The time was recorded for each effort was performed using two synchronized stop watches (Interval$^®$ 2000, Nielsen-Kellerman, Boothwyn, USA). Following a standard warm up that consisted of 3-min of paddling at ~85% of HR_{max} followed by two 15 s accelerations interspersed with 45 s rest and two standing starts of 24 strokes with 45 s rest between each ending with 3 min of paddling at 85% HR_{max}, the athlete positioned the boat at the start line and was required to paddle in the shortest time possible for the 200 and 1000-m. After the 200-m trial, the athletes performed a moderate 25-min active recovery (~ 70% HR_{max}) followed by the 1000-m time trial.

Statistics

The data are presented as mean ±SD, unless otherwise stated. The 90% confidence interval is also presented. All data was initially assessed for normality and transformed where required. Initially, product-moment Pearson's correlation was used to determine the relationship between all the physiological, anthropometrical and performance variables. The correlation coefficients were also used to represent the effect size where 0.1, 0.3, 0.5, 0.7, 0.9 and 1 were considered as *trivial, small, moderate, large, very large, nearly perfect* and *perfect*, respectively as described elsewhere (Hopkins 2002). Hierarchical multiple regression analyses were carried out in order to determine the best predictors for performance in Sprint Kayak racing. Influential cases were checked using the difference between the original and predicted value (DFFit), the Cook's distance and

leverage. Data was also checked for multicollinearity using the variance inflation factor, tolerance statistic and homoscedasticity. Independent errors were checked using Durbin-Watson test. To test for differences between models, one-way ANOVA was applied. The cross validation of the models were done by calculating the adjusted R^2. Significance level was set at $p<0.05$. All statistic procedures were conducted using R statistics software (Team 2013), car (Weisberg 2011) and QuantPsyc packages for R (Fletcher 2012).

Results

The aerobic fitness measures and their relationships with on-water 200 and 1000-m time trial performance are shown in Table 4.1. There were *large-to-nearly* perfect relationships between relative and absolute $\dot{V}O_{2max}$ and MAP with both kayak time trial performances, with slightly stronger relationships observed with the 1000-m. Moreover, there were also *moderate-to-large* relationships between the power:weight ratio, lactate threshold, energy expenditure and gross paddling efficiency and performance in both time trials.

Table 4.1: Mean (±SD), 90% confidence intervals and correlations coefficients of physiological, energetic and performance characteristics of well-trained junior Sprint Kayak athletes.

	Mean	±	SD	90% CI			TT$_{200}$ (s) 46.6 ± 4.5 R	TT$_{1000}$ (s) 279.3 ± 22.2 R
$\dot{V}O_2$max (ml . kg^{-1} . min^{-1})	56.6	±	8.0	53.6	to	59.6	-0.76	-0.84
$\dot{V}O_2$max (l . min^{-1})	4.1	±	0.7	53.9	to	59.5	-0.86	-0.9
[Lac]peak (mmol . L^{-1})	9.0	±	2.3	8.3	to	10.0	-0.23	-0.26
HR(bpm)	197.1	±	7.7	193.5	to	199.3	0.03	-0.12
P:Wratio (Kg . W^{-1})	2.4	±	0.4	2.2	to	2.5	-0.49	-0.66
MAP (W)	169.3	±	29.9	157.4	to	179.0	-0.74	-0.84
LT1 (W)	108.9	±	18.4	100.9	to	116.0	-0.65	-0.68
LT2 (W)	129.4	±	22.8	119.3	to	137.8	-0.74	-0.75
Energy Expenditure (ml . kg^{-1} . min^{-1})	61.7	±	10.4	57.9	to	65.5	-0.42	-0.59
Gross Efficiency (%)	13.1	±	1.6	12.5	to	13.7	-0.48	-0.34

HR – heart rate; P:Wratio- power to weight ratio; MAP – maximal aerobic power; LT$_1$ – lactate threshold 1; LT$_2$ – lactate threshold 2; CI – confidence interval.

Table 4.2 shows the muscle oxygenation parameters and the fast component on–kinetics for muscle and whole body as well as their relationship with 200 and 1000-m on-water performance. *Trivial-to-large* correlations were found between the muscle oxygenation parameters, $\dot{V}O_{2kinetics}$ and $M_{O2kinetics}$ and on-water performance over both distances (Table 2). Both the HHb and TSI responses showed *moderate-to-large* correlations with on-water time trial performances for both distances.

Multiple regression showed that 88% of the unadjusted variance for the 200-m time trial performance was explained by $\dot{V}O_{2max}$, HHb, and MAP ($F_{3, 17}$ = 40.6, p<0.001). The coefficient estimates for this model were -7.89 (90% CI: -10.16 to -5.62), 0.08 (90% CI: 0.03 to 0.14) and -0.25 (90% CI: -0.35 to -0.14) for absolute $\dot{V}O_{2max}$, MAP and HHb, respectively. Similarly, multiple regression showed that 85% of the unadjusted variance in 1000-m kayak time trial performance was explained by $\dot{V}O_{2max}$

and HHb ($F_{3, 17}$ = 34.8, p<0.001). The coefficient estimates for absolute $\dot{V}O_2$max were -27.40 (90% CI: -39.50 to -15.30); MAP, 0.05 (90% CI: -0.24 to 0.35), and; HHb, -0.78 (90% CI: -1.35 to -0.21).

Table 4.2: Mean (±SD), 90% confidence interval and correlation coefficients of whole body and muscle oxygen on-kinetics, muscle deoxygenation parameters and performance characteristics of well-trained junior Sprint Kayak athletes.

	Mean	±	SD	90% CI			TT_{200} (s) 46.6 ± 5.0 R	TT_{1000} (s) 279.3 ± 22.0 R
HHb (μM)	12.1	±	6.8	9.6	to	14.6	-0.54	-0.49
O2Hb (μM)	0.6	±	6.5	-1.8	to	3.0	0.17	0.26
tHb (μM)	12.8	±	7.3	10.1	to	15.5	-0.36	-0.23
TSI (%)	55.3	±	16	49.4	to	61.3	0.42	0.49
O_2 tau Moderate (s)	36.5	±	5.4	34.1	to	38.2	-0.2	-0.03
O_2 tau Heavy (s)	24.1	±	5.2	22.1	to	26.0	-0.11	0.01
O_2 tau Severe (s)	24.3	±	5	23.1	to	26.5	-0.17	-0.05
TSI tau Moderate (s)	9.8	±	3.7	8.6	to	11.6	0.07	0.19
TSI tau Heavy (s)	14.8	±	6.6	11.1	to	15.9	0.25	0.3
TSI tau Severe (s)	13.4	±	7.2	10.4	to	15.7	-0.12	-0.2

HHb – deoxyhaemoglobin; O_2Hb – oxyhaemoglobin; tHb – total haemoglobin; TSI – tissue saturation index; CI –confidence interval.

Discussion

The aims of this study were to profile the physiological characteristics of well-trained junior Sprint Kayak athletes and to establish the relationships between physiological variables and performance in Olympic distances of Sprint Kayak racing. The main results demonstrated the Junior Sprint Kayak paddlers were smaller and had inferior physiological capacities than older and higher level kayakers (Fry and Morton 1991, van Someren and Howatson 2008, Garcia-Pallares, Sanchez-Medina et al. 2009, Garcia-Pallares, Garcia-Fernandez et al. 2010). Additionally, the aerobic fitness characteristics demonstrated strong relationships with 1000-m paddling performance,

whereas muscle oxygen kinetics appeared better related to 200-m Sprint Kayak performance.

The present results demonstrated that the well-trained junior Sprint Kayak athletes possessed lower absolute maximal aerobic fitness and poorer gross efficiency when compared to previous data on older and better-developed counterparts. However, when expressed relative to body mass, the maximal aerobic fitness characteristics were similar or even higher than values previously reported in senior Sprint Kayakers. For example, older paddlers (~25.4 y) ranging from club to elite level have been reported to be ~11% heavier, possess ~15% higher absolute $\dot{V}O_{2max,}$ 25% higher MAP, 26 % and higher $[BLa^-]_{max}$. However, when $\dot{V}O_{2max}$ is normalized for body mass, the difference in $\dot{V}O_{2max}$ was reduced to $4 \pm 8\%$ (Fry and Morton 1991, van Someren and Howatson 2008, Garcia-Pallares, Sanchez-Medina et al. 2009). Similarly, despite absolute power output at LT_2 being typically ~14% higher in mature elite paddlers, the current younger paddlers had a similar LT_2, when expressed as a percentage of MAP (i.e. older: ~74 $\pm$9% MAP vs. younger 77 $\pm$8%) (van Someren and Palmer 2003, van Someren and Howatson 2008, Garcia-Pallares, Garcia-Fernandez et al. 2010, Gomes, Mourão et al. 2012, Bullock, Woolford et al. 2013). Furthermore, despite the poorer absolute maximal aerobic fitness levels, the younger paddlers in the present study had a higher level of gross efficiency (~30%) than well trained older sprint kayak athletes (Gomes, Mourão et al. 2012). This may be explained by the lower muscle mass in younger athletes and the lower production of anaerobic energy in the younger athletes (Bishop 2000). Collectively, these results suggest that the younger paddlers in this study were well trained, albeit it seems that further sustained training is required to meet the maximal aerobic fitness required of elite level performance at the open level.

Similar to other studies, strong relationships were observed between maximal aerobic fitness and time-trial performance. Additionally, the correlations in the present study were *very large* and *nearly perfect* between $\dot{V}O_{2max}$ and MAP for the 200-m and the 1000-m distances, respectively. These findings are in accordance with Fry and Morton (1991) who reported *very large* correlations between both $\dot{V}O_{2max}$ and MAP with on-water Sprint Kayak performance over the 1000-m. In contrast, van Someren and Howatson (2008) found only *trivial* correlations between $\dot{V}O_{2max}$, MAP and on-water 1000-m race performance, whilst *trivial* and *large* correlations were also present between on-water 200-m race performance, $\dot{V}O_{2max}$ and MAP. Possible explanation for the differences in the relationship between these studies was that time-trial performance was assessed in controlled conditions and not race conditions, limiting the influence of other paddlers on pacing strategies and overall performance. In any case, the present study demonstrated that maximal aerobic fitness indices are related to both 1000-m and 200-m Sprint kayak performance, with stronger relationships present for the longer distance event. Based on the present findings, coaches and sport scientists should prescribe training programs aimed at developing aerobic fitness and maybe muscle strength as the power produced at $\dot{V}O_{2}max$ level not only presented *very large* correlations with on-water performance in both distances, but was also powerful in predicting performance, as evidenced through the multiple regression results.

Similar to maximal aerobic fitness variables, strong relationships were present between submaximal measures of aerobic fitness such as LT_2 and gross efficiency, with both 1000-m and 200-m time trial performance. Indeed, these measures are typically more sensitive to changes in training, and may reflect how athletes are adapting to training. It has been suggested that submaximal fitness variables represent relative

energy demand to perform a certain task (Saunders, Pyne et al. 2004, Gomes, Mourão et al. 2012). For example, it has been shown that submaximal fitness variables can be manipulated by as little as weeks depending on the training program and initial fitness level of the people being tested (Billat, Mille-Hamard et al. 2002). Moreover, submaximal fitness indicators have previously shown *large-to-very large* correlations with the 1000-m and the 500-m on-water performance in Sprint Kayaking (Bishop 2000, van Someren and Howatson 2008). Our findings corroborate these findings for the 1000-m while being the first data to demonstrate a *very large* correlation with on-water 200-m performance. One reasonable explanation may be the training background and the age of the athletes from these different studies. It should be acknowledged that the athletes in the present study were well-trained Junior Sprint Kayak athletes, whose training may have been designed towards more generalized development, compared to that of older athletes, which likely focused on specific race demands. Collectively, this information supports the suggestion that junior Sprint Kayak paddlers should maintain a sustained training program over time in order to further develop physiological attributes that will be related to performance into the opens-higher class levels.

Importantly, this is the first study to assess the relationships between $\dot{V}O_{2kinetics}$, $M_{O2kinetics}$ and Sprint Kayak on-water performance over 200 and 1000-m. The athletes in the current study presented a $\dot{V}O_{2kinetics}$ phase II time constant (τ^p) that was 17% slower for the heavy domain when compared to 1500-m international runners (Ferri, Adamo et al. 2012). Moreover, Ingham et al. (2007) reported τ^p values for the moderate domain of 19.4 ± 5.6 and 13.9 ± 4.0 s and in the heavy domain they were 22.4 ± 3.7 and 18.7 ± 2.1 s for the club and elite rowers, respectively. Furthermore, trained cyclists ($\dot{V}O_2max$ 66.6 ± 2.5 mL·kg·min^{-1}) presented τ^p of 11.7 ± 2.5 and 15.2 ± 2.0 s while their untrained

counterparts ($\dot{V}O_2$max 42.9 ± 5.1 mL·kg·min^{-1}) showed τ^p of 21.5 ± 6.6 and 23.5 ± 2.8 s in the moderate and heavy domains, respectively (Koppo, Bouckaert et al. 2004). These results may reflect discrepancies between exercise mode and the magnitude of muscle mass recruited. For example, the upper body tends to be comprised of predominantly fast-twitch fibres compared to lower limbs (Mygind 1995), and past data has shown fast twitch fibres to be linked to slower phase II time constants (Pringle, Doust et al. 2003). Taken together, this information strengthens the evidence that the $\dot{V}O_{2kinetics}$ response is dependent on exercise mode and muscle fibre type.

The investigation of muscle oxygenation parameters can help to clarify the specific physiological demands of Sprint Kayak. The $MO_{2kinetics}$ represents how efficient an individual is at delivering and extracting oxygen within the working muscle at the onset of an exercise. The current $M_{O2kinetics}$ was similar to that reported by Grassi et al. (2003) for moderate domain exercise (8.5 ± 0.9 vs. 9.8 ± 3.7 s), but somewhat slower across the heavy domain (~7 s vs. 14.8 ± 6.6 s). These differences likely reflect differences in the training status of the present group of young kayakers, and also other factors such as muscle fibre composition and exercise mode.

The present study also profiled the changes in muscle oxygenation parameters (i.e. ΔHHb, ΔO$_2$Hb, ΔtHb and TSI), and examined the relationships of these with Sprint Kayak on-water performance. Our findings demonstrated that the muscles ability to extract oxygen (represented by the HHb and TSI responses) has a *large* relationship with Sprint Kayak performance. Our data (Table 2) differ from Dascombe et al. (2011) who reported higher values for ΔHHb (20.5 ± 1.1 μM) and lower for Δ O$_2$Hb (-16.7 ± 0.8 μM), ΔtHb (3.9 ± 0.3 μM), and TSI (37.3%) in a group of ~23 y old elite paddlers.

These differences are likely to reflect the application of the NIRS-device to different musculature use in Sprint Kayak (i.e. forearm, which requires isometric contraction to hold the paddle vs. lattisimus dorsi) and, that the subjects of Dascombe et al. were older, with similar $\dot{V}O_2max$ levels, lower relative power output at LT_2 level (64.6 vs. 76.4% for the current study) and higher (37%) MAP compared to the ones participating in this study.

The present results data suggest that the ability to rapidly extract oxygen for energy production has stronger relationships with 200-m performance, whereas the ability to reload haemoglobin with O_2 is more important for 1000-m performance. These results are not surprising due to the demands of each distance. Indeed, it has been estimated that in the 200-m only ~37% of energy is supplied through oxidative sources, whilst ~82% of energy is supplied through these mechanisms in the 1000-m event (Byrnes and Kearney 1997). The multiple regression analysis further support these observations by demonstrating that the predictive power of the absolute $\dot{V}O_{2max}$ and MAP was increased when ΔHHb was added to the model for 200-m performance. These findings further demonstrate the importance of anaerobic parameters for 200-m performance in Sprint Kayak as changes in HHb represents the amount of O_2 consumed during the effort. Indeed, the correlation analysis also demonstrated that the athletes that could extract greater O_2 from the muscle performed better in the 200-m time trial performance. Collectively, these results support other studies and show that the race distances of Sprint Kayak have distinctly different physiological requirements. This finding suggests that targeted training programs that focus on developing these characteristics may be required if athletes are to specialise in either the 200-m or 1000-m event. A limitation of this study was that controlled laboratory based time trials over the 200 and 1000-m was

not accomplished, which limits further insight on the basis of these findings and actual physiological response of well-trained Sprint Kayak athletes. Moreover, since breath-by-breath analysis of oxygen consumption is sensitive it can produce outlier values. To account for this, these outliers were carefully examined and cleaned and we also reported 90% confidence interval to increase the interpretation of the data. Future research may look at laboratory based demands or even on-water performance, using portable metabolic measurement devices.

Conclusion

In conclusion, the present findings showed that well-trained junior Sprint Kayak athletes possess lower absolute maximal aerobic fitness, despite similar relative aerobic fitness when compared to older counterparts. Furthermore, the current data supports the relationship between maximal aerobic capacities and performance, and the importance of the ΔHHb for performance during 200-m Sprint Kayak. Future studies should examine best methods for developing absolute aerobic fitness variables including maximal indicators such as $\dot{V}O_2max$, MAP and submaximal variables like the thresholds associated with the balance between lactate production and consumption (LT_2) as well as looking at the best training strategy to enhance these variables.

CHAPTER FIVE

A new field test for assessing and monitoring Sprint Kayak athletes

Abstract

This study aimed to develop a valid, reliable and sensitive field-based test (SK_{test}) for Sprint Kayak athletes. Test of ten 100-m efforts was designed to assess kayakers within the typical training environment. For validity, aerobic fitness, 200 and 1000-m kayak time-trial performances from 11 well-trained young kayak athletes were compared with SK_{test} results measured on-water and in the laboratory. SK_{test}'s test-retest reliability was determined on-water and in the laboratory within a 10-day period. On-water SK_{test} sensitivity was determined in a separate group of eight well-trained young kayak athletes during four weeks of training. All validity correlations were *very large-to-nearly perfect* (0.82-to-0.98) between SK_{test} and time-trials (on-water and laboratory). Similar correlations were found for the long and short SK_{test}. Test-retest reliability (% coefficient of variation(CV) was below 2.7% for the SK_{test} times, regardless of test duration, whilst for power output in the laboratory SK_{test} was 3.6 and 8.1%. Changes in SK_{test} performance during the 4-week training periods (signal) was greater than the noise (test-retest variation), showing good sensitivity. Collectively, these findings showed the SK_{test} (both laboratory-based and on-water) to be valid, reliable and sensitive performance test for monitoring performance changes sprint kayak athletes in training and the laboratory.

Key Words: Sprint Kayak, Validity, Reliability, Sensitivity, Field Testing

Introduction

The primary aim of physical training for many athletes is to elicit sport-specific adaptations that improve competitive performance. Recently, athlete monitoring systems have been developed to examine how athletes are responding to training and to inform the selection of future training (Lambert and Borresen 2006, Borrensen and Lambert 2009). This is typically achieved through systematic assessment of training load, fitness and fatigue responses or changes in physical performance (Banister 1991, Taha and Thomas 2003, Robson-Ansley, Gleeson et al. 2009). Whilst the methods used to quantify fitness, fatigue and training load tend to be generic and applicable to most sports (Lambert and Borresen 2006, Buchheit, Racinais et al. 2013), performance tests should be specific to the physiological and physical demands of the event (Smith and Hopkins 2012). These tests should also have low measurement error and to be sufficiently sensitive to detect small changes in performance (Currell and Jeukendrup 2008).

Unfortunately, coaches can be reticent to have their athlete's complete periodic laboratory tests as these can be expensive, have limited ecological validity and, decreased transfer of results from the results in the laboratory to the training environment. Moreover, these tests may require athletes to travel and interfere with training routines. To overcome these problems, several field-based tests have been developed as athlete monitoring tools for both individual (Lamberts, Swart et al. 2009) and team sport athletes (Rampinini, Bishop et al. 2007, Impellizzeri, Rampinini et al. 2008, Austin, Gabbett et al. 2012). For example, field tests to assess jump performance (Chamari, Chaouachi et al. 2008), repeated-sprint ability (Rampinini, Bishop et al. 2007, Impellizzeri, Rampinini et al. 2008, Austin, Gabbett et al. 2012), and cycling

endurance (Lamberts, Swart et al. 2009) have been applied to monitor how the athletes are responding to training. However, whilst there has been one report of an attempt to develop on-water step testing protocols (i.e. 6-7 x 1000-m efforts increasing until exhaustion) (Bullock, Woolford et al. 2013), there are no simple on-water performance tests for regular assessment of Sprint Kayak athletes.

Sprint Kayak is an Olympic sport that requires the athletes to compete over 200-m (~35 s), 500-m (~110 s) and 1000-m (~215 s) in individual, double and four-seat boats. During races, energy is supplied via the anaerobic and aerobic pathways (Garcia-Pallares, Sanchez-Medina et al. 2009), with aerobic metabolism contributing ~82 ± 5.0% for the 1000-m event, ~62 ± 3.5% for the 500-m and ~37 ± 4.4% for the 200-m event (Byrnes and Kearney 1997). Reports from laboratory studies showed that, despite similar blood lactate responses (~9.6 ±1.6 mmol·L^{-1}), the shorter duration events (30 s maximal efforts) have higher anaerobic oxygen deficit (~29% higher) compared to 120 s maximal efforts (Bishop 2000, van Someren and Palmer 2003). Accordingly, if a test for monitoring training adaptations for Sprint Kayak to have good validity, it should recruit these energy pathways. At present, however, there have been no reports of scientifically validated field tests for monitoring training adaptations in Sprint Kayak.

Ideally, a test for monitoring training adaptations should be able to assess changes in either metabolic or performance characteristics specific to the competitive demands of an event. Currently, there are no field tests that assess these qualities in Sprint Kayak athletes. Moreover, there are no known field tests that can be applied on the water to assess athletes in their typical training environment. With this in mind, the purpose of this study was to develop a valid, reliable and sensitive field-based test for Sprint Kayak

athletes that could be applied to athletes on a regular basis. The test was designed to provide the ability to test a group of athletes in a short period of time and that the testing could fit directly into a normal training program with minimal disturbance.

Methods

Experimental design

This study was completed in three parts. First, the athletes had their anthropometric, aerobic fitness (maximum oxygen uptake ($\dot{V}O_2$max), power output at $\dot{V}O_2$max intensity (MAP) and lactate profile assessed and completed a Sprint Kayak monitoring test both on the water (SK_{water}) and in a laboratory (SK_{ergo}). In addition, the athletes also performed 200 and 1000-m time trials in the laboratory set up and on-water. Second, SK_{test} procedures were repeated within a ten-day period in both on-water and in the laboratory under similar conditions to assess the test-retest reliability. Finally, the sensitivity of the test to detect training-induced changes was determined by comparing the test-retest reliability of the SK_{water} with the typical variation this test during a four-week training period.

Parts A and B

Participants

Eleven developing national level Sprint Kayak athletes (Age: 16.5 ± 1.4 y; body mass: 69.8 ± 10.4 kg; $\dot{V}O_{2max\ relative}$: 50.7 ± 9.4 mL·kg^{-1}·min^{-1}; $\dot{V}O_{2max\ absolute}$: 3.8 ± 1.0 L·min^{-1}; MAP: 161.0 ± 45.8 W) volunteered to participate in the validity and reliability assessment of the new Sprint Kayak monitoring test. As inclusion criteria, the athletes had to be following a training routine of at least 4–6 training days/week and to be

competing at the national level. After ethics approval from the University of Technology Sydney Ethics Committee, all procedures, risks and benefits were explained to the participants and also to their parents or legal responsible if they were younger than 18 years old, which signed a written consent.

Standard Procedures

For the SK_{ergo}, SK_{water} and time trials, the athletes completed a standard warm up protocol consisting of 5−10 minutes of passive stretching of the upper and lower body followed by 3-min paddling at ~85% of their maximum heart rate. Two 15 s accelerations interspersed with 45 s rest and two standing starts of 24 strokes with 45 s rest between each followed by 3 min of paddling at 85% of maximum heart rate were completed. At the end of the warm up, the athletes rested for 10 minutes before start testing.

A dynamically calibrated WEBA kayak ergometer (Weba Sport und Med. - Artikel GmbH, Vienna, Austria) was used for all laboratory tests. This ergometer's power output varies according to the tension applied in each stroke, mimicking the actual movement of the on-water stroke. The calibration was done against a calibration rig, which showed that the typical error of estimate for power output was 7.2%. All blood lactate measures were determined from a 5 μL sample taken from hyperaemic earlobe and then analysed by a calibrated portable lactate analyser device (Lactate PRO®, Arkray, Japan). The athletes had their heart rate monitor throughout all testing using a 12 lead ECG (Mortara X12+, Mortara, USA).

Performance and Physiological Assessments

Time Trials.

The athletes performed the standard warm up (described above), followed by the 200-m time trial. After 20 minutes of active easy paddling recovery (on water or on the kayak ergometer), the athletes performed the 1000-m time trial. For all trials, the athletes received consistent verbal encouragement. To ensure maximal effort for the on-water test, both on-water time trials were taken from the Queensland State Championship finals. During this championship, the athletes paddled in a tail wind and temperatures ranging from 22 to 30°.

Maximum oxygen uptake test.

An incremental step test was used to determine $\dot{V}O_{2max}$, MAP and lactate threshold (Bullock, Woolford et al. 2013). According to protocol, the first six four-minute stages were sub-maximal and performed at fixed intensities depending upon the gender, age and performance ability of the athlete. The maximal final four-minute stage was performed at perceived time trial intensity. For this study, only the first five submaximal intensities were completed before the final maximal step. Each work load was separated by 60 s rest. Blood lactate concentration, average power, average stroke rate and ratings of perceived of exertion were taken at the completion of each stage and at the completion of the test. The gas exchange was measured continuously via a Parvomedics System (ParvoMedics TrueOne Metabolic System, Software: OUSW 4.3.4 (updated 20111006). This system had been accredited by the National Sports Science Quality Assurance Scheme. For oxygen uptake, the last minute of each submaximal stage was used and for the maximal stage, the highest consecutive minute was used as the maximum value ($\dot{V}O_2max$) (Bullock, Woolford et al. 2013). The system was

calibrated before each test session using known O_2 and CO_2 concentrations, according to the manufacturer specifications. The flow meter was calibrated using a 3 L syringe. This system has been shown to be accurate and reliable to the measurements of ventilation, $\dot{V}O_2$ and $\dot{V}CO_2$ (Crouter, Antczak et al. 2006). The lactate threshold was determined by the D-max method described elsewhere (Zhou and Weston 1999).

Sprint Kayak tests.

The SK_{water} consisted of two sets of five efforts of 100-m each interspersed with 20 s recovery between each effort and a 1000-m active recovery paddling between sets. Each 100-m effort commenced with a rolling start and during the 20 s recovery the athletes were required to turn 180º and prepare for the next effort (Figure 5.1). To record each test, two video cameras (Sanyo Xacti, model VCP – HD2000, recording rate: TV-SHQ: 640 x 480 (30 fps/3Mbps)), mounted on tripods, were synchronized and placed at a standard marked position at the start and finish line to record accurate times. The horizontal axis of the screen was parallel to the start and finish buoys. The time was subsequently verified using specific video analysis software (Kinovea 0.8.15, www.kinovea.org). The error of this digitizing process was 0.1 %. Blood lactate measures were taken at rest, after the first set, after active recovery and at the end of the second set. During the first testing period the temperature was $24.8 \pm 1.6°C$ and wind speed 1.8 ± 1.2 m·s^{-1}. During the re-test the temperature was $25.3 \pm 1.2°C$ and a wind speed of 1.2 ± 0.9 m·s^{-1} for re-test., A calibrated portable weather meter (Kestrel$^{®}$ 4000, USA) recorded all the values for each athlete.

The SK_{ergo} consisted of two sets of five efforts of 100-m each interspersed with 20 s of rest between efforts and a 1000-m active recovery paddling between sets. Time and

power output for each effort was recorded by the kayak ergometer's computer system and blood lactate was sampled at rest, after the first set, after the active recovery and at the end of the second set. For part B of the study, the both on-water and laboratory SK_{test} procedures were repeated within a 10-day period. Total time, mean time and the best time were determined for the full protocol (10 efforts) and also for each set separately both in the laboratory and on-water. In addition, the SK_{test} in the laboratory allowed the calculation of mean power and peak power output for the 10 efforts and for each set separately.
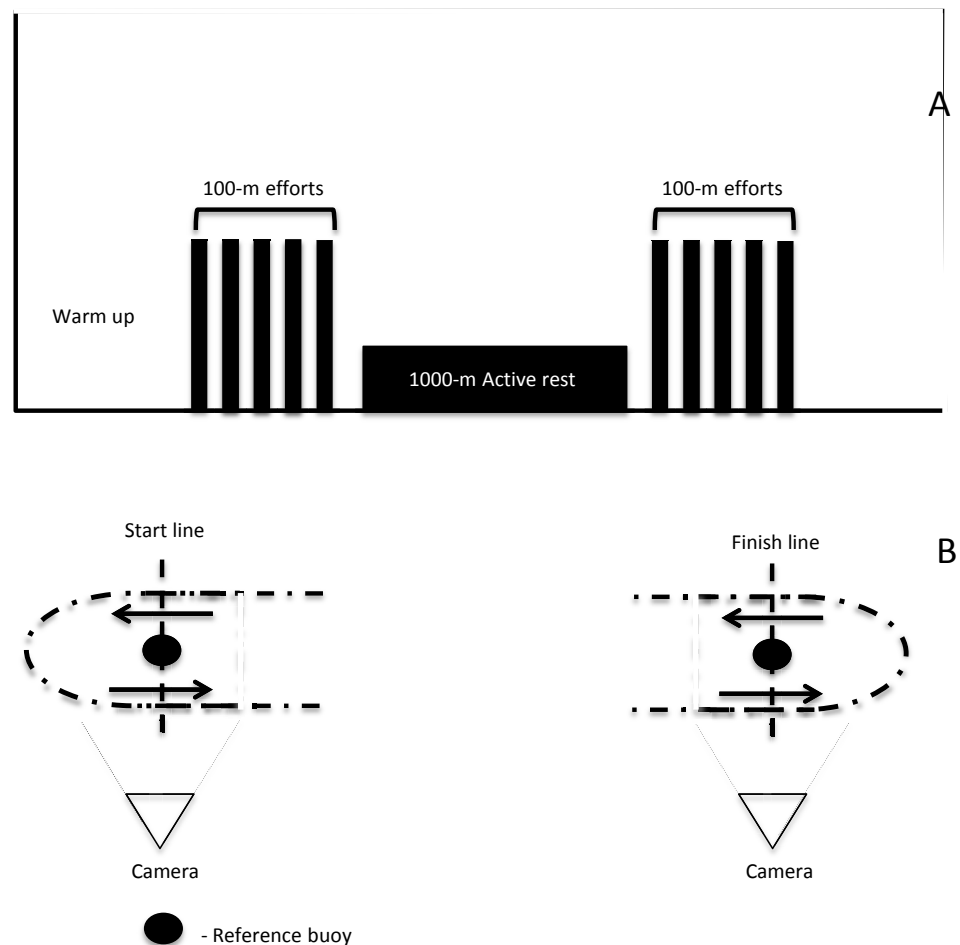
Figure 5.1: SK_{water}: A – Representation of the full protocol; B - SK_{water} set up.

Part C

Participants

The test sensitivity of the on-water SK_{test} was conducted with eight well-trained young Sprint Kayak athletes (Age: 17.0 ±1.2 y; body mass: 71.6 ±8.0 kg; $\dot{V}O_2max$: 56.7 ±8.2 mL·kg^{-1}·min^{-1}; Absolute $\dot{V}O_2max$: 4.5 ±0.6 L·min^{-1}; MAP: 167.0 ±31.6 W). Inclusion criteria were the same applied in parts A and B.

On-water SK_{test} sensitivity.

Following the results of parts A and B (see Results), a shorter version of the on-water SK_{test} (i.e. one set of five efforts) was applied during a four-week period, to determine the signal of the test. The typical variation of the shorter version was determined from the weekly on-water testing, performed as part of their training routine at the same time on a standard day (following the standard warm up).

Statistics

All data are presented as mean ±SD, unless stated otherwise. When a data set violated the assumption of normality, they were log transformed to reduce non-uniformity of error and these data were then back-transformed to provide the estimate means (Hopkins 2000, Hopkins 2000).

Pearson's product-moment correlations and typical error of the estimate, calculated as a coefficient of variation (%) were used to establish the validity of the SK_{test} performance test variables (i.e. for both SK_{water} and SK_{ergo}) using fitness (i.e. $\dot{V}O_{2max}$, MAP and lactate threshold) and both laboratory and on-water time trial performance as the criterion measures. All calculations were conducted using a Microsoft Excel

customised spreadsheet (downloaded from www.newstat.org). The magnitude of correlation (r) was interpreted as the following criteria: <0.1, *trivial*; 0.1–0.3, *small*; 0.3–0.5, *moderate*; 0.5–0.7, *large*; 0.7–0.9, *very large*; 0.9–1.0 *nearly perfect* (Hopkins 2000).

To assess the reliability of each of the Sprint Kayak tests outcome variables, the test-retest coefficient of variation (CV) with 90% confidence intervals (CI) and intraclass correlations (ICC) with 90% confidence intervals (CIs) were calculated according to Hopkins (2000).

To assess the sensitivity, the signal: noise ratio was determined using the results from part B of the study. To determine the smallest worthwhile change for each variable of the SK_{water} its CV was then multiplied by 0.2 (Hopkins 2000). All statistical analyses were performed using Microsoft Excel® (Microsoft, Redmond, USA).

Results

Table 5.1 shows the validity measures for both on-water and laboratory tests. The correlations were all *very large-to-nearly perfect* between on-water and laboratory variables (time and power output) and kayak ergometer time trials, with slightly larger correlations between on-water 1000-m performance and SK_{test} variables, compared to laboratory results. The typical error of estimate was similar for the on-water and laboratory SK_{test} (Table 5.1).

When the first and second set of the on-water SK_{test} protocol were analysed separately for the mean time, total time, and best time, the results showed similar correlations and typical error of estimate with the full protocol (table 5.1). *Large-to-very large* correlations were found between total, mean and the best time for both full (e.g. 10 efforts) and short (e.g. 5 efforts) protocols and $\dot{V}O_{2max}$ (r: -0.86 to -0.88, CV: 5.3 to 5.9%), MAP (r: -0.85 to -0.91, CV: 4.8 to 6.0%) and lactate threshold (r: -0.89 to -0.94, CV: 4.2 to 5.1%). Moreover, the correlation between the on-water and laboratory SK_{test} variables with the physiological measures (i.e. $\dot{V}O_{2max}$, lactate threshold, MAP and lactate concentrations) were *large-to-nearly perfect*. Finally, the typical error of estimate were <9% for all physiological variables and the on-water and laboratory SK_{test}. The typical error of estimate for the power output measures during the laboratory-based SK_{test} were from 9–16%.

Table 5.1. Validity measures of the sprint kayak performance test variables (mean ±SD).

Variable	Mean ±SD	Pearson's Correlation	Typical error of estimate CV(%)	Pearson's Correlation	Typical error of estimate CV(%)
Kayak Ergometer		*Ergometer 1000-m: 283.4 ± 24.9 (s)*		*Ergometer 200-m: 49.2 ± 6.4 (s)*	
Total Time (s)	253.2 ± 26.2	0.86 ± 0.16	4.7 ×/÷1.5	0.95 ± 0.06	4.2 ×/÷ 1.5
Total Time$_{set1}$ (s)	125.7 ± 14.0	0.86 ± 0.16	4.7 ×/÷ 1.5	0.96 ± 0.05	3.9 ×/÷ 1.5
Total Time$_{set2}$ (s)	127.4 ± 12.2	0.85 ± 0.16	4.8 ×/÷ 1.5	0.93 ± 0.08	5.0 ×/÷ 1.5
Mean Time(s)	25.3 ± 2.6	0.86 ± 0.16	4.7 ×/÷ 1.5	0.95 ± 0.06	4.2 ×/÷ 1.5
Mean Time$_{set1}$(s)	25.1 ± 2.8	0.86 ± 0.16	4.7 ×/÷ 1.5	0.96 ± 0.05	3.9 ×/÷ 1.5
Mean Time$_{set2}$ (s)	25.5 ± 2.4	0.85 ± 0.16	4.8 ×/÷ 1.5	0.93 ± 0.08	5.0 ×/÷ 1.5
Best Time (s)	23.6 ± 2.7	0.86 ± 0.16	4.8 ×/÷ 1.5	0.97 ± 0.04	3.4 ×/÷ 1.5
Best Time$_{set1}$(s)	23.8 ± 2.8	0.85 ± 0.17	4.9 ×/÷ 1.5	0.95 ± 0.06	4.3 ×/÷ 1.5
Best Time$_{set2}$ (s)	24.3 ± 2.3	0.88 ± 0.14	4.5 ×/÷ 1.5	0.96 ± 0.05	3.9 ×/÷ 1.5
Peak Power (W)	292.1 ± 86.8	-0.84 ± 0.18	5.1 ×/÷ 1.5	-0.94 ± 0.07	4.7 ×/÷ 1.5
Peak Power$_{set1}$ (W)	284.7 ± 89.1	-0.87 ± 0.15	4.6 ×/÷ 1.5	-0.96 ± 0.05	3.8 ×/÷ 1.5
Peak Power$_{set2}$ (W)	271.0 ± 72.3	-0.82 ± 0.19	5.3 ×/÷ 1.5	-0.89 ± 0.13	6.4 ×/÷ 1.5
Mean Power (W)	237.3 ± 67.2	-0.86 ± 0.16	4.8 ×/÷ .5	-0.95 ± 0.06	4.2 ×/÷ 1.5
Mean Power$_{set1}$ (W)	241.4 ± 72.5	-0.86 ± 0.16	4.8 ×/÷ 1.5	-0.97 ± 0.04	3.6 ×/÷ 1.5
Mean Power$_{set2}$ (W)	233.2 ± 62.7	-0.85 ± 0.17	4.9 ×/÷ 1.5	-0.93 ± 0.09	5.3 ×/÷ 1.5
On-Water		*On-Water 1000-m: 263.4 ± 26.0 (s)*		*On-Water 200-m: 48.8 ± 5.9 (s)*	
Total Time (s)	264.2 ± 28.5	0.96 ± 0.05	2.9 ×/÷ 1.5	0.98 ± 0.03	2.6 ×/÷ 1.5
Total Time$_{set1}$ (s)	131.9 ± 13.8	0.97 ± 0.04	2.6 ×/÷ 1.5	0.98 ± 0.03	2.7 ×/÷ 1.5
Total Time$_{set2}$ (s)	132.3 ± 14.9	0.95 ± 0.07	3.3 ×/÷ 1.5	0.98 ± 0.03	2.8 ×/÷ 1.5
Best Time (s)	24.8 ± 2.8	0.96 ± 0.05	2.9 ×/÷ 1.5	0.95 ± 0.06	3.9 ×/÷ 1.5
Best Time$_{set1}$(s)	24.9 ± 2.8	0.95 ± 0.07	3.3 ×/÷ 1.5	0.95 ± 0.07	4.1 ×/÷ 1.5
Best Time$_{set2}$ (s)	25.2 ± 2.9	0.97 ± 0.05	2.7 ×/÷ 1.5	0.96 ± 0.05	3.4 ×/÷ 1.5
Mean Time (s)	26.4 ± 2.9	0.96 ± 0.05	2.9 ×/÷ 1.5	0.98 ± 0.03	2.6 ×/÷ 1.5
Mean Time$_{set1}$(s)	26.4 ±2.8	0.97 ± 0.04	2.6 ×/÷ 1.5	0.98 ± 0.03	2.7 ×/÷ 1.5
Mean Time$_{set2}$ (s)	26.5 ± 3.0	0.95 ± 0.07	3.3 ×/÷ 1.5	0.98 ± 0.03	2.8 ×/÷ 1.5

CV – coefficient of variation

Table 5.2 presents results for reliability measures and the smallest change needed to yield likely worthwhile performance enhancement in the SK$_{test}$. The CV for performance times ranged between 1.5 and 2.7% for both laboratory and on-water SK$_{test}$, however, lower CVs were found for the laboratory SK$_{test}$. Moreover, the test-retest CV for mean and peak power output measures (3.6 and 8.1%, respectively) were

higher in the laboratory SK_{test} compared to the mean and the best time taken from the full protocol of the same test (1.5 and 2.3%, respectively). The reliability of variables collected from set 1 and set 2 were similar CV for both full protocol and each set separately for on-water and laboratory SK_{test}. The SWC ranged from 0.3 to 0.5 % for the on water measures and 0.3 to 1.7% for the kayak ergometers measures (Table 5.2).

The sensitivity of the on-water SK_{test} was determined using a different group of athletes with similar fitness and performance characteristics. The signal [CV - 2.2 (90% CI 1.7 to 3.0)] and ICC [0.95 (90% CI 0.90 to 0.98)] were the same for total time, mean time and the best time. The noise were smaller than the signal for the total time, mean time and the best time, respectively [CV - 1.7 (90% CI 1.3 to 2.7), 1.7 (90% CI 1.3 to 2.7) and 2.6 (90% CI 1.9 to 4.0). The intraclass correlations were 0.98 (90% CI 0.95 to 0.99), 0.98 (90% CI 0.95 to 0.99) and 0.96 (90% CI 0.90 to 0.99) for total time, mean time and the best time, respectively.

Table 5.2. Reliability measures for the on-water and ergometer sprint kayak test.

Performance Variable	Grand Mean	Test – Re-test CV (%)	CI (%)	SWC (%)	ICC	CI
On Water						
Total Time (s)	264.7	1.6	(1.2 to 2.5)	0.32	0.98	(0.96 to 0.99)
Best effort (s)	24.6	2.4	(1.8 to 3.8)	0.48	0.97	(0.91 to 0.99)
Mean Time (s)	26.5	1.6	(1.2 to 2.5)	0.32	0.98	(0.96 to 0.99)
Total Time$_{set\ 1}$ (s)	132.1	1.7	(1.3 to 2.7)	0.34	0.98	(0.95 to 0.99)
Best effort $_{set\ 1}$ (s)	24.8	2.6	(1. 9 to 4.0)	0.52	0.96	(0.90 to 0.99)
Mean Time$_{set\ 1}$ (s)	26.4	1.7	(1.3 to 2.7)	0.34	0.98	(0.95 to 0.99)
Total Time$_{set2}$ (s)	132.6	2	(1.5 to 3.1)	0.40	0.98	(0.94 to 0.99)
Best effort $_{set\ 2}$ (s)	25	2.7	(2.0 to 4.2)	0.54	0.96	(0.90 to 0.99)
Mean Time$_{set\ 2}$ (s)	26.5	2	(1.5 to 3.1)	0.40	0.98	(0.94 to 0.99)
Ergometer						
Total Time (s)	252.5	1.5	(1.1 to 2.3)	0.30	0.98	(0.96 to 0.99)
Best effort (s)	23.5	2.3	(1.7 to 2.5)	0.46	0.97	(0.92 to 0.99)
Mean Time (s)	25.3	1.5	(1.1 to 2.3)	0.30	0.98	(0.96 to 0.99)
Total Time$_{set\ 1}$ (s)	125.2	1.7	(1.2 to 2.6)	0.34	0.98	(0.95 to 0.99)
Best effort $_{set\ 1}$ (s)	23.7	2.6	(1.9 to 4.1)	0.52	0.96	(0.90 to 0.99)
Mean Time$_{set\ 1}$ (s)	25	1.7	(1.2 to 2.6)	0.34	0.98	(0.95 to 0.99)
Total Time$_{set2}$ (s)	127.3	1.7	(1.3 to 2.7)	0.34	0.97	(0.93 to 0.99)
Best effort $_{set\ 2}$ (s)	24.2	2.6	(1.9 to 4.1)	0.52	0.95	(0.87 to 0.98)
Mean Time$_{set\ 2}$ (s)	25.5	1.7	(1.3 to 2.7)	0.34	0.97	(0.93 to 0.99)
Mean Power (W)	238.5	3.6	(2.6 to 5.6)	0.72	0.99	(0.97 to 1.00)
Peak Power (W)	294.6	8.1	(6.0 to 12.8)	1.62	0.96	(0.89 to 0.99)
Mean Power$_{set\ 1}$ (W)	244.7	4.5	(3.3 to 7.0)	0.90	0.99	(0.96 to 0.99)
Peak Power$_{set\ 1}$ (W)	289.7	7.2	(5.4 to 11.5)	1.44	0.97	(0.91 to 0.99)
Mean Power$_{set\ 2}$ (W)	232.2	4	(3.0 to 6.2)	0.80	0.99	(0.96 to 0.99)
Peak Power$_{set\ 2}$ (W)	269.7	8.4	(6.2 to 13.3)	1.68	0.95	(0.85 to 0.98)

CV – coefficient of variation; CI – confidence interval; SWC – smallest worthwhile

change; ICC – intraclass correlation coefficient

Discussion

For a performance test to be efficacious, it must not only be valid and reliable, but also be sensitive so that results from testing can be transferred to actual performance estimates (Currell and Jeukendrup 2008). This study aimed to develop a valid, reliable and sensitive field-based performance test to monitor training adaptations in Sprint Kayak athletes, where a group of athletes could be tested and the actual testing set could be embedded within the training session. The main findings showed that both the on-water and laboratory SK_{test} are valid and reliable tests of Sprint Kayak performance for both the 200 and 1000-m events. Moreover, the on-water version of this test, also showed sufficient sensitivity for monitoring changes in performance in the training environment when conducted in consistent environmental conditions.

The repeated effort Sprint Kayak test in the present study was chosen as a practical field test because the ability to repeat high-intensity efforts has demonstrated strong relationships with both aerobic and anaerobic fitness and performance in a number or competitive events (Glaister 2005, Girard, Mendez-Villanueva et al. 2011). Moreover, the on-water SK_{test} test was designed so that it could be completed within a relatively confined space as the efforts were only 100-m in length. In addition, the test was of short duration, which allowed it to be used as a solid training session in itself or could be used as the first part of a training set. Most importantly, the test was time efficient as it was short and would allow several athletes to be tested at once. To assess the efficacy of the Sprint Kayak test, we initially determined the concurrent validity of both laboratory and on the water tests by examining the relationships of SK_{test} variables with Sprint Kayak performance over 200 and 1000-m.

The results showed *large-to-nearly* perfect validity correlations between laboratory SK$_{test}$ and competitive performance and typical error of measurement smaller than 5% for time and 6.5% for power. Similarly, the on-water SK$_{test}$ also showed a low typical error (i.e. <4.5%) and *large-to-nearly* perfect correlations with Sprint Kayak performance. The relationships between the SK$_{test}$ variables and time trial performance showed that ~85–90% of the variance in 200 and 1000-m on-water performances is explained by the on-water SK$_{test}$ performance time. These strong relationships provide good evidence supporting the concurrent validity of the on-water and laboratory SK$_{test}$ for monitoring Sprint Kayak performance. The correlations between the laboratory SK$_{test}$ and the kayak ergometer 1000-m time trial performance were *large-to-nearly perfect*, albeit slightly smaller than the 200-m performance (total time: 0.86 ±0.16 vs. 0.95 ±0.06 for the 1000-m and 200-m, respectively; Table 1). These slightly lower correlations with the laboratory test measures may be due to pacing influence and specific technical skill such as lack of boat run, required when paddling a kayak ergometer for longer duration efforts. Indeed, not only has pacing been shown to be an important aspect of 1000-m Sprint Kayak performance (Oliveira Borges, Bullock et al. 2013), but it has also been shown to increase in the noise in the data collected during exercise performance test (Jeukendrup and Currell 2005). Together, these findings demonstrate the importance of technical skills for Sprint Kayak performance and highlight the importance of technical skills and having athletes experience the 'feel' of the water during testing. Notwithstanding, the present results show that both the on-water and laboratory SK$_{test}$ are valid measures of Sprint Kayak performance. Importantly, all test-retest ICC fell above 0.95 (Table 5.2) with the signal determined in the reliability part of the study exceeding the noise, determined in a similar group of athletes under a real training routine period. A performance test with the signal

exceeding the noise ensures the test can detect changes a result of an intervention and an ICC above 0.81 can be used as a parameter for yes or no decisions (Hopkins 2000, Jeukendrup and Currell 2005)

Several studies have shown strong relationships between aerobic (i.e. $\dot{V}O_{2max}$, lactate threshold, MAP) characteristics and Sprint Kayak performance (Fry and Morton 1991, Bishop 2000, Bullock, Woolford et al. 2013). Similarly, others have shown a strong relationship between aerobic fitness measures and other repeated sprint tests (Bogdanis, Nevill et al. 1996, Gastin 2001, Glaister 2005, Girard, Mendez-Villanueva et al. 2011). In agreement, we also observed correlations between SK_{test}, TT performances and aerobic fitness measures (i.e. $\dot{V}O_{2max}$, lactate threshold, MAP). Indeed, we observed *very large-to-nearly perfect* correlations between $\dot{V}O_{2max}$, MAP and lactate threshold with on-water SK_{test} total mean and the best time performance. These findings demonstrate that on-water SK_{test} may be useful for estimating changes in aerobic fitness throughout the training season.

Separate analysis of the performance results from the shorter version of the SK_{test} using only one set of 5 x 100-m efforts showed a similar level of reliability compared to the longer 2 x 5 x 100-m efforts (Table 2). Overall, reliability of total time and mean time of the SK_{test} was smaller than the scores of the best time for both laboratory and on-water SK_{test}. Similarly, the mean power and peak power of laboratory SK_{test} had higher CVs when compared to time scores demonstrating greater between-subject variability in power measures. The CV data also allowed us to calculate a threshold for the smallest worthwhile change (SWC) in the score likely to be relevant (Hopkins 2000). Indeed, the combination of the SWC and CV provides a reference that helps to

detect significant changes in test scores (with more than 75% confidence) and also to determine sample size for single-group studies using a nomogram (Batterham and Atkinson 2005). For example, future pre-post design interventions in Sprint Kayak using the short version of the on-water SK_{test} should recruit approximately 20 paddlers to detect 1% change in the test scores (Batterham and Atkinson 2005). Taken collectively, this information suggests that these methods can be implemented on the practice, to enhance the interpretation of results of future studies.

Despite there being no accepted criterion against which sensitivity of a performance test can be established, the present results showed that the shorter on-water SK_{test} had a greater signal (i.e. weekly variation) than noise (typical variation) for both mean time, and total time taken to complete the test. These observations have important practical implications as to demonstrate that the test measures are sufficiently sensitive to detect changes, as a result of typical training intervention (Jeukendrup and Currell 2005, Impellizzeri, Rampinini et al. 2008). Collectively, these findings support the application of the shorter on-water SK_{test} in the field for monitoring training induced performance changes in Sprint Kayak athletes.

As with all field-based tests, there are limitations. A Sprint Kayak on-water testing will be affected by environmental conditions such as wind speed and direction, water and ambient temperature. In this study, the weather conditions were similar for all on-water sessions, which is likely to have contributed to the good level of reliability observed in these tests. However, from a practical point view, it is important to apply the SK_{test} under consistent weather conditions, to reduce the noise in the measurement.

Practical Applications

Monitoring athletes' responses to training during a training season is generally considered a fundamental aspect of controlling training so that performance is maximised at competitions (Impellizzeri, Rampinini et al. 2005, Borrensen and Lambert 2009). The main practical application of our results is that coaches and sport scientist can confidently use the SK_{test} as a valid monitoring tool over the training season. A 2% change in laboratory SK_{test} performance times can be considered meaningful, whilst a 3% change represents meaningful change for the best time performance in the on-water SK_{test}. Because the signal of the on-water SK_{test} is typically larger than the noise (signal to noise ratio > 1), coaches can use this test to assess the effectiveness of their training programs throughout the season by implementing it at the start of the on-water training sessions across a season under similar environmental and water conditions.

Conclusions

The SK_{test} is a valid, reliable and sensitive test that can be used by Sprint Kayak athletes both in the laboratory and on the water. The advantages of the modified version of the on-water SK_{test} are that it is short, so does not have a big impact on training disturbance, can be used as a good training session and most importantly, does not take the athlete out of their normal environment. On the basis of the present observations, we recommended using the on-water test as athletes can be tested in their own boats in more ecologically valid environment as long as the environment conditions are standardised.

CHAPTER SIX

Methods for quantifying training in Sprint Kayak

Abstract

The aims of this study were to determine the validity of the session-RPE method by comparing three different scales of perceived exertion to common measures of training load (TL). A secondary aim was to verify the relationship between training loads, fitness and performance in Sprint Kayak athletes. Following laboratory assessment of maximal oxygen uptake ($\dot{V}O_{2max}$) and lactate threshold, the athletes performed on water time trials over 200 and 1000-m. TL was quantified for external (distance and speed) and internal (session-RPE: 6-20, CR-10 and CR-100 scales, TRIMP and iTRIMP). Ten (six male, four female) well-trained junior Sprint Kayak athletes (age 17.1 ±1.2 years; $\dot{V}O_{2max}$ 4.2 ±0.7 L·min^{-1}) were monitored over a seven-week period. There were *large-to-very large* within-individual correlations between session the distance and the various HR and RPE-based methods for quantifying TL (0.58 to 0.91). Correlations between mean session speed and other HR and RPE-based methods for quantifying TL were *small-to-large* (0.12 to 0.50). The within-individual relationships between the various objective and subjective methods of internal TL were *large-to-very large* (0.62 to 0.94). *Moderate-to-large* inverse relationships were found between mean session-RPE TL and various aerobic fitness variables (-0.58 to -0.37). *Large-to-very large* relationships were found between mean session-RPE TL and on water performance (0.57 to 0.75). In conclusion, session-RPE is a valid method for monitoring TL for junior Sprint Kayak athletes, regardless of the RPE scale is used. The session-RPE TL relate to fitness and performance, supporting the use of session-RPE in Sprint Kayak training.

Key words: Sprint Kayak; Training; Perceived Exertion

Introduction

Monitoring training is now a fundamental part of scientific support for high performance athletes. It is important that methods for quantifying training are valid and can be practically applied in the training environment. Advances in microtechnology allow new devices, including global positioning systems (GPS), accelerometers, power meters and heart rate monitors to quantify different constructs of training load. For example, accelerometers and GPS measure the external load of training, whilst heart rates are used to quantify the internal response to that load. The drawbacks of using these devices are that they require technical expertise and can be relatively expensive. Furthermore, the risk of losing data is high (Foster, Florhaug et al. 2001, Impellizzeri, Rampini et al. 2004, Alexiou and Coutts 2008). Another important consideration when using these devices, is that each method assesses slightly different constructs of load (Scott, Black et al. 2013), which makes it difficult to compare loads determined by different methods.

The session rating of perceived exertion (session-RPE) method for quantifying training load, is a simple method that requires the athletes to rate the intensity of the entire training session using a rating of perceived exertion (RPE) scale. The training intensity measure is multiplied by the duration of the session creating a single measure of internal training load (Foster, Hector et al. 1995, Borg 1998). A large body of evidence shows that the session-RPE can measure the training dose for a variety of different training activities with favourable comparisons using heart rate measures of training load and session-RPE load reported in various team sports (Coutts, Reaburn et al. 2003, Impellizzeri, Rampini et al. 2004, Alexiou and Coutts 2008, Manzi, D'Ottavio et al. 2010, Scott, Black et al. 2013), resistance training (Day, McGuigan et al. 2004,

Sweet, Foster et al. 2004) endurance (Foster, Florhaug et al. 2001), taekwondo (Haddad, Chaouachi et al. 2011) and swimming (Wallace, Slattery et al. 2009). To date, no studies have examined the validity of session-RPE for Sprint Kayak training.

Sprint Kayak races at the Olympic Games and World Championships are contested over 200-m, 500 and 1000-m. To prepare for these competitions, Sprint kayak athletes undertake extensive training programs that contain endurance, resistance training, interval training, repetition and technique work both on and off the water (Garcia-Pallares, Sanchez-Medina et al. 2009). The diversity in modality of these training activities makes it difficult to quantify and compare the training dose applied to Sprint Kayak athletes accurately. Moreover, on-water training is completed in an open environment where wind, flowing water, ambient and water temperature and water depth vary on a daily basis which influence the training loads imposed on the athletes. Unfortunately, these influences may not be properly accounted for through traditional measures of external load of speed and distance. These environmental factors can significantly affect training responses and outcomes; therefore it is important that the method for quantifying training can account for these variables.

The perceived exertion scales are based on psychophysical principles and describe the integrated perceptual signals from a variety of internal and external sources (Borg 1998, Borg and Kaijser 2006). There are several different RPE scales, each of which has been used to quantify exercise intensity. The original and best known RPE scale is the 6–20 category scale developed based on the linear relationship between heart rate and oxygen consumption with power output (Borg 1970). The CR 10 scale is a category scale with ratio properties that allows the values of the scale to grow exponentially and

has been used as the basis for the modified scale applied in Foster's session-RPE method (Foster, Hector et al. 1995, Foster, Daines et al. 1996, Foster, Florhaug et al. 2001). More recently, the CR 100 scale was developed to provide a wider range (0-100) of values in an attempt to provide greater measurement precision of perceived exertion (Borg and Kaijser 2006). This scale provides a valid measure of training load for team sport (Scott, Black et al. 2013) but has yet to be tested over an extended range of sports.

According to the model presented by Impellizzeri, Rampinini and Marcora (Impellizzeri, Rampinini et al. 2005), the physiological and performance outcomes derived from a training program may be dependent upon both internal characteristics of the athletes; such as genetics and fitness characteristics and the external training load applied during training. Following this model, it is logical that each athlete's perception of training effort may be also dependent upon their individual fitness characteristics (Billat, Faina et al. 1996, Bishop 2000, Esteve-Lanao, Juan et al. 2005, Garcia-Pallares, Sanchez-Medina et al. 2009, Manzi, D'Ottavio et al. 2010, Milanez, Pedro et al. 2011). In support of this, Milanez *et al.* (Milanez, Pedro et al. 2011) reported nine futsal players with higher $\dot{V}O_{2max}$ experienced lower session-RPE training loads during a four-week period consisting of 39 training sessions. Similarly, Manzi *et al.* (2010), found that professional basketball players with better performance on the Yo-Yo intermittent recovery test, had lower session-RPE training loads over 12 weeks of training. Whilst these relationships have been reported in other sports, it is not known if better performing or physically superior Sprint Kayak athletes also perceived an external training load to be lower than their poorer performing or less fit counterparts. Further studies are required to elucidate the relationships between these fitness, performance and training characteristics in Sprint Kayak athletes.

Whilst the session-RPE method has been validated for use in many sports, no studies have examined the validity for quantifying training in Sprint Kayak. There have been few studies comparing the validity of different RPE scales for assessing training loads. Therefore, the main aim of this study was to determine the validity of the session-RPE method using the three different scales of perceived exertion compared to common measures of training load. A secondary aim was to verify the relationship between the training loads, fitness and performance in Sprint Kayak athletes. It was hypothesized that session rating of perceived exertion methods were valid in Sprint Kayak and the training loads are related to physiological variables and performance.

Methods

Study design

This study investigated the validity of methods for quantifying the training loads in Sprint Kayak using methods for measuring both internal and external training loads in individual boats (K1). The relationships between session-RPE training loads, fitness and performance outcomes were determined over a seven-week training period. During the first week of the study, the athletes completed an anthropometrical assessment and the Australian Institute of Sport Sprint Kayak National step test to determine maximal oxygen consumption ($\dot{V}O_{2max}$), maximal heart rate, maximal aerobic power and individual lactate profile (Bullock, Woolford et al. 2013). All athletes were monitored during each training session using a heart rate-enabled GPS device placed on the deck of their boats. The athletes also rated the intensity of each training session according to three different scales of perceived exertion (RPE 6-20, CR-10 and CR-100) (Borg and Borg 1994, Borg 1998, Borg and Borg 2001, Borg and Borg 2002, Borg and Kaijser 2006). All data collected during the first week of training was excluded from the final

analysis as it formed part of familiarisation and anchoring of the RPE scales. From week two to week seven, each athlete completed a variety of individual training sessions over a range of intensities and duration. Thirty minutes after the end of each training session the athletes had their perception of exercise intensity recorded and the results were compared to heart rate-based methods to quantify the internal training loads. In addition, the distance covered and session-mean speeds were used as measures of external training load. The heart rate-based methods (TRIMP and iTRIMP) were the criterion measures of internal training load (Banister and Calvert 1980, Manzi, Castagna et al. 2009, Manzi, Iellamo et al. 2009). The athletes performed on water time trials over the 200 and 1000-m distances at the end of the seven-week period.

Participants

Ten (six males, four females) well-trained junior Sprint Kayak athletes (age 17.1 ±1.2 y; height 179.9 ±7.8 cm; body mass 73.3 ±7.3 kg; Σ7 skinfolds 76.8 ±27.9 mm; $\dot{V}O_{2max}$ 4.2 ±0.7 L·min^{-1}) volunteered to participate in this study. Seven athletes had previous international racing experience for their age group and were national team representatives at the time of the study. Before the commencement of the study, all risks and benefits associated with this study were explained to the participants and written consent were obtained from the athletes and also from either their parents or legal guardian. Ethics clearance was granted by the University Human Research Ethics Committee.

The study commenced two weeks after the National Championships following two weeks of low intensity training. The athletes coach designed each training program, without intervention from the researchers. The training sessions included interval,

continuous and repetition training with session distances ranging from 0.5 to 10 km. All physical training sessions lasted between 30 to 70 minutes.

Testing procedures

Anthropometry

The participants had seven skinfold sites measured (triceps, subscapular, biceps, supraspinale, abdominal, thigh and calf) according to the international society for the advancement of kinanthropometry standards (ISAK) (Marfell-Jones, Stewart et al. 2006). A calibrated Harpenden skinfold calliper (Baty international, UK) with a 0.2 mm precision has been used for skinfold measuring. The body mass was determined by a Tanita digital scale (BC-590BT, Tanita, USA) and the stature by a wooden stadiometer with a 0.1 cm precision.

Incremental exercise test

At the commencement of the study each athlete completed the National Step Test for Sprint Kayak athletes on a dynamically calibrated kayak ergometer (WEBA kayak, WEBASport, Vienna, Austria) to determine the individual lactate profile, maximal heart rate and $\dot{V}O_{2max}$. The test consisted of 6 x 4 min of increasing intensity to maximal efforts (Bullock, Woolford et al. 2013). Upon arrival at the laboratory, the athletes were weighed (BC-590BT, Tanita, USA) and the kayak ergometer was adjusted to match the set-up of their personal boats. The tension of the ergometers' shock cords were checked before each test using a calibrated digital portable hook scale (Ep503, HC electronic scales, China). The workloads during the test were previously determined according to the athletes' gender and age group. Following each four-minute workload, a one-minute break was allowed to record RPE and to collect a capillarised blood sample (5 µl) taken

from a hyperaemic earlobe. Lactate levels were determined using a calibrated Lactate Scout (Lactate Scout, EKF Diagnostics, Germany) and the lactate threshold was determined by the D-max method (ICC 0.77-0.93, p<0.01) as described elsewhere (Zhou and Weston 1999). During the step test, gas exchange and oxygen uptake were assessed by a metabolic cart (MedGraphics Ultima CPX, Medical Graphics Corporation, USA). The $\dot{V}O_{2max}$ was considered the highest value attained over a full one-minute period during the last stage of the test. In addition, other criteria for attaining $\dot{V}O_{2max}$ were reaching age-predicted maximum heart rate and presenting a respiratory exchange ratio of 1.15 or greater (Maritz, Morrison et al. 1961, Issekutz, Birkhead et al. 1962).

Quantification of the training loads

In order to quantify the internal training loads, the session-RPE (Foster, Hector et al. 1995, Foster, Daines et al. 1996, Foster, Florhaug et al. 2001) and heart rate were recorded for every training session. The session-RPE method originally required the multiplication of the exercise intensity, described by a RPE scale, and the duration in minutes of the training session (Foster, Hector et al. 1995). As this is the first study to determine training loads in Sprint Kayak athletes, one category scale (RPE 6–20) and two category-ratio scales (CR-10 and CR-100) (Borg 1982, Borg 1998, Borg and Borg 2002) were used to determine the most appropriate scale of perceived exertion for Sprint Kayak. The training intensity measured by the session-RPE was recorded 30 minutes after the completion of the session to avoid the influence of the last minutes of the training session (Foster, Florhaug et al. 2001, Wallace, Slattery et al. 2009). In addition to the session-RPE method, the athletes had their heart rate, distance, speed and duration of the sessions recorded by a coded heart rate capable GPS device (Garmin

Forerunner 305, Garmin, USA) and information were downloaded after every training session to a computer by using a specific software (SportTracks 3 version 3.1.4415, SportTracks - ZoneFive). The athletes were instructed to check their GPSs devices regularly during the training sessions.

Two heart rate-based methods were used as the criterion measures for quantifying internal training load. The Banister's TRIMP (Banister and Calvert 1980) and the individual TRIMP (iTRIMP) (Manzi, Castagna et al. 2009, Manzi, Iellamo et al. 2009) were applied. The Banister's TRIMP determined the internal training load by the following formulas:

For males: TRaining IMPulse (training load) $= D \cdot (\Delta HRratio) \cdot 0.64 \cdot e^{1.92 \cdot (\Delta HRratio)}$ Eq. 1

For females: TRaining IMPulse (training load) $= D \cdot (\Delta HRratio) \cdot 0.86 \cdot e^{1.672 \cdot (\Delta HRratio)}$ Eq. 2

Where D is the duration of the session, the base e is the natural logarithm and $\Delta HRratio$ is represented by the formula:

$$\Delta HR_{ratio} = (HR_{session} - HR_{rest})/(HR_{max} - HR_{rest}) \qquad\qquad \text{Eq. 3}$$

Where the $HR_{session}$ is the mean heart rate from the training session; the HR_{rest} is the heart rate at resting state, and HR_{max} represents the maximal heart rate.

To avoid giving disparity importance to longer efforts with lower ΔHR_{ratio} compared to shorter duration and higher ΔHR_{ratio}, the ΔHR_{ratio} is weighted to reflect the intensity of the effort based on the exponential rise of the [BLa⁻] and the fractional elevation of the heart rate during exercise (Banister and Calvert 1980). However, it has been argued

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that the Banister's TRIMP lacks in individuality as it applies the same weighting specific factor for men population and a specific factor for the female population. The iTRIMP has been suggested to overcome this issue (Manzi, Castagna et al. 2009). Therefore, the iTRIMP method applies individual exponential response of the relationship between [BLa⁻] and the fractional rise of the heart rate during exercise (Manzi, Castagna et al. 2009)(Figure. 6.1).

Weighting factor $= 0.1073e^{4.0962 \cdot \Delta HRratio}$
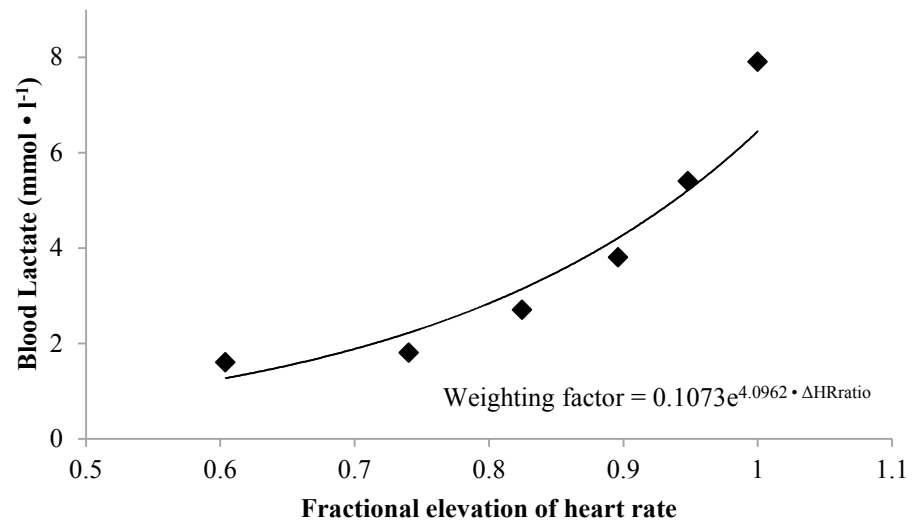
Figure 6.1: iTRIMP weighting factor from a representative sprint kayaker participating in the study. ΔHR_{ratio} equals (Session HR − Rest HR)/(Max HR − Rest HR).

Time trials

To assess Sprint Kayak performance the athletes performed maximal effort time trials (TT) over 200 and 1000-m. The athletes paddled their own standard Canoe Sprint K1 (520 cm length, 12 kg weight) on a protected part of the lake, away from wind and other craft. To avoid influences of pacing or competition with other kayakers, the athletes performed the TT individually. Time was recorded using two synchronized stopwatches (Interval® 2000 Split/Rate Watch, Nielsen-Kellerman, USA).

Statistical analyses

The data is presented as mean ± SD. Shapiro-Wilk's test was used to check the normality of data sample. The individual training loads, determined by the three RPE based methods applied in the study, had their relationships established by the Pearson product-moment correlation. The relationships between physiological variables, training loads and performance were also established by the Pearson product-moment correlation with 95% confidence intervals. In addition, the effect size of the correlations were determined according to Hopkins (2000) where the reference values of 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1 were described as *trivial, small, moderate, large, very large, nearly perfect* and *perfect*, respectively. Partial correlation was applied to establish the relationship between the internal training load and performance, controlling for aerobic fitness. Statistica 8 (Statsoft. Inc., Tulsa, USA) statistical package and Excel (Microsoft Office 2010, Microsoft Corporation, USA) were used for the statistical calculations. Level of significance was set at $p < 0.05$.

Results

Whilst the coach planned 30 training sessions, the ten athletes completed 22.5 ±2.5 training sessions. Complete data sets containing distance, duration, speed, HR and RPE measures were obtained from 20 sessions, due to technical issues with some of the GPS–heart rate enabled devices. These data sets with all variables required could be used in the within-subject analysis. The average internal training loads were 767 ±89, 2890 ±825 and 305 ±69, and 89 ±31 and 170 ±785 A.U. for the session RPE using the 6-20, the CR100 and the CR10, and TRIMP and iTRIMP methods, respectively whereas the external training load represented by the distance covered was on average 68.8±682.2 m and the average speed was 8.0±0.6 km $\square$h^{-1}. The mean within-individual correlations were *large-to-very large* between session distance and the various HR and RPE-based methods for quantifying training load (Table 6.1). The mean session speed presented *small-to-large* mean within-individual correlations with the RPE and HR-based method for quantifying training loads (Table 6.2). Similarly, the within-individual relationships between the various subjective and objective measures of internal training load were also *large-to-very large* (Table 6.3).

Table 6.1: Mean (±SD) of the within individual correlations between the training distance and the internal methods to quantify the training loads.

Athlete	Distance vs. Duration	Distance vs. 6-20 TL	Distance vs. CR100 TL	Distance vs. CR10 TL	Distance vs. TRIMP	Distance vs. iTRIMP
1	0.89	0.82	0.71	0.66	0.88	0.88
2	0.95	0.94	0.91	0.92	0.90	0.90
3	0.86	0.60	0.35	0.36	0.69	0.69
4	0.94	0.78	0.63	0.64	0.96	0.96
5	0.83	0.80	0.70	0.70	0.83	0.83
6	0.84	0.55	0.08	0.32	0.63	0.63
7	0.88	0.77	0.52	0.53	0.84	0.84
8	0.93	0.90	0.83	0.80	0.88	0.88
9	0.77	0.75	0.51	0.61	0.82	0.82
10	0.91	0.82	0.57	0.63	0.74	0.74
Mean ± SD	**0.88 ± 0.06**	**0.77 ± 0.12**	**0.58 ± 0.12**	**0.62 ± 0.18**	**0.82 ± 0.10**	**0.82 ± 0.10**

TL – Training loads; TRIMP – Training impulse; iTRIMP – Individual training impulse

Table 6.2: Mean (±SD) of the within individual correlations between the training mean speed and the internal methods to quantify the training loads.

Athlete	Speed vs. 6-20 TL	Speed vs. CR-100 TL	Speed vs. CR-10 TL	Speed vs. TRIMP	Speed vs. iTRIMP
1	0.41	0.30	0.25	0.63	0.63
2	0.39	0.37	0.43	0.41	0.41
3	-0.05	-0.17	-0.18	0.45	0.45
4	0.38	0.21	0.22	0.81	0.81
5	0.21	0.15	0.09	0.64	0.64
6	0.39	0.37	0.43	0.41	0.41
7	0.03	-0.12	-0.07	0.56	0.56
8	-0.31	-0.31	-0.37	0.02	0.02
9	0.40	0.31	0.32	0.72	0.72
10	0.11	0.09	0.12	0.30	0.30
Mean ±SD	**0.20±0.25**	**0.12±0.24**	**0.12±0.26**	**0.50±0.23**	**0.50±0.23**

TL – Training loads; TRIMP – Training impulse; iTRIMP – Individual training impulse

Table 6.4 shows *moderate-to-large* inverse relationships between mean session-RPE training load measures and various aerobic fitness variables including maximal aerobic power, absolute and relative maximal oxygen consumption and power at the lactate threshold. There were also *large-to-very large* correlations between mean session training loads during the training period with performance over 200 and 1000-m (Figure 6.2). In contrast, there were *small-to-moderate* correlations between the mean session speed and the various measures of aerobic fitness (Table 6.4).

Table 6.3: Mean (±SD) of the within individual correlations between the subjective (RPE) and the objective (HR-based) methods to quantify the internal training loads.

Athlete	6-20 TL vs. TRIMP	6-20 TL vs. iTRIMP	CR-100 TL vs. TRIMP	CR-100 TL vs. iTRIMP	CR-10 TL vs. TRIMP	CR-10 TL vs. iTRIMP
1	0.83	0.83	0.80	0.80	0.75	0.75
2	0.90	0.90	0.92	0.92	0.90	0.90
3	0.52	0.52	0.44	0.44	0.38	0.38
4	0.76	0.76	0.66	0.66	0.63	0.63
5	0.57	0.57	0.55	0.55	0.51	0.51
6	0.94	0.94	0.66	0.66	0.73	0.73
7	0.72	0.72	0.53	0.53	0.54	0.54
8	0.74	0.74	0.63	0.63	0.61	0.61
9	0.56	0.56	0.39	0.39	0.46	0.46
10	0.78	0.78	0.68	0.68	0.65	0.65
Mean ± SD	**0.73 ± 0.14**	**0.73 ± 0.14**	**0.63 ± 0.16**	**0.63 ± 0.16**	**0.62 ± 0.15**	**0.62 ± 0.15**

TL – Training loads; TRIMP – Training impulse; iTRIMP – Individual training impulse.

Table 6.4: Correlations between the mean session RPE training loads, time trial performances, mean session speed and aerobic fitness variables.

	MAP (W)	$\dot{V}O_2$ (L·min^{-1})	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	LT$_2$ (W)
Load RPE	-0.41	-0.58	-0.52	-0.52
Load CR100	-0.42	-0.52	-0.37	-0.56
Load CR10	-0.45	-0.58	-0.52	-0.54
Speed	0.44	0.46	0.35	0.24
TT$_{200\text{-m}}$	-0.76	-0.87	-0.67	-0.67
TT$_{1000\text{-m}}$	-0.87	-0.93	-0.77	-0.86

MAP – mean aerobic power, LT$_2$ – lactate threshold, TT – time trial

The partial correlation between the several session-RPE scores and TT performances were between *small-to-large*, when controlled for aerobic fitness (for the 200-m performance 0.6, 0.4 and 0.5 for the session-RPE 6-20, session-RPE CR100 and session-RPE CR10 respectively and for the 1000-m performance 0.3, 0.2 and 0.3 for the session-RPE 6-20, session-RPE CR100 and session-RPE CR10 respectively).
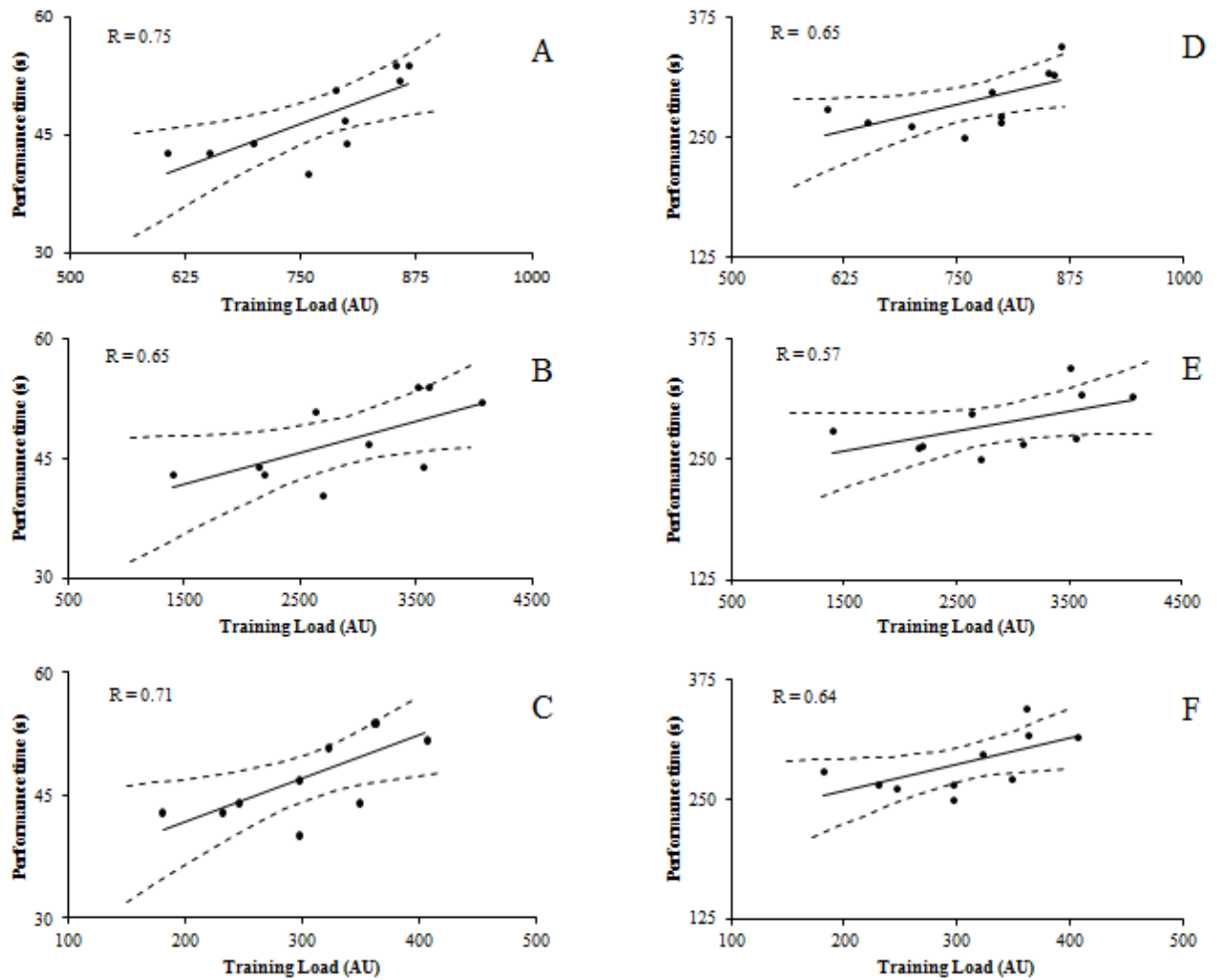
Figure 6.2: Correlations between performance in 200-m and the training loads quantified by the session rating of perceived exertion methods using the RPE 6-20, CR 100 and CR 10 scales (A, B and C respectively); Correlations between performance in 1000-m and the training loads quantified by the session rating of perceived exertion methods using the RPE 6-20, CR 100 and CR 10 scales (D, E and F respectively);

Finally, the correlations between the mean session speed and the subjective measures of session intensity were -0.10, -0.03 and -0.19 for the session RPE, session CR100 and session CR10, respectively. On the other hand, the mean session speed presented *moderate* (0.48) and *large* (0.57) correlations with mean maximal session HR and mean session HR, respectively.

Discussion

The aims of this study were to determine the validity of the session-RPE method using the three different scales of perceived exertion compared to common measures of training load; and to verify the relationship between the training loads, fitness and performance in Sprint Kayak athletes. The main findings showed *large-to-very large* validity coefficients for the three session-RPE methods or quantifying training load with various heart rate and GPS-derived training load methods. The 6-20 session-RPE method showed the strongest correlations of each of the RPE-based training load methods with both the criterion heart rate-based and GPS-derived training loads. We also found that aerobic fitness variables were inversely related to the mean training loads completed during the study and that *large-to-very large* correlations were observed between the mean training loads derived by the various session-RPE methods and Sprint Kayak race performance over 200 and 1000-m.

The present results are in line with previous research showing that the training loads derived from the category-ratio 10-point session-RPE scale is associated with heart rate-based and external training load measures. Our findings agree with others in swimming (Wallace, Slattery et al. 2009), cycling (Foster, Florhaug et al. 2001) and team sports (Foster, Florhaug et al. 2001, Impellizzeri, Rampini et al. 2004, Milanez, Pedro et al. 2011, Scott, Black et al. 2013). Wallace *et al*. (2009) found *large-to-very large* correlations between session-RPE and heart rate-based methods and *moderate-to-very large* correlations between session-RPE and distance travelled in swimming. Moreover, the session-RPE training load has shown *very large* correlations with both heart rate-based methods and external training loads (distance, running speed and player load) in Australian Football players (Scott, Black et al. 2013) . Collectively, our results support

that the session-RPE method can be broadly applied to different exercise modes with upper and lower body dominance.

A novel finding of the present study was that the session-RPE training loads derived from both the CR 100 and 6–20 RPE scales showed *large* validity coefficients when compared with various heart rate-based training load measures. Whilst previous studies have established the validity of the CR 100 session-RPE method in team sport, where the exercise content is of an intermittent nature (Scott, Black et al. 2013), the present study is the first to examine these relationships in sports that require more continuous work. Nonetheless, the present results were not unexpected, since the constructs underlying the CR 100 and the commonly used CR 10 scale are similar. The main difference between these scales is that the CR 100 scale presents a broader range of values for intensity, which allows athletes to choose an intensity rating, regardless of the location of the verbal anchors (Borg and Kaijser 2006). In contrast, the stronger correlations found between the 6–20 session-RPE and the criterion methods may be due to the relationship between the construct of this particular scale and the content of the training program (i.e. aerobic work and long interval efforts). The growth of the scores in the RPE 6–20 scale was designed to present linear increments between power output, oxygen consumption and heart rate (Borg 1998), which best describes aerobic and long interval work, such as the training performed in this study. These results corroborate other findings from our laboratory which suggests that the use of the 6–20 scale to be more accurate in continuous cycling than the CR10 or CR100 scales (unpublished data). Therefore, since the training program performed by the athletes had a large load of aerobic and long interval work, it is likely that these features of both training content and scale design influence the accuracy of the method.

Distance travelled during a training session is often quantified by coaches and used to describe the external training load (Foster, Florhaug et al. 2001, Borrensen and Lambert 2009, Garcia-Pallares, Sanchez-Medina et al. 2009). However, the distance travelled during training may be a poor estimate of the perceptual strain placed on athletes as it does not take into account the intensity of the training session (Wallace, Slattery et al. 2009) or environmental influences. Our results showed *large-to-very large* correlations (r = 0.58–0.82) between the mean training distance, all the subjective (session-RPE methods) and objective heart rate-derived methods for quantifying internal loads. In the present study, similar correlations were observed between training distance and the 6–20 session-RPE, TRIMP and iTRIMP training load measures, suggesting strong inter-relationships between these training constructs. We also used the mean session speed as a measure of external training load, and found lower correlations with HR and RPE-based measures of exercise intensity. The most plausible explanation for these poor relationships is the influence of the environmental conditions (i.e. wind direction and intensity, water depth, tides and flowing water) on the psychological and physiological response during on water kayak training (Gray, Matheson et al. 1995, Jackson 1995, Bullock, Woolford et al. 2013). These data suggest that boat speed may not be a suitable measure for assessing exercise intensity placed on individuals in sprint kayak – especially in changing weather conditions. Taken together with other studies showing similar correlations between the various session-RPE methods and criterion training dose measures (Coutts, Reaburn et al. 2003, Impellizzeri, Rampini et al. 2004, Borrensen and Lambert 2009, Scott, Black et al. 2013), this information suggests that the session-RPE methods are valid and can be used in a wide range of exercise modalities.

Another important observation from the present study was the *moderate-to-large* inverse relationship between aerobic fitness measures and the average training loads during the study (Figure 6.2). Aerobic fitness is well known to be a good indicator of a global training state in athletes (Tesch and Karlsson 1984, Faina, Billat et al. 1997, Garcia-Pallares, Sanchez-Medina et al. 2009), and it is logical that those with higher aerobic fitness would perceive similar external training loads to be less stressful than their less fit counterparts. The present observations agree with others who reported relationships between aerobic fitness and CR10-derived session-RPE training loads in well trained futsal and basketball players (Manzi, D'Ottavio et al. 2010, Milanez, Pedro et al. 2011). Our current findings extend previous research, and show that regardless of the construct of the RPE scale used to quantify the training loads; perceived training intensity is associated with the aerobic fitness status of athletes. Our findings are strengthened when the relationship between performance and training loads are taken into account. The *large-to-very large* correlations suggest that the faster athletes had lower perceived effort from similar training. Moreover, the partial correlations showed that even when controlling for aerobic fitness, the faster athletes still had *small–to-large* relationships with perception of the training. However, the lower partial correlation coefficients involving the 1000-m performance highlight the importance of aerobic fitness for performance in this particular distance. Other mechanisms including neuromuscular and the technical skills component may explain the rest of the variation. Further research is required to test this hypothesis.

The RPE is a psychophysical construct, which takes into account not only the actual effort but also the athletes' state at the moment of rating. The three scales used in this study were designed using different constructs, and differed in how the verbal anchors

were positioned. For example, the 6-20 RPE scale provides data that grow linearly with the intensity of the stimulus and heart rate and oxygen consumption. In contrast, both the CR 10 and CR 100 offer results where data increase exponentially which is in line with the response of lactate during incremental exercise (Borg 1998, Borg and Kaijser 2006). Studies conducted in the field that have quantified the training loads are mostly from team sports, combat sports and swimming (Foster, Florhaug et al. 2001, Coutts, Reaburn et al. 2003, Impellizzeri, Rampini et al. 2004, Wallace, Slattery et al. 2009, Haddad, Chaouachi et al. 2011, Eston 2012). The results of the present study support the choice of different scales according to the demands of the sport. Indeed, the present findings show that if a sport requires more aerobic/long interval-based training the 6–20 RPE scale may provide a more valid representation training loads, while other studies have shown sports with mixed or anaerobic work prevalence may require the use of the ratio scales (CR 10 or CR 100). In conclusion, the session-RPE method is a valid method to quantify the K1 training loads in Sprint Kayak athletes, regardless if the 6–20, CR10 or CR100 scale is used. The session-RPE training loads related to fitness and performance provide further support for its use in Sprint Kayak for monitoring training. However, our study provides evidence that the optimal RPE scale to quantify the training loads may be dependent on the nature of the exercise being undertaken. It seems that the 6-20 RPE may be the best suited for monitoring K1 training in Sprint Kayak athletes. Moreover, we showed that the perception of the training loads plays an important role to performance in Sprint Kayak although the importance of the aerobic fitness presented to be greater for the 1000-m performance.

A limitation of this study was that a greater sample of paddlers of various ages and fitness level would increase the generalization of our findings. However, since the data

was collected in a real training environment in highly trained junior kayakers, these data have strong ecological applicability. Further studies may be required to assess the efficacy of using session-RPE to assess TL in a more diverse range of kayak athletes.

Practical Applications

The practical implications from the present study are that athletes, coaches and sport scientists can be confident in quantifying training loads using the session-RPE method, regardless of the RPE scales used. However, coaches should be aware that aerobic fitness and Sprint Kayak performance are related to athletes perception of training intensity during training, suggesting that better performing and fitter athletes may have perceived the same training session to be easier than their poorer performing or less fit counterparts. Coaches could use this information as a simple monitoring tool to assess how athletes within a training squad are adapting to training. On this basis, we recommend that the relationships between the external load of distance and speed and the session-RPE load be examined as a practical monitoring tool for Sprint Kayak athletes. Specifically, if an athlete's session-RPE/external load ratio was reduced as a consequence of training, then this would suggest that the athlete was coping or adapting with training. Alternatively, if the athletes RPE increased in response to a standard external load, then this may be interpreted as an athlete losing fitness or having elevated fatigue levels. However, further research is required to investigate the relationship between team boat session-RPE, distance, fitness and performance.

CHAPTER SEVEN

Comparison of the acute physiological responses of repeated sprint and high-intensity aerobic training sessions in Junior Sprint Kayak athletes.

Abstract

The aims of this study were to describe the acute physiological responses to common repeated sprint (RS) and high intensity aerobic (HIA) training sessions in well-trained junior Sprint Kayak athletes. The athletes (n= 11, nine males) performed both repeat sprint (RS) and high-intensity aerobic interval (HIA) training sessions on a kayak ergometer in the laboratory. The RS sessions consisted of 2 sets of six 10 s efforts with 10 s rest between efforts and eight minutes between sets and six 30 s efforts with 3 min 30 s rest between efforts. HIA was 2 sets of three 3-min efforts with 3-min rest between efforts and five min between sets and 3 efforts of 2 km each with 15-min to paddle and rest. All sessions were monitored for training loads, power output and physiological (heart rate [HR], blood lactate [BLa⁻], $\dot{V}O_2$, and tissue saturation index [TSI]) and perceptual (Rating of Perceived Exertion [RPE]) variables. Mean power output was similar for all sessions; there were differences in the external loads placed on the athletes in the RS and HIA sessions, with RS sessions requiring significantly shorter distances to be covered when compared to the HIA sessions. The physiological responses and external loads in the HIA were considerably different from RS sessions, with the exception of TSI which was similar for all training sessions. Mixed modelling showed significant random variation for the time spent in different training zones for mean power output and $\dot{V}O_2$. The present study highlighted distinct differences in the HR, $\dot{V}O_2$, [BLa⁻], and perceptual responses to common RS and HIA training, with the shorter RS sessions placing a greater stimulus on glycolytic pathways, and the longer HIA sessions requiring greater aerobic demands. Importantly, *large* inter-individual physiological responses were observed across each of the different training sessions.

Key words: Training, Interval Training, Training loads.

Introduction

Training-induced adaptations in athletes are largely determined by both the external loads prescribed to the athlete, such as exercise mode, intensity, volume, rest periods or density and the athlete's internal (physiological) responses to these loads. Well-designed and implemented training programs aim to generate adaptations specific to the physical, technical and tactical requirements of competition through the manipulation of several training variables like volume, intensity, type and frequency (Smith 2003, Issurin 2008). For example, Junior Sprint Kayak, athletes who have not yet specialised in a specific race distance often compete across distances of 200-m, 500m and1000-m which require diverse yet specific physiological requirements (Byrnes and Kearney 1997, van Someren and Howatson 2008, ICF 2013). Well-trained Sprint Kayak athletes complete maximal 200-m time trials ~36.9–43.1 s, maintaining a mean power output of ~546 W, with an accumulated oxygen deficit of ~48.8 ml O_2 $Eq^.kg^{-1}$. Conversely, 1000-m time trials last ~216–248 s with a mean power and accumulated oxygen deficit of ~226 ± 30 W and an ~31.0 ml O_2 $Eq^.kg^{-1}$, respectively (van Someren, Phillips et al. 2000, van Someren and Palmer 2003, Bullock, Woolford et al. 2013). These findings suggest elite Sprint Kayak athletes require specialised training programs, which vary in effort duration and effort to help optimally prepare them for specific race distances. However, at present there is a poor understanding of the appropriate training sessions that meet the demands of each of Sprint Kayak racing.

The training program of Sprint Kayak athletes integrate both repeated-sprint (RS) and high-intensity aerobic (HIA) training sessions as fundamental aspects as they target important components of sprint kayak competition. Indeed, anecdotal evidence suggests that coaches use longer HIA to develop speed endurance for the 1000-m event, while

RS sessions are often used to improve maximal boat speed. Additionally, it has been demonstrated that physiological characteristics such as higher maximal aerobic power and $\dot{V}O_2$max are better related to 1000-m time-trial performance (Oliveira Borges, Dascombe et al. 2013), whilst anaerobic characteristics and muscle oxygenation have stronger relationships with 200-m time trial performance (van Someren and Palmer 2003, Oliveira Borges, Dascombe et al. 2013). Additionally, it is well established that HIA increases aerobic maximal power, $\dot{V}O_2$max, lactate threshold and endurance capacity (Buchheit and Laursen 2013). Furthermore, others have shown that both neuromuscular (e.g. neural drive, motor unit activation) and metabolic factors (e.g. oxidative capacity, PCr recovery, H^+ buffering) can be enhanced through RS training (Bishop, Girard et al. 2011, Buchheit and Laursen 2013). Logically, it would seem that athletes training for 200-m would benefit more from greater RS training, whilst 1000-m specialists might benefit more from longer HIA training. However, despite the popular use of both these training strategies in the field, no studies have examined the acute physiological responses of differing training methods in well-trained junior Sprint Kayak athletes.

Many studies have described the efficacy of different exercise training methods on the physiological and performance characteristics within various athletic populations, with the data collectively demonstrating that the exercise and training responses/adaptations are specific to the exercise and/or training content (for reviews see (Buchheit and Laursen 2013, Buchheit and Laursen 2013). However, no previous studies have investigated the acute physiological responses to RS or HIA training sessions in well-trained junior Sprint Kayak athletes. Such data may help to inform Sprint Kayak coaches when designing appropriate targeted training sessions that meet

the specific physical and physiological aspects for individual athletes or events. Therefore, the aims of this study were to describe the acute physiological responses to common RS and HIA training sessions in well-trained junior Sprint Kayak athletes. It was hypothesized that RS training bouts would provide a greater anaerobic training stimulus, whilst the HIA training bouts would provide a greater aerobic training stimulus. We also hypothesized that there would be large intra-individual variability in the responses across training sessions. Finally, it was also expected that there would be large inter-individual responses to each of the training bouts.

Methods

Design

This study investigated the acute physiological and perceptual responses to controlled high-intensity training sessions that are commonly used in well-trained junior Sprint Kayak athletes. All testing sessions were carried out within a ten-day period in the same human performance laboratory. First, each athlete completed an incremental Sprint Kayak step test (Bullock, Woolford et al. 2013) to determine individual physiological characteristics including $\dot{V}O_2$max, maximal aerobic power and lactate threshold before undertaking two shorter and two longer repeated-sprint and high-intensity aerobic training sessions on separate occasions. The RS sessions consisted of either a short 10 s or long 30 s effort duration and the HIA sessions consisted of either a shorter 3 min or a longer 2 km efforts. The acute physiological (heart rate [HR], blood lactate [BLa⁻], $\dot{V}O_2$, and tissue saturation index [TSI]) and perceptual (Rating of Perceived Exertion [RPE]) responses were assessed across each training bout. The training sessions were performed in a random-counterbalanced order at the same time of the day, with 48 hours separating each visit. Throughout the study, the athletes

performed an easy aerobic training session between each test sessions to provide active recovery and minimise excessive fatigue.

Participants

Eleven well-trained (nine males, two females) junior Sprint Kayak athletes (age 17.5 ±1.3 y; body mass 77.4 ±6.8 kg; $\dot{V}O_2max$ 4.4 ±0.5 L·min^{-1}; MAP 178 ±23 W; Peak [BLa$^-$] 10.7 ±1.6 mmol·L^{-1} and HR 195 ±11 bpm) volunteered to take part in this study. Prior to participation, all risks and benefits associated with this study were explained to the participants, and written consent was obtained from the athletes and/or their legal guardian. Ethics clearance was granted by the University's Human Research Ethics Committee (UTS HREC REF NO. 2012000241).

Procedures

Following two familiarisation sessions, the Sprint Kayak athletes underwent assessment for aerobic power (MAP), lactate thresholds, maximal heart rate (HR$_{max}$) and maximum oxygen uptake ($\dot{V}O_2max$) as described elsewhere (Bullock, Woolford et al. 2013). The oxygen uptake was determined as the highest minute average during submaximal stages, whereas $\dot{V}O_{2max}$ was the highest consecutive minute average during the final maximal stage. The D-max method was used to calculate both aerobic (LT$_1$) and lactate (LT$_2$) thresholds according to the methods of (Zhou and Weston 1999). These thresholds were subsequently used as anchor points for assessing the intensity zones of the training sessions. The MAP was taken as the average power output recorded across the final maximal stage of the incremental step test.

Heart rate was monitored using a telemetric system, (Polar RS800, Polar, Finland) and HR$_{max}$ was recorded from final maximal stage across the step test. Blood lactate

was measured from samples taken from a hyperaemic earlobe at the end interval between steps in the incremental step test using a portable lactate analyser (Lactate Scout, EKF Diagnostics, Germany). The RPE was recorded at the same time points where lactate was measured in both incremental step test and training sessions and 30-min after the completion of the training session where the session-RPE (s-RPE) was also recorded using Borg's RPE 6–20 scale (Foster, Daines et al. 1996, Borg 1998, Oliveira Borges, Bullock et al. 2013).

The power output during all testing sessions was recorded by the WEBA kayak system (Weba Sport und Med. - Artikel GmbH, Vienna, Austria) and analysed with proprietary software (WEBA Expert 2.43.31.0, Weba Sport und Med. - Artikel GmbH, Vienna, Austria). The previously determined typical error of estimate for power output for this ergometer against a calibration rig was 7.2%. During the testing session, athletes were able to monitor their power output, force, distance travelled in real-time through the power meter display of the kayak ergometer. This range of variables were recorded at 10 Hz and used in subsequent analysis.

Warm Up

Before each testing session, all athletes performed a standard warm up that consisted of 3-min paddling at ~85% HR_{max} followed by two 15 s accelerations interspersed with 45 s rest and two standing starts of 24 strokes with 45 s rest between each ending with 3 min of paddling at 85% HR_{max}. Similarly, following each session the athletes also completed a standard cool down consisting of 5 min of paddling at 75% HR_{max}.

The main body of each of sprint kayak training sessions consisted of either RS or HIA training, with participants complete both a short and long session of each method.

The shorter RS session (RS1), consisted of two sets of six maximal 10 s efforts with 10 s rest between each effort with an 8 min active recovery rest between each set. The longer RS (RS2) session consisted of 6 x 30 s efforts interspersed with 210 s of active rest between each effort. The shorter HIA session (HIA1) consisted of 2 sets of 3 x 3-min efforts with 3-min active recovery between each effort and a 5-min active recovery between sets. The longer HIA session (HIA2) consisted of 3 x 2 km efforts on a 15-min cycle. The training intensities were planned in accordance with the national guidelines for Sprint Kayak training (Bullock, Woolford et al. 2013). While both the RS1 and RS2 sessions were performed maximally, the HIA1 and HIA2 sessions were performed ~85-90 and 75-85 % $\dot{V}O_2$, respectively. Heart rate and RPE were used as a reference for intensity during the aerobic sessions.

Physiological measurements

During each test session, the paddlers' $\dot{V}O_2$, TSI, HR and RPE were assessed. Continuous breath-by-breath $\dot{V}O_2$ was measured using a metabolic cart (MedGraphics Ultima CPX, Medical Graphics Corporation, USA). Prior to each testing and training session, the metabolic cart was calibrated using known O_2 and CO_2 concentration and the pneumotach was calibrated using a 3-litre syringe according to manufacturing directions. Muscle tissue saturation index (TSI) was continuously measured throughout each testing session via a near infrared spectroscopy (NIRS) device (Portamon, Artinis Medical Systems, Zetten, the Netherlands) and expressed as a percentage. Data was recorded using a 10 Hz sampling rate and averaged to 1 Hz using a tailored application (LabView, National Instruments Corporation, TX, USA) for further analysis. The TSI was calculated as the difference between the deoxyhaemoglobin ([HHb]) and oxyhaemoglobin ([O_2Hb]) and represents the average saturation of the targeted muscle. The muscle of choice was the *latissimus dorsi* as it is considered responsible for most

the propulsive force in the kayak stroke (Fleming, Donne et al. 2012). The NIRS device was placed at the midpoint between the inferior border of the scapula and posterior axillar fold and orientated parallel to the muscle fibre orientation.

Each athletes HR was recorded every 5 s using a telemetric system (Polar RS800, Polar, Finland) during all testing sessions and expressed as a percentage of maximal HR. Blood lactate was sampled from a hyperaemic earlobe immediately before and after each effort for the RS2, HIA1 and HIA2 sessions and immediately before and after each set of the RS1 using a portable lactate analyser (Lactate Scout, EKF Diagnostics, Germany). The raw values recorded were averaged for analysis. The RPE was recorded at the same time points as lactate measures. Thirty minutes following the completion of the training session, the session-RPE (s-RPE) was also acquired (Foster, Daines et al. 1996, Oliveira Borges, Bullock et al. 2013).

The physiological responses during each session were expressed relative to each paddler's individual LT with the power output at LT_1 and LT_2 levels taken as anchor points. The responses below LT_1, LT_1-LT_2 and $>LT_2$ were considered as being low, moderate and high-intensity, respectively. The percentage contribution of both power output and $\dot{V}O_2$ within each of these zones for each training session was computed using a tailored code in R (Team 2013).

The training sessions were analysed from three different perspectives. First, the whole training session was evaluated as a whole (i.e. inclusive of warm up, body and cool down) to provide a general assessment of the overall training sessions. Second, the content of the main body of each training set was assessed separately. Finally, the contribution of $\dot{V}O_2$ and power output in the individualized low, moderate and high-

intensity zones for both the overall and main body of each training session were also examined.

Statistical analyses

Data are presented as mean ±SD of the raw scores. After testing for normality using Shapiro-Wilk's test, repeated measures ANOVA was performed to identify differences between the physiological, perceptual, power output and distance travelled during both the entire session (warm up, main section and cool down combined), as well as the main body of each session, which were considered separately. A multiple pairwise comparison using Bonferroni correction was applied as a *post hoc* method. Sphericity was tested using the Mauchly's test and Greenhouse-Geisser correction was applied where appropriate. A linear mixed-effects model using the "multilevel" package in R (Bliese 2013, Team 2013) was used to determine the individual responses to internal ($\dot{V}O_2$) and external (power output) load measures to each training session. Finally, these responses were transformed into *z*-scores in order to allow for comparison of individual responses between internal and external responses of the training sessions. The *t* statistics scores from the linear mixed modelling were then converted into r-values and considered as the effect size (ES) (Cooper and Hedges 1994). The r-values were then interpreted as ES using thresholds of 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1 as *trivial, small, moderate, large, very large, nearly perfect* and *perfect*, respectively (Hopkins 2002). All statistical procedures were performed using the R software (Team 2013) and the multilevel (Bliese 2013), lattice (Sarkar 2008) and ggplot2 (Wickham 2009) packages for R. Level of significance adopted was p<0.05.

Results

Table 7.1 shows the various responses recorded across each entire training session. The physiological responses were significantly higher in the shorter RS session compared with the longer HIA session. Whilst mean power output was similar for all sessions, there were differences in the external loads placed on the athletes in the RS and HIA sessions, with RS sessions requiring significantly shorter distances to be covered when compared to the HIA sessions (Table 7.1). Moreover, Table 7.2 presents the physiological responses for the main body of the each training session (i.e. without warm up and cool down) was isolated. Collectively, the physiological responses and external loads in the HIA were considerably different from RS sessions, with the exception of TSI which was similar for all training sessions.

Table 7.1: Mean (± SD) internal responses (physiological and perceptual) and external loads for each Sprint Kayak training session (i.e. including, warm up, main section and cool down).

	RS1	RS2	HIA1	HIA2
Duration (min:s)	45:00	50:00	55:00	60:00
Internal response				
Mean HR (%)	70.5 ± 7.0	72.6 ± 6.1	73.5 ± 5.6	75.8 ± 7.4[a]
$\dot{V}O_2$ (L)	72.3 ± 19.1	78.8 ± 11.4	93 ± 12.0[b]	98.3 ± 11.7[ab.]
Blood lactate (mmol·L^{-1})	8.5 ± 2.2	9.5 ± 2.3	5.4 ± 1.8[ab]	5.1 ± 1.9[ab]
TSI$_{average}$ (%)	67 ± 4.2	66.3 ± 4.1	64.9 ± 4.5	63.4 ± 6.0[a]
s-RPE (AU)	16.2 ± 1.7[b]	18.3 ± 0.9	15.1 ± 0.9[b]	14.3 ± 1.2[ab]
External load				
Mean Power (W)	116 ± 15	136 ± 35	138 ± 19	131 ± 18
Distance (km)	6.7 ± 0.8	7.2 ± 1.4	8.1 ± 0.6[abd]	9.5 ± 0.5[abc]

[a] different from RS1; [b] different from RS2; [c] different from HIA1, [d] different from HIA2, all $p < 0.05$. HR - heart rate; $\dot{V}O_2$ oxygen consumption; TSI – tissue saturation index; s-RPE – session ratings of perceived exertion

Table 7.2: Internal responses and external loads (mean ± SD) for the main body of each Sprint Kayak training session.

	RS1	RS2	HIA1	HIA2
Duration (min:s)	3:40	3:00	18:00	33:00
Mean HR (%)	75.2 ± 6.1	78.4 ± 4.3	81.9 ± 5.1[ab]	81.2 ± 6.4[a]
$\dot{V}O_2$ (L)	54.5 ± 2.4	58.5 ± 4.8	81.5 ± 8.4[abd]	102 ± 10.7[abc]
TSI (%)	61.9 ± 6.4	63.8 ± 5.1	62.2 ± 6.2	60.1 ± 8.2
RPE (AU)	17.4 ± 2	18.1 ± 1.4	14.9 ± 0.7[ab]	14 ± 0.9[ab]
Blood lactate (mmol·L^{-1})	10.3 ± 2.2	10.4 ± 2.3	5.8 ± 1.8[ab]	5.3 ± 1.9[ab]
Mean Power (W)	339 ± 50	369 ± 88	165 ± 23[ab]	144 ± 24[ab]

[a] different from RS1; [b] different from RS2; [c] different from HIA1; [d] different from HIA2; all $p < 0.05$. HR - heart rate; $\dot{V}O_2$ oxygen consumption; TSI – tissue saturation index; RPE – ratings of perceived exertion

Figure 7.1 shows the contribution of the internal ($\dot{V}O_2$) and external (power output) in the low, moderate and high training zones for each of the RS and HIA training sessions. The training zones were based on anchor points of physiological (LT_1 HR: 82.8 ±4.9 %; LT_1 $\dot{V}O_2$: 3.3 ±1.1 L·min^{-1}, and LT_2 HR: 89.6 ±5.5 %; LT_2 $\dot{V}O_2$: 3.7 ±0.9 L·min^{-1}) and performance (LT_1 power: 114 ±18 W and LT_2 power: 138 ±17 W) variables, in order to describe and internal and one external intensity marker for the training sessions.

A linear mixed-effects model showed a significant quadratic trend for the $\dot{V}O_2$ contribution in each training zone (t (114) = 4.7, p<0.001, ES = 0.40) and power output (t (116) = 9.6, p<0.001 ES =0.66). For $\dot{V}O_2$ contribution in each zone, the model showed a significant random slope variation of the interaction between training zones and the RS2 session (t (109) = -2.0, p =0.047, ES = 0.18). Similarly, the power output showed significant random slope variation of the interaction between training zones and the RS1 session (t (111) = -2.0, p = 0.044, ES = 0.18) and random slope variation of the interaction between training zones and the RS2 session (t (111) =-2.2, p= 0.027, ES = 0.20). The linear mixed-effects model also showed that the random variation of the slopes of the training zones significantly varied for the training responses (internal and external) (t (244) =7.7, p<0.001, ES =0.44).
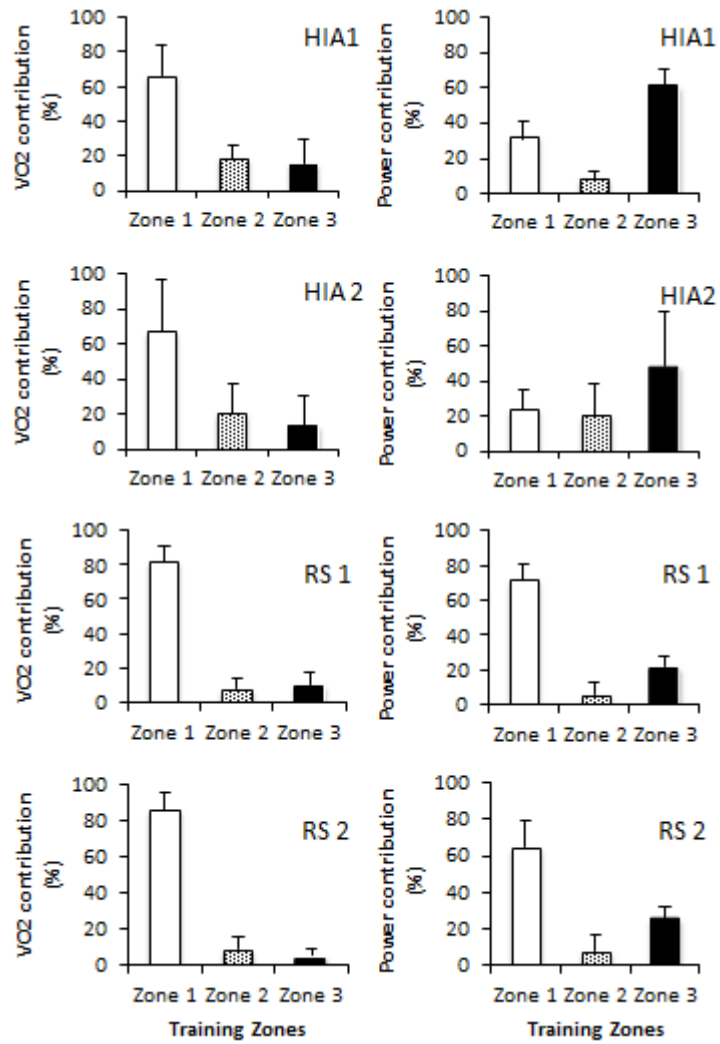
Figure 7.1: Percentage contribution of each low ($<LT_1$), moderate (LT_1-LT_2) and high ($>LT_2$) intensity training zones for internal responses and external loads for the different high-intensity training sessions.

Discussion

This study aimed to describe and compare the acute internal (physiological) responses to RS and HIA training sessions in Sprint Kayak athletes. The main findings of this study were that the main body of the RS sessions required greater mean power production, elicited higher [BLa$^-$] concentrations and were perceived to be more intense, whilst the main body of the HIA sessions demonstrated greater HR response and $\dot{V}O_2$ cost, but were of longer duration. When each training sessions was considered as a whole (i.e. including warm-up, main body and cool down), the physiological loads between RS1 and RS2 were relatively similar. Further, these selected responses were also similar between HIA1 and HIA2. However, the two RS training sessions were of higher intensity than the HIA training, as validated by [BLa$^-$] and RPE responses. In contrast, the two HIA sessions demonstrated greater values for HR and distance covered. Moreover, whole session mean power outputs and TSI were similar for all training sessions. Finally, the data also demonstrated that both the acute physiological responses and power outputs for each specific HIA or RS training session significantly varied within and between athletes.

Coaches and sport scientists design training programs with the aim of eliciting specific physiological, biomechanical and technical adaptations, with the ultimate goal of improving performance (Siff and Verkhoshansky 1999, Smith 2003, Impellizzeri, Rampinini et al. 2005). These purpose of each program is typically guided by the specific goals of the athlete (Smith 2003) and requirements of their chosen event. Importantly, these may change as athlete's progress across a season or throughout their careers. For example, periodised programs may provide training periods where general metabolic adaptations are the priority, while other periods of training may target other

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specific physical, technical and tactical aspects (Siff and Verkhoshansky 1999, Smith 2003, Garcia-Pallares, Garcia-Fernandez et al. 2010). The present results demonstrated that the main body of each of the different training sessions elicit distinct physiological responses, with the RS eliciting greater power, blood [BLa⁻] responses and perception of effort, whilst the HIA sessions had greater O_2 cost and HR responses. However, each training bout was shown to facilitate a similar TSI. Our results also confirm our hypothesis that the RS training would provide a greater stimulus to the anaerobic glycolytic system. Whilst not assessed in this study, it is also likely that the RS sessions placed greater strain on the neuromuscular system, given the high level of stimulation required at each of the repeated accelerations at the start of each effort during each bout. Taken collectively, these findings suggest that, as the RS training stimulates physiological variables involving the anaerobic responses it may be that such training approach suits for developing physiological capacities that better relates to improved 200-m Sprint Kayak performance (van Someren and Palmer 2003, Oliveira Borges, Dascombe et al. 2013).

In contrast to the RS sessions, the physiological responses to the HIA sessions suggest that this type of training is more suited to developing 1000-m Sprint Kayak performance. For example, the $\dot{V}O_2$ response during these training sets were ~92 and ~80 % of the $\dot{V}O_2$max, which are more closely related to the physiological responses during 1000-m Sprint Kayak time trialling in a laboratory set up (i.e. ~93.7% of $\dot{V}O_2$max) and on water (e.g. ~94% of $\dot{V}O_2$max). Whilst it is attractive to suggest that RS training maybe more suitable for improving 200-m performance and HIA suited for preparing athletes for 1000-m performance, future long-term training studies are required to determine the efficacy of such an approach.

It is likely that both the overall energetic cost of these Sprint Kayak sessions contribute to the cardiopulmonary adaptations whilst the higher power outputs achieved during the main body of each session facilitates changes in neuromuscular adaptations and anaerobic capacities. The present results also demonstrate that whilst the main body of each training session provided different external loads and physiological responses, the overall physiological responses to the entire sessions were not as distinct as the results from the main body of each session. Indeed, there were no significant differences for the TSI and HR, although the TSI was significantly higher (*large* ES = 0.6) and HR significantly lower (*large* ES = 0.6) for the RS1 and HIA2, respectively. It appears that the cardiovascular lag prevented the TSI and HR to achieve higher values as RS1 efforts duration was only 10 s as opposed to the ~10 min for the HIA2 session. Indeed, Hill et al. (2002) suggest that a certain amount of time is required for higher levels of metabolic adjustment. However, there were marked differences in the power outputs achieved in the main body of the RS sessions compared to when analysed as a whole. These findings show that it is possible that there may be an 'interference effect' on the anaerobic and neuromuscular adaptations through increasing duration of these RS sessions by extending the warm-up and cool down periods. Future studies should examine the relative contribution of the overall session energetic load compared to the neuromuscular load applied through the main session on chronic training adaptations.

A further notable finding of the present study was the *large* differences in the distribution of $\dot{V}O_2$ and power output responses to each of the HIA sessions. For example, a larger proportion of the power outputs were in the high zones (i.e. $> LT_2$) for the HIA sessions, yet paradoxically the majority of session time for the $\dot{V}O_2$ responses

were $<LT_1$. The most likely explanation for the differences in the proportions of session times spent in high and lower intensity zones for the $\dot{V}O_2$ and power output measures is the lag in metabolic adjustments to fast changes in power output (Hill, Poole et al. 2002). These findings have important practical implications for effective manipulation of the acute responses to high-intensity training sessions. This may be especially important given that coaches often manipulate these variables with the aim of eliciting specific physiological and performance adaptations.

In contrast to the HIA, the relative distribution of the $\dot{V}O_2$ and power output was similar for the RS sessions with the majority of time (~70-80%) being spent in the low zone for both the long and short RS sessions, with between ~5-20% of time being spent in the high-intensity zone. However, similar to the HIA sessions, there was greater time spent in the higher zones for power output (RS1: 21.9%, RS2: 26.0%) compared to the $\dot{V}O_2$ responses (RS1: 10.8%, RS2: 4.9%), which is also likely due to the lag in metabolic adjustments to changes in work. The similar contribution of time spent in lower intensity zones throughout the RS sessions is likely attributable to the large proportion of the session that was spent warming up, cooling down and resting between higher intensity efforts of each session (Figure 7.1).

Although speculative, a possible explanation for the variability in the distribution of the physiological responses within the higher zones for the HIA sessions may be due to different levels of anaerobic fitness across the athletes or other individual characteristics of the athletes (i.e. genetics, etc.,) (Smith 2003, Impellizzeri, Rampinini et al. 2005, Costa, Breitenfeld et al. 2012). Indeed, the data from both RS sessions demonstrated a significant slope random variation whereas the significant effect for the intercept was

fixed. The fixed effect for the intercept was not surprising as all the athletes performed a standard warm up for all training sessions. Nevertheless, the significant variation in the time spent in low, moderate and high-intensity zones seems to represent the individual's individual characteristics (Impellizzeri, Rampinini et al. 2005, Bouchard 2012). Coaches and sports scientists could implement these findings to help individualize the training loads to best reflect the individual potential of the athletes.

One limitation of the present study when comparing the responses between the different training sessions completed in this study was that it was difficult to match each session for each internal and external training load. Initially it was intended to match training sessions for external load using mean power output. Clearly the present results confirm that the physiological responses to these sessions are dependent upon many factors such as session duration, work interval intensity, work interval duration, between-effort relief characteristics, work/relief ratio and exercise mode. A more systematic approach to manipulating each of these prescriptive variables is warranted for a more thorough comparative understanding of the responses to different high-intensity interval training sessions for Sprint Kayak. Additionally, important information may also have been obtained from assessing neuromuscular load and recovery markers from these sessions. Nonetheless, the contribution of this study is that it provides a more detailed understanding of the physiological responses of common RS and HIA sessions used within Sprint Kayak training. Finally, as this was not a training study, it may be difficult to infer effects on on-water 200 and 1000-m performance.

Conclusions

The RS training sessions stimulated variables related to the anaerobic metabolism in a greater magnitude whereas the response to HIA elicited a higher aerobic response. In spite of distinct responses of each training session, when considering the main body of the session, the amount of oxygen present at the muscle, determined by the NIRS measures in both entire training session and when the main body only was considered, was similar. The dynamics of the effort:rest ratio seems to have determined this result. However, further research is necessary to clarify this issue. The hypotheses that the response to each of training session would agree with the specificity of the stimulus has been confirmed, corroborating the principle of training specificity (Siff and Verkhoshansky 1999, Issurin 2008). Finally, the findings of this study provide evidence to support the principle of individuality, with significant variability of the responses between athletes, for the same training session. These results suggest that training programs should become more individualised to suit the athletes' needs.

As practical applications, coaches and sports scientists design training programs with the goal of achieve peak performance at an important competition fixture. The findings of this study can be used to inform coaches on specific physiological responses to common RS and HIA training sessions in Sprint Kayak athletes. Indeed, the present findings suggest that the responses to the RS sessions are more similar to the competitive demands of the 200-m event, whilst the HIA sessions are similar to the demands of the 1000-m time trial. These findings may be used to direct Sprint Kayak athletes towards preparing for the 200-m event with a greater focus on RS training, and likewise, being more reliant on HIA training for preparation for the 1000-m event. The findings also highlight the potential impact of the warm-up and cool down on the

overall sessions' stimulus that should be taken into account when planning training. We also suggest that coaches be aware that even in homogenous groups of well-trained athletes, *large* between-athlete variation is likely in the physiological stimulus provided, even when external loads are controlled.

In summary, the present study highlighted distinct differences in the HR, $\dot{V}O_2$, [BLa$^-$], and perceptual responses to common RS and HIA training, with the shorter RS sessions placing a greater stimulus on glycolytic pathways, and the longer HIA sessions requiring greater energetic demands. Importantly, *large* inter-individual physiological responses were observed across each of the different training sessions. Collectively, these findings can be used to guide coaches in planning training for the individual needs of Sprint Kayakers preparing for specific competitions. Future studies should examine the long-term adaptations of RS and HIA training in Sprint Kayak athletes.

CHAPTER EIGHT

Comparison of repeat sprint and high-intensity aerobic interval training on physiological variables and performance in junior Sprint Kayak athletes.

Abstract

The purpose of this study was to verify the effects of RS compared to HIA interval training on selected physiological including $\dot{V}O_2$max, maximum aerobic power, lactate threshold and the whole body and muscle oxygen kinetics as well as on-water time trial performance over 200 and 1000-m in well trained junior Sprint Kayak athletes. A matched-groups, pre-post parallel control design was used to compare the effects of 5 weeks of either RS or HIA training on water (6 sessions·wk^{-1}) and resistance training (3 sessions·wk^{-1}) in 20 well-trained junior Sprint Kayak athletes. They were matched by $\dot{V}O_2$max and TT performance at the beginning of the study. Training was monitored using heart rate, session-RPE and GPS. On water Sprint Kayak performance (200 m and 1000 m), aerobic fitness ($\dot{V}O_2$max and lactate threshold), muscle and whole body oxygen (O_2) kinetics were assessed pre, and post training. Following training, there were *trivial* differences for the 200 and 1000-m time-trial performance between the RS and HIA interval training interventions. Similarly, there were *trivial* differences in the changes in HRmax, $\dot{V}O_2$max, P:W ratio, LT_2 and MAP between the RS and HIA interval training interventions. However, *small* changes were possibly found for the muscle oxygen kinetics (-8.2% CL -32.9 to 25.5) in the severe domain, for the RS group. The HIA interval training induced *small* changes in the whole body oxygen kinetics in the moderate (-2.2% CL -10.9 to 7.2) and *moderate* changes in the severe domains (1.8% CL -18.5 to 27.1). In summary, the addition of five weeks of twice weekly RS or HIA interval training induced *trivial to small* performance impairments in on-water 200 and 1000-m Sprint Kayak time trial performance in well-trained Sprint Kayak athletes. Nevertheless, this short intervention in already well-trained Sprint Kayak athletes induced a *small* speeding of the muscle oxygen kinetics at the severe domain in the RS

training group whereas whole body oxygen kinetics improved with a *small* change for the moderate and *moderate* change for the severe domain.

Key words: Sprint Kayak, Monitoring training, Oxygen kinetics

Introduction

Since Olympic Sprint Kayak athlete's race over a variety of distances (e.g. 200, 500 and 1000-m) and different boats (K1, K2 and K4), designing programs for athletes who compete in several events can be complex. Each event has different physical and tactical demands, requiring individualized training and coaching strategies (Byrnes and Kearney 1997, Bishop 2000, Garcia-Pallares, Sanchez-Medina et al. 2009). Whilst Olympic Sprint Kayak events require a high level of aerobic fitness, the shorter all out 200-m race appears best suited to larger athletes with better anaerobic characteristics (van Someren and Palmer 2003). Alternatively, athletes with higher maximal aerobic power and maximum oxygen uptake ($\dot{V}O_2max$) perform better in the 1000-m time-trial (Fry and Morton 1991, Bishop 2000, van Someren and Howatson 2008, Oliveira Borges, Dascombe et al. 2013). Despite these differences in the physiological requirements for the various Sprint Kayak events, relatively little is known about the best method for training these specific capacities for each event.

Anecdotal reports suggests that developing Sprint Kayak athletes undertake a more generalized training program, as they often compete in many events and boat categories that require a diverse range of physiological characteristics, and a variety of technical and tactical skills. Typically, when Sprint Kayak athletes reach higher levels of competition, they begin to specialize in either the 200-m or 1000-m event. Once athletes begin to specialise in specific race distances, their training focus shifts toward the developing the specific factors related to performance in these events. Surprisingly, relatively little is known about the most appropriate methods to train for specific Sprint Kayak events (Garcia-Pallares, Sanchez-Medina et al. 2009, Garcia-Pallares, Garcia-Fernandez et al. 2010). Indeed, recent data has demonstrated diverse acute physiological

responses to repeat sprint (RS) and high-intensity aerobic (HIA) interval training sessions in well-trained junior Sprint Kayak athletes (Oliveira Borges, Bullock et al. 2013). Our findings demonstrated that RS sessions required greater mean power production, elicited higher blood lactate (BLa⁻) concentrations and were perceived to be more intense, whilst the main body of the HIA sessions elicited greater HR and oxygen uptake responses. These findings suggest that RS training may best suit the development of physiological capacities that correlate to 200-m Sprint Kayak performance, whilst the HIA sessions seem beneficial for preparing athletes for the 1000-m. Indeed, it is now well established that HIA training increases maximal aerobic power, $\dot{V}O_2$max, lactate threshold and endurance capacity (Buchheit and Laursen 2013), whilst RS training can improve both neuromuscular (e.g. neural drive, motor unit activation) and metabolic factors (e.g. oxidative capacity, PCr recovery, O_2 kinetics, H^+ buffering) (for reviews see: (Buchheit and Laursen 2013, Buchheit and Laursen 2013). Despite this rationale, it is surprising that no studies have examined the physiological and performance adaptations to RS and HIA training in Sprint Kayak programs.

Targeted physical training programs that improve selected physiological, technical and tactical factors that underlie optimal performances in sport are likely to improve the chances of an athlete's success in competitions. Indeed, specific programs may be critically important to young, talented Sprint Kayakers who are beginning to specialize in either the 200-m or 1000-m event. In Sprint Kayak, athletes who specialise in the 200-m would likely benefit from developing anaerobic capacity, muscle oxygenation and neuromuscular characteristics. In contrast, 1000-m specialists would benefit most from developing their maximal aerobic power, $\dot{V}O_2$max, lactate threshold and endurance capacity. However, at present no studies have examined the adaptation of

physiological or performance indicators in response to RS or HIA interval training in well-trained junior Sprint Kayak athletes. Therefore, the purpose of the present study was to verify the effects of RS compared to HIA interval training on selected physiological including $\dot{V}O_2max$, maximum aerobic power, lactate threshold and the whole body and muscle oxygen kinetics as well as on-water time trial performance over 200 and 1000-m. It was hypothesised was that RS training would improve muscle oxygenation, glycolytic responses and 200-m time trial performance, whilst the HIA interval training would have a greater increase upon maximal aerobic power, $\dot{V}O_2max$, lactate threshold and 1000-m performance.

Methods

Design

A matched-groups, pre-post parallel control design was used to compare the effects of 5 weeks of twice weekly RS and HIA interval training on aerobic fitness ($\dot{V}O_2max$, maximal aerobic power and lactate threshold), oxygen kinetics (muscle [$M_{O2kinetics}$] and whole body [$\dot{V}O_{2kinetics}$]) and on-water time trial performance (i.e. 200 and 1000-m) in well-trained junior Sprint Kayak athletes. The two training groups were matched for $\dot{V}O_2max$ and time trial performance at the beginning of the study. Following baseline testing, the athletes completed their usual training program (6 day/week) for five weeks, followed by a short 4-d taper. Additional experimental training sessions (i.e. RS or HIA interval training) were completed twice weekly throughout the study. The training loads for the entire training program and the experimental training sessions were matched. The athletes were familiarized with the exercise procedures before commencement of

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study and were informed not to perform intense exercise on the day before each test, and to consume their last meal at least 3 h before the scheduled test time.

Participants

Twenty well-trained junior Sprint Kayak athletes (age 17.0 ±1.2 y; body mass 71.6 ±8.0 kg; $\dot{V}O_2$max 4.1 ±0.8 L·min^{-1}) volunteered to take part in this study. Prior to participation, all risks and benefits associated with this study were explained to the participants, and written consent was obtained from the athletes and/or their legal guardian. Ethics clearance was granted by the University's Human Research Ethics Committee (HREC REF NO. 2011-159A).

Procedures

For baseline testing, all athletes visited the laboratory three times to assess aerobic fitness and metabolic kinetic responses. During the first visit, athletes completed an incremental Sprint Kayak step test on a kayak ergometer (Weba Sport und Med. - Artikel GmbH, Vienna, Austria) for the assessment maximal aerobic power (MAP), lactate threshold (LT$_2$), maximal heart rate (HR$_{max}$), maximum oxygen uptake ($\dot{V}O_2$max) and power:weight ratio (P:W$_{ratio}$) as described elsewhere (Bullock, Woolford et al. 2013). During submaximal stages of the step test, the $\dot{V}O_2$ was determined as the average highest minute whereas $\dot{V}O_2$max was the highest consecutive minute during maximal stage. The LT$_2$ was calculated using the D-max method (Zhou and Weston 1999), whilst the MAP was considered the average power output from the final maximal stage of the test. HR was monitored using a telemetric system every 1-s (Polar RS800, Polar, Finland) and HR$_{max}$ was recorded from the step test. Blood lactate was measured from samples taken from a hyperaemic earlobe at the end interval between

steps in the incremental step test using a portable lactate analyser (Lactate Scout, EKF Diagnostics, Germany). The ratings of perceived exertion (RPE) were recorded using Borg's RPE 6 – 20 scale (Borg 1998) at the end of each stage in the incremental step test.

In the second and third visit to laboratory, the athletes performed each day a series of square wave transitions to determine their on-transient $\dot{V}O_2$ kinetics and $M_{O2kinetics}$ (e.g. phase II fast kinetics – τ). The intensity for each square wave transition was calculated based on individual results from the incremental step test for the moderate (~ 80% of LT_2), heavy ($\Delta50$ - 50% of the distance between LT_2 and $\dot{V}O_2max$) and severe ($\Delta80$ - 80% of the distance between LT_2 and $\dot{V}O_2max$) (Ingham, Carter et al. 2007). The athletes paddled for two minutes at an intensity of 20 W followed by six minutes at constant intensity for the moderate, heavy or severe domain. A 6-min rest was allowed between the moderate and heavy domain, whilst a 10-min break was provided between the heavy and severe domain to ensure metabolic rate to return to resting levels (Burnley, Jones et al. 2000, Ingham, Carter et al. 2007)

The power output during all testing sessions was recorded by the WEBA kayak ergometer system (Weba Sport und Med. - Artikel GmbH, Vienna, Austria). The previously determined typical error of estimate for power output for this ergometer against a calibration rig was 7.2%. In the first visit to the laboratory, the footrest and paddle length were adjusted according to each athlete's specification. The shock cords of the ergometer were calibrated before each test according to standard calibration recommendations (Bullock, Woolford et al. 2013).

Training and monitoring training

After baseline testing, athletes completed five weeks of Sprint Kayak training that included six on water sessions (including two experimental sessions) per week (Table 1). The RS and HIA sessions replaced two of the regular training sessions. Additionally, three resistance training sessions and a separate single running session was completed each week. The training sessions lasted approximately one hour and were performed either early in the morning or later in the afternoon/early evening. During the training period, each athlete had a HR-enabled GPS (Forerunner 305, Garmin, Olathe, KS, USA) fitted to their kayaks. The GPS units were given to the athletes before each training sessions and retrieved at the end for recording the information of the session and charging when needed. All training loads were monitored via the session-RPE method, using the RPE 6-20 scale (Oliveira Borges, Bullock et al. 2013). After 30 minutes of the end of each training session, the athlete was asked to rate the intensity of the entire training session. The product of this score and the duration in minutes represents the internal training loads (Foster, Florhaug et al. 2001). The weather conditions including wind speed, temperature and humidity were recorded each day using a calibrated portable weather meter (Kestrel® 4000, USA) at the beginning and end of the training sessions, with environmental measures being averaged for further analysis.

The athletes also performed maximal 200 and 1000-m on water time trials at the start and the end of the study. Following a standard warm up the athletes completed a 200-m time trial. After 20 minutes of active recovery, the athletes performed the 1000-m time trial. For all trials, the athletes followed the same course and received consistent verbal encouragement.

Table 8.1. Typical training week for the period of the study.

Weekday	Period	
	AM	PM
Monday	Strength and conditioning	Long endurance 10-12 km
Tuesday	Rest	Rest
Wednesday	Strength and conditioning	RS1 or HIA1 sessions
Thursday	Running 20 min	Long intervals 5 x 10 min
Friday	Sprint intervals 5 x 100 m	Strength and conditioning
Saturday	Team Boats - Long intervals 7 x 2 km	Rest
Sunday	Rest	RS2 or HIA2 sessions

All the experimental training sessions were preceded by a standard warm up that consisted of 3-min of paddling at ~85% of HR_{max}, followed by two 15 s accelerations interspersed with 45 s rest and two standing starts of 24 strokes with 45 s rest between each ending with 3 min of paddling at 85% HR_{max}. Similarly, at the end of each experimental session the athletes followed as standard cool down consisting paddling at 75% HR_{max} until the session duration goal was met.

The main body of each of the experimental training sessions consisted of either RS (a short and a long session) or HIA interval training (a short and a long session). The shorter RS session (RS1), consisted of two sets of six maximal 10 s efforts with 10 s rest between each effort with an 8 min active recovery rest between each set; a longer RS session (RS2) consisted of 6 x 30 s efforts interspersed with 210 s active rest

between each effort. The shorter HIA session (HIA1) consisted of 2 sets of 3 x 3-min efforts with 3-min active recovery between each efforts and a 5-min active recovery between sets. In this session, the athletes paddled at the lactate threshold intensity. The longer HIA sessions (HIA2) consisted of 3 x 2 km efforts on a 15-min cycle at 90% of their lactate threshold intensity. The total duration of each training session was set in an attempt to make them to match for training loads, whilst the training intensity was planned in accordance with the national guidelines for Sprint Kayak training (Bullock, Woolford et al. 2013). The remaining training sessions were of a variety of duration (e.g. from 40 to 60 min) and length (from 50-m to 12 km efforts). The head coach designed this main training program, which all the athletes performed whereas each group (RS and HIA) performed the experimental training sessions separately.

Physiological measurements

During the step test and square wave transitions, continuous breath-by-breath $\dot{V}O_2$ was measured using a metabolic cart (MedGraphics Ultima CPX, Medical Graphics Corporation, USA). Prior to each testing session, the metabolic cart was calibrated using known O_2 and CO_2 concentration and the pneumotach was calibrated using a 3-litre syringe according to manufacturer directions. The data from the square wave transitions were interpolated from breath-by-breath to second-by-second using a tailored application (LabView, National Instruments Corporation, TX, USA) to be later used in the $\dot{V}O_{2\ kinetics}$ modelling.

The muscle oxygenation responses were measured using near infrared (NIR) spectroscopy (NIRS) (Portamon, Artinis Medical Systems, Zetten, the Netherlands). Muscle tissue saturation index (TSI) was continuously measured throughout each

testing session and data was recorded using a 10 Hz sampling rate and averaged to 1 Hz using a tailored application (LabView, National Instruments Corporation, TX, USA) to allow for synchronization with $\dot{V}O_2$. The TSI was calculated as the difference between the change in deoxyhaemoglobin ([ΔHHb]) and oxyhaemoglobin ([ΔO_2Hb]) and represents the average oxygen saturation of the targeted muscle. The muscle of choice was the *latissimus dorsi* as it is considered responsible for most the propulsive force in the kayak stroke (Yoshio, Takagi et al. 1974, Trevithick, Ginn et al. 2007, Fleming, Donne et al. 2012). The midpoint between the inferior border of the scapula and posterior axilla fold, with the probe following the orientation of the muscle fibres was used as the reference for consistency. To prevent the sweat to cause any issue with the NIRS light transmission/absorption, a translucid waterproof adhesive was placed between the NIRS and the skin and the device was kept on site using a dark coloured sports tape. Additionally, a black sports crop top was used for both holding the device on place and helps to prevent any external light to penetrate (Oliveira Borges, Bullock et al. 2013, Oliveira Borges, Dascombe et al. 2013).

Modelling of $\dot{V}O_{2kinetics}$ and $MO_{2kinetics}$.

After a thorough examination of the $\dot{V}O_2$ data, any data point found more than four standard deviations away from the mean response was deleted. The breath-by-breath data was interpolated to second-by-second values, and the response of the $\dot{V}O_2$ for each domain was time aligned and averaged. For the $M_{O2kinetics}$, the main parameter of choice was the tissue saturation index (TSI). The raw data recorded at 10 Hz was initially averaged to one second samples and then time aligned. A non-linear least squares regression technique was used to model the time course of the $\dot{V}O_2$ response and TSI. A single (Eq. 1 and 2) component exponential equation was used to model the moderate

response whilst for the heavy and severe domains, a double (Eq. 3 and 4) component equation was applied (Koppo, Bouckaert et al. 2004, Burnley and Jones 2007). The Solver function within Microsoft Excel (Microsoft Corporation™, USA) was used to determine the best fit of the parameters.

$\dot{V}O_2$ Moderate Domain - $\dot{V}O_2$ (t) = $\dot{V}O_2$ (b) + $A_p \cdot [1\text{-}e^{-(t\text{-}TDp)/}\tau_P]$ (Eq. 1)

TSI Moderate Domain - TSI (t) = TSI (b) - $A_p \cdot [1\text{-}e^{-(t\text{-}TDp)/}\tau_P]$ (Eq. 2)

$\dot{V}O_2$ Heavy and Severe Domain - $\dot{V}O_2$ (t) = $\dot{V}O_2$ (b) + $A_p[1\text{-}e^{-(t\text{-}TDp)/}\tau_P] + A_s \cdot [1\text{-}e^{-(t\text{-}TDs)/}\tau_s]$ (Eq. 3)

TSI Heavy and Severe Domain - TSI (t) = TSI (b) + $A_p[1\text{-}e^{-(t\text{-}TDp)/}\tau_P] + A_s \cdot [1\text{-}e^{-(t\text{-}TDs)/}\tau_s]$ (Eq. 4)

Where, $\dot{V}O_2$ (t) and TSI (t) are the $\dot{V}O_2$ and TSI at a given time; $\dot{V}O_2$ (b) and TSI (b) are the baseline value across the last 2 minutes of 'unloaded' paddling; A_p and A_s are the asymptotic amplitudes for the primary and slow exponential component; τ_p and τ_s are the time constants for each component; and TD_p and TD_s are the time delays for the primary and slow components.

Even though a two-component model was used to fit both the heavy and severe-intensity $\dot{V}O_2$ and TSI responses, only the time constant for the fast component of the $\dot{V}O_2$ and TSI kinetics was reported.

Sprint Kayak Performance

The on-water Sprint Kayak performance was determined during time trials at the lake where the athletes usually trained. The athletes used their own standard kayak (520 cm long, 12 kg) and were assessed individually, to avoid any of pacing or wash influence from other paddlers (Perez-Landaluce, Rodriguez-Alonso et al. 1998). The

time was recorded for each effort was performed using two synchronized stop watches (Interval$^®$ 2000, Nielsen-Kellerman, Boothwyn, USA). Following a standard warm up that consisted of 3-min of paddling at ~85% of HR_{max} followed by two 15 s accelerations interspersed with 45 s rest and two standing starts of 24 strokes with 45 s rest between each ending with 3 min of paddling at 85% HR_{max}, the athlete positioned the boat at the start line and was required to paddle in the shortest time possible for the 200 and 1000-m. After the 200-m trial, the athletes performed a moderate 25-min active recovery (~ 70% HR_{max}) followed by the 1000-m time trial.

Statistical analyses

Data are presented as mean ±SD of the raw scores and the mean change with 90% confidence limits of either relative or standardized scores. A progressive approach using analysis of pre-post parallel-groups controlled trial was applied to look for possible effects from the different training groups (RS and HIA) (Hopkins 2006). The comparisons for within and between RS or HIA real (unknown) change used the smallest worthwhile change (SWC – 0.2 times between subject SD) to determine better, trivial or poorer effects (Hopkins 2000). The qualitative chances for better, trivial or poorer were: < 1%, *almost certainly not*; 1 to 5%, *very unlikely*; 5 to 25%, *unlikely*; 25 to 75 %, *possible*; 75 to 95%, *likely*; 95 to 99%, *very likely*; >99% *almost certain*. Moreover, effect sizes of changes in performance and physiological variables between groups were calculated based on pre-training standard deviations. Effect sizes were interpreted using thresholds of 0.0, 0.2, 0.6, 1.2, 2.0 and 4.0 *trivial, small, moderate, large, very large* and *nearly perfect* effect sizes, respectively (Hopkins 2002). All statistical procedures were performed Microsoft Excel (Microsoft Office, Microsoft, Redmond, USA).

Results

Of the 30-planned on-water training sessions, the athletes from the RS and HIA group completed 19.8 ± 4.3 and 18.2 ± 3.8 sessions, respectively. No experimental sessions were missed by any athlete. Table 8.2 shows the athletes in the RS and HIA groups had similar levels of fitness and performance prior to the training intervention. Figure 8.1 shows the training intensity, accumulated volume, session-RPE training loads and weather conditions for both groups during the period of the study. The change in average session session-RPE was *small* when comparing week 1 with weeks 2, 3, 4, 5. *Small* change was also observed between weeks 3 and 5. *Large* changes were found between weeks 2 and 4 and 4 compared to 5. All other changes were *trivial*. There were *trivial* changes in training volume between weeks 4 and 5, *small* changes between weeks 1 vs. 3 and 2 vs. 3. The remaining comparisons were all *large-to-very large*. There were *small* changes in training loads between weeks 3 vs. 4, *moderate* between weeks 1 vs. 2, 1 vs. 3 and 1 vs. 4 whereas a *large* effect size was observed for comparisons between weeks 2 vs. 5, 3 vs. 5 and 4 vs. 5. The RS and HIA interval training contributed $30.9 \pm 8.2\%$ and $32.3 \pm 14.7\%$ of the total training loads for the experimental groups, respectively.

The pairwise comparisons for weather conditions for the period of the study showed *small* temperature changes in weeks 1 vs. 3, 3 vs. 4 and 4 vs. 5. For weeks 1 vs. 5, 2 vs. 5 and 3 vs. 5 the change was *large*. There were *small* changes in humidity between weeks 1 vs. 2, 1 vs. 5 and 2 vs. 3. *Moderate* changes were observed between weeks 2 vs. 5. *Large-to-very large* changes were observed between weeks 1 vs. 4, 2 vs. 4, 3 vs. 4 and 4 vs. 5. Finally, average wind speed during the period of the study tended to increase. There were *small* changes between weeks 1 vs. 3, 1 vs. 5, 2 vs.3, 2 vs. 5, and 3 vs. 5. *Moderate* changes were seen between weeks 1 vs. 2 and 4 vs. 5 (Figure 8.1).
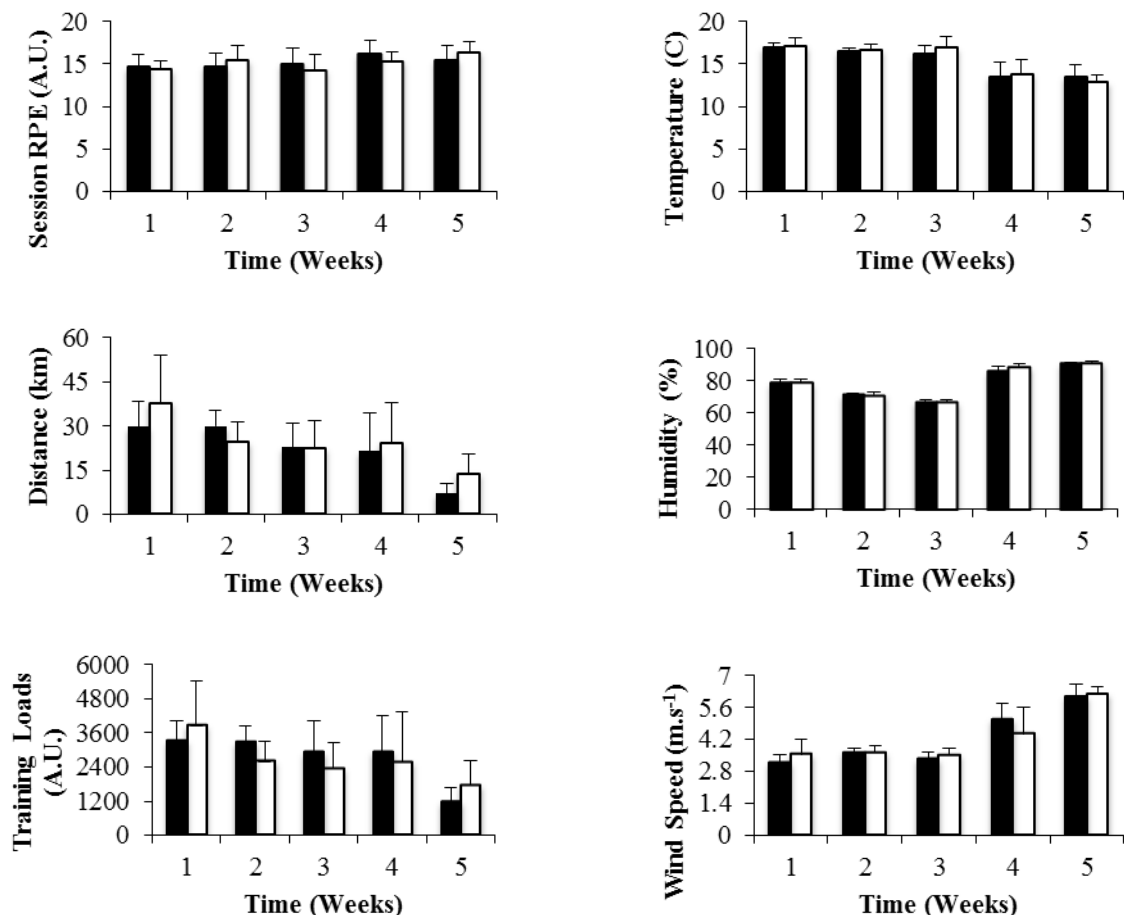
Figure 8.1: Average training intensity (A), accumulated training volume (B) and training loads (C), average temperature (D), humidity (E) and average wind speed for the 5-week training period. (■) Repeated Sprint Group, □ High-intensity aerobic interval group.
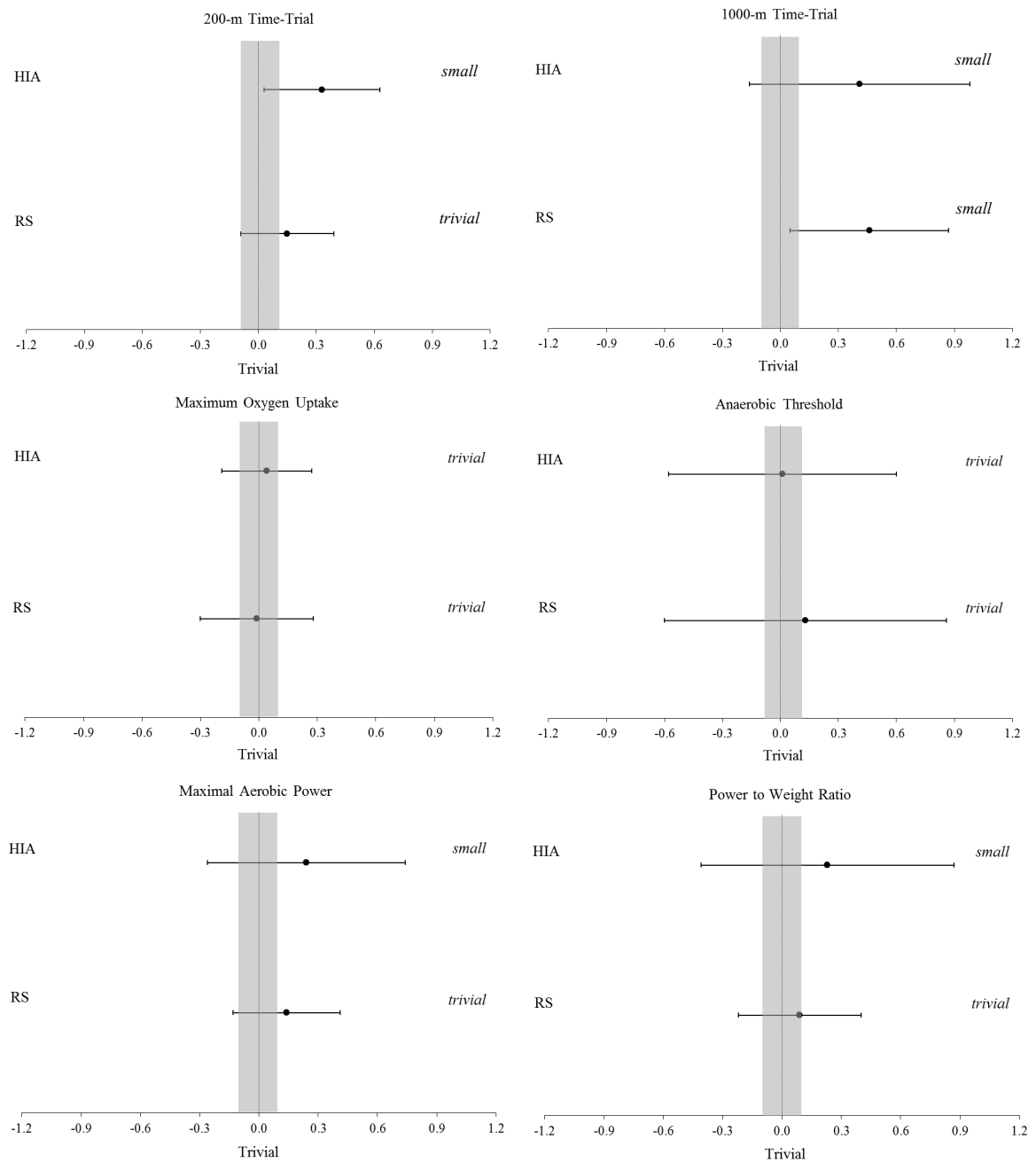
Figure 8.2: Within-group standard difference in change for 200 and 1000-m time trial performance, maximum oxygen uptake, anaerobic threshold, maximal aerobic power and power to weight ratio with repeat sprint (RS) and high-intensity aerobic (HIA) interval training programs (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial area was calculated from the smallest worthwhile change.

Changes in Physical Performance and Physiological Parameters after Training

Within-Group Changes

The relative changes in performance and physiological responses for the RS and HIA interval training groups are shown in Figure 8.2. There were *trivial* and *small* changes in the 200-m (1.5% CL 0.1 to 2.9) and 1000-m (3.8% CL 1.8 to 5.8) time trial performance for the RS group. Similarly, there were also *small* changes in the 200-m (3.2% CL 1.5 to 5.0) and in the 1000-m (3.4% CL 0.7 to 6.2) time-trial performance for the HIA group. The RS training induced *trivial* changes in the $\dot{V}O_2$max (-0.2% CL -3.6 to 3.4), MAP (3.0% CL -0.3 to 6.4), LT_2 (3.2% CL -6.7 to 14.1) and power to weight ratio (1.5% CL -1.4 to 4.6). However, *small* changes were possibly found for the muscle oxygen kinetics (-8.2% CL -32.9 to 25.5) in the severe domain. The HIA interval training induced *trivial* changes in $\dot{V}O_2$max (0.8% CL -1.9 to 3.6), MAP (3.0% CL -0.3 to 6.4), *small* changes in LT_2 (0.3% CL -7.5 to 8.9) and power to weight ratio (3.8% CL -2.4 to 10.4), although these two latter were unclear. Moreover, *small* changes were observed for the whole body oxygen kinetics in the moderate intensity domain (-2.2% CL -10.9 to 7.2) and *moderate* changes were found in the severe intensity domains (1.8% CL -18.5 to 27.1) (Figure 8.4)

Between-Group Changes

Figure 8.2 and Table 8.3 show the between-groups analysis for performance and physiological responses to the training interventions. Following training, there were *trivial* differences for the 200 and 1000-m time-trial performance between the RS and HIA interval training interventions (Figure 8.3). Similarly, there were *trivial* differences in the changes in and HRmax, $\dot{V}O_2$max, P:W ratio, LT_2 and MAP between the RS and HIA interval training interventions.
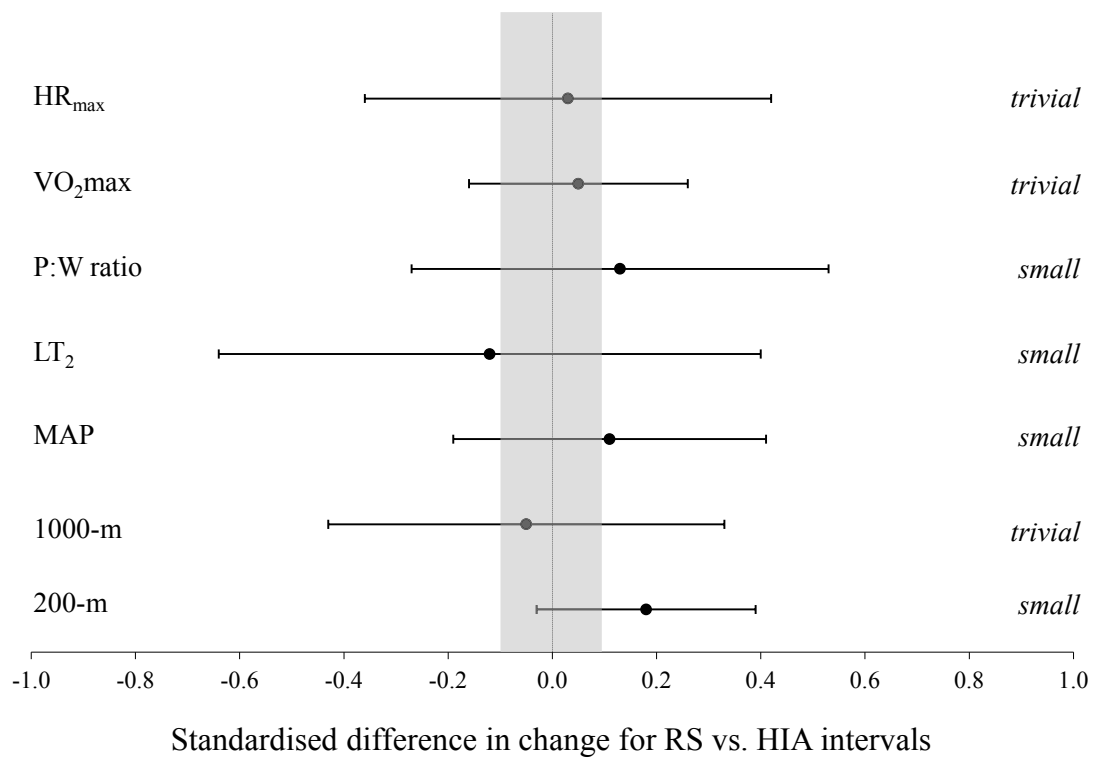
Figure 8.3:. Comparison of the performance and physiological responses to both interventions. Differences in the changes in maximum heart rate (HR$_{max}$), maximum oxygen uptake ($\dot{V}O_2$max), power to weight ratio (P:W ratio), anaerobic threshold (LT$_2$), maximal aerobic power (MAP), 1000-m time trial performance and 200-m time trial performance for repeat sprint (RS) vs. high–intensity aerobic (HIA) interval training group. The shaded area represents the smallest worthwhile change.
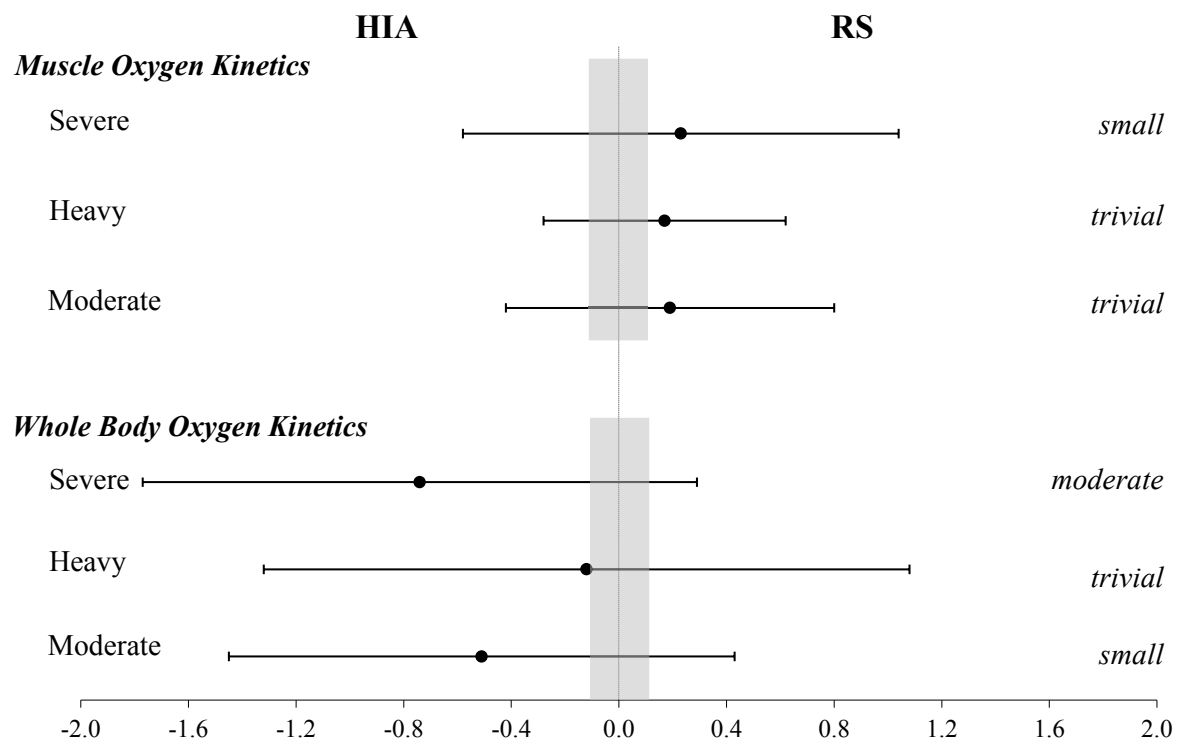
Figure 8.4: Comparison of the muscle and whole body oxygen kinetics to repeat sprint (RS) vs. high-intensity aerobic (HIA) interval training interventions. The shaded area represents the smallest worthwhile change.

Table 8.2: Changes in time-trial performance and physiological responses following 5 weeks of RS and HIA interval training (mean ±SD).

| | Repeat Sprint | | High-Intensity Aerobic | | Differences in change observed between RS vs. HIA | | |
	Pre	Post	Pre	Post	Standardised Differences (90%CL)	Rating	% chances of a better / trivial / poorer effect
200-m (s)	46.0 ± 4.1	46.7 ± 4.4	47.3 ± 4.7	48.8 ± 4.5	0.18 (-0.03, 0.39)	*Trivial*	0/ 57/ 43
1000-m (s)	278.2 ± 19.2	289 ± 24.5	278.2 ± 25.4	288.4 ± 33.8	-0.05 (-0.43, 0.34)	*Trivial*	25/ 61/ 14
MAP (W)	166 ± 27	171 ± 33	169.0 ± 38.0	177.0 ± 35.0	0.11 (-0.21, 0.43)	*Trivial*	31/ 64/ 5
LT_2 (W)	131.3 ± 27.1	135 ± 24.5	127.2 ± 25.2	128.6 ± 24.7	-0.12 (-0.63, 0.40)	*Trivial*	15/ 46/ 39
P:Wratio (W/kg)	2.3 ± 0.2	2.3 ± 0.2	2.4 ± 0.5	2.5 ± 0.4	0.13 (-0.27, 0.53)	*Trivial*	39/ 53/ 8
$\dot{V}O_2$max (L/min)	4.1 ± 0.8	4.1 ± 0.7	4.0 ± 0.8	4.0 ± 0.7	0.05 (-0.16, 0.25)	*Trivial*	10/ 87/ 3
HRmax (bpm)	195 ± 7	192 ± 7	201.0 ± 8.0	198.0 ± 9.0	0.03 (-0.36, 0.42)	*Trivial*	16/ 61/ 23

MAP-maximum aerobic power; LT_2 - Anaerobic threshold; P:W ratio - Power to weight ratio; $\dot{V}O_2$max - Maximum oxygen uptake; HRmax – maximum heart rate; bpm - beats per minute; CL – confidence limits.

Table 8.3: Changes in whole body and muscle level O_2 kinetics (phase II time constant - τ^p) pre and post treatment for the moderate, heavy and severe domains following 5 weeks of RS and HIA interval training (mean ±SD).

| | Repeat Sprint | | High-Intensity Aerobic | | Differences in change observed between RS vs. HIA | | |
	Pre	Post	Pre	Post	Standardised Differences (90%CL)	Rating	%chances of a better / trivial / poorer effect
Whole body							
Moderate	38.3 ± 5.9	35.7 ± 4	34.7 ± 5.1	31.5 ± 5.9	-0.51 (-1.46, 0.45)	*Small*	71/ 18/ 11
Heavy	26.5 ± 4.5	24.0 ± 6	23.1 ± 5.4	22.2 ± 6.2	-0.12 (-1.36, 1.11)	*Unclear*	46/ 22/ 33
Severe	26.9 ± 4.8	26.5 ± 10	22.6 ± 3.5	19.6 ± 6.4	-0.74 (-1.77, 0.30)	*Moderate*	81/ 12/ 7
Muscle							
Moderate	11.4 ± 4.2	10.6 ± 4	9.6 ± 4.3	9.0 ± 3.2	0.19 (-0.41, 0.80)	*Unclear*	14/ 37/ 49
Heavy	15.9 ± 5.8	14.8 ± 6	12.0 ± 7.1	11.4 ± 7.2	0.17 (-0.32, 0.67)	*Unclear*	10/ 44/ 46
Severe	15.6 ± 6.8	13.6 ± 6	12.2 ± 7.9	11.9 ± 6.7	0.23 (-0.57, 1.04)	*Small*	18/ 29/ 53

CL – confidence limits.

Discussion

This study compared the effects of 5 weeks of twice weekly RS and HIA interval training on markers of aerobic fitness, oxygen kinetics (muscle and whole body) and on-water time trial performances in well-trained junior Sprint Kayak athletes. The main findings were that most maximal and submaximal physiological responses and on-water time trial performances over both 200 and 1000-m were not greatly affected by either high levels of RS or HIA interval training. However, the RS induced *small* increases in muscle oxygen kinetics in the severe domain and HIA interval training interventions induced *small* improvements in whole body oxygen kinetics (i.e. *small* changes) for moderate and moderate increases in the severe domains.

The main findings of this study were that the RS and HIA interval training had *trivial* effects upon 200 and 1000-m on water Sprint Kayak performance. Specifically, the athletes from RS group presented *small* and *trivial* decrements for the 200 and 1000-m on water time trials, whilst HIA interval training elicited *small* decrease over both time-trail distances. Since no studies have previously examined optimal interval training protocols for improving performance in well-trained Sprint Kayakers it is difficult to comment on the efficacy of either training approach. However, the slightly poorer on-water time trial performances at the end of the study period was not a desired outcome but may reflect differences in the environmental conditions that influenced the on-water performance assessment. The magnitude of change in performance in the present study were the opposite of those reported following six weeks of HIA or RS in competitive male tennis players (Fernandez-Fernandez, Zimek et al. 2012). This previous study demonstrated that HIA training induced greater improvements in tennis-specific

endurance (HIA 28.9% vs. RS 14.5%; p < 0.05) whilst the RS training elicited significant improvements (3.8%) in repeated sprint performance. However, the previous study data were collected during the pre-season period of the tennis season, where training-induced gains in performance and physiological variable are often substantial. In contrast, the present study commenced two weeks after the national championships where the athletes had planned their annual peaking in performance, and hence, were extremely well trained. It is likely that the high training status of the athletes prior to the study, and the poorer weather conditions at the final testing week also explains why decrements in Sprint Kayak performance were observed. Taken collectively, that the present results suggest that that well-trained athletes require either greater specific stimulus than provided in the present study or alternatively, longer periods of specific training to provide positive performance adaptations.

Separately, the oxygen kinetics represents the adjustment rate of oxygen uptake to changes in exercise intensity (Burnley and Jones 2007) and have recently been shown to correlate with Sprint Kayak performance (Oliveira Borges, Dascombe et al. 2013). The present results showed that five weeks of either RS or HIA interval training induced *small* (13.9% CL -27.5 to 79.1) speeding in muscle oxygen kinetics in the severe domain of the RS groups and *small* (-7.5% CL -20.2 to 7.1) and *moderate* (-17.6% CL -37.1 to 8.1) improvement of the $\dot{V}O_{2kinetics}$ at moderate and severe domains, respectively in the HIA interval training group. Similar to the present observations, Berger et al. (2006) also observed an 26–34% reduction in $\tau\dot{V}O_{2kinetics}$ in both moderate and severe domain after 6 weeks of interval (at 90% $\dot{V}O_2max$) or continuous (at 60% $\dot{V}O_2max$) cycle training in 23 healthy males after six weeks training. Others have also reported that high-intensity interval training improves $\dot{V}O_{2kinetics}$ but not $MO_{2kinetics}$ in as little as

eight sessions of either high-intensity interval training (8-12 x 1-min intervals at 120% MAP) or endurance training (90-120 min at 65% $\dot{V}O_2max$) in 12 healthy males (McKay, Paterson et al. 2009). Similarly, Bailey et al.,(2009) also demonstrated that just six sessions of RS (4-7 x 30 s intervals) resulted in 20–25% reductions in both the τ $\dot{V}O_{2kinetics}$ in transition to moderate intensity exercise and the $\dot{V}O_2$ slow-component amplitude, whereas $\dot{V}O_{2kinetics}$ were not altered by six sessions of work-matched endurance training (90% gas exchange threshold) in recreationally active young males. However, it is difficult to compare results between these studies due to different training methodologies and exercise modes. Nevertheless, the present study is the first to demonstrate changes in both $\dot{V}O_{2kinetics}$ and $MO_{2kinetics}$ in well-trained athletes with different training interventions. Notably however, is the smaller magnitude of change in these variables compared to other studies with participants of lower training status.

Whilst the differences in the changes in $\dot{V}O_{2kinetics}$ between the RS and HIA interval training were small, it is notable that the HIA speeded the $\dot{V}O_{2kinetics}$ to a greater extend that the RS training. It may be that the high-intensity nature of both training programs stimulated both central (cardiopulmonary) and peripheral (muscles) adaptation. It has been suggested that long interval training implies metabolic load emphasizing aerobic, anaerobic and neuromuscular systems, whilst the shorter sprinting nature of the other sessions loaded peripheral O_2, anaerobic and neuromuscular systems (Poole, Barstow et al. 2008). Taken together, this information suggests that five weeks of HIA interval training can speed the $\dot{V}O_{2kinetics}$. The response of muscle oxygen kinetics in the severe domain for the RS group seems to reflect specificity of adaptation to the higher training intensities.

Previous studies have shown the predictive power of aerobic fitness for Sprint Kayak performance. Moreover, we have recently shown that well-trained junior Sprint Kayak athletes presented *large-to-very large* correlations between both 200 and 1000-m on-water performance (Oliveira Borges, Dascombe et al. 2013) and aerobic fitness. We found maximal physiological variables to be similar to the responses in performance with *trivial* changes in $\dot{V}O_2$max, MAP and in both the RS or HIA interval training groups, and a *small* improvement in power to weight ratio in the HIA interval training group. These findings were different of those found by Billat et al. (2002) that encountered 5.3 % of improvement the in velocity associated with $\dot{V}O_2$max after four weeks of HIA training. It may be that the training dose in the present study was too small to induce substantial changes in the assessed variables of the present study. Indeed, the experimental training sessions corresponded to approximately one-third of the total training load performed in both groups. Moreover, the athletes may have been close to their peak performance at the beginning of the study and have not received the specific load to maintain the high levels of the maximal physiological variables. Collectively, these findings show how a short term training intervention impacts upon physiological and performance variables in well-trained junior Sprint Kayak athletes. This information may be particularly useful in situation where selection trials for major events occur close (i.e. around five weeks) the major competition. Coaches, sport scientists and athletes can benefit from this information to set up the training program for such situation. Indeed, it may be that in order to induce substantial adaptation in already well-trained in junior Sprint Kayak athletes seems to require either a greater training load than what this study employed or a longer period for specific preparation.

The athletes participating in this study completed ~10 sessions per week, which is an arduous training program for young Sprint Kayak athletes. However, despite maintaining hard training (i.e. mean weekly RPEs ~14-16), the training loads were slightly reduced as the study progressed, with a larger reduction in volume and an increase in intensity prior to the final testing period. The approach used in this study is not uncommon as training loads are often varied by coaches according to the competitive calendar and to achieve optimal performances at important competitions (Smith 2003, Issurin 2008). In this study, there was a decrease in load as the study progressed, which is similar to the approaches to training previously described in well-trained middle distance runners (Esteve-Lanao, Juan et al. 2005) and a case study of an elite track and field sprinter (Suzuki, Sato et al. 2006). Since we observed mostly *trivial-to-small* changes in performance and a few beneficial changes in physiological characteristic to training, the approach to training used in this study may be applied by Sprint Kayakers when there are relatively short training periods between major competitions, especially when high performance levels need to be maintained. However, when this is the case, additional specific race pace stimulus should be implemented in order to maintain performance levels. Nonetheless, future studies are also required to examine if different training periodization strategies and methodologies may improve Sprint Kayak performance during short training cycles.

Limitations

Whilst the present study provides new information on difference training approaches for young Sprint Kayak athletes, it has several limitations that must be acknowledged. The first is the relatively low sample, which lowers the statistical power of the study. However, well-trained junior Sprint Kayak athletes are a very specific and

small population, and the group that participated in this study were representative of highly trained young Sprint Kayak athletes. Indeed, 18 out of 20 of the athletes in the present study had competed at national championships with 10 being selected for the national team. A further limitation of the study was the short duration of the intervention period which may not have been sufficient to elicit greater training adaptations in well-trained athletes. However, due to the invasive nature of the study on the training routines of these athletes, we were unable to interfere with their training programs for a greater duration. Future studies should investigate the efficacy of the RS and HIA interval training over longer training periods. Finally, methodological issues with assessing time-trial performance on water such as wind influence may have influenced the performance results. Even though wind intensity was similar at testing days, random changes of wind direction could not be totally kept consistent. Whilst, no as ecologically valid, future studies should consider using well-controlled time trials in the laboratory conditions.

Practical applications

This was the first study to verify the effects of RS and HIA interval training on selected physiological, oxygen kinetics at whole body and muscle level and on-water performance. Coaches and sport scientists could use the training dose applied in this study as a reference to guide for developing optimal training strategies for training in Sprint Kayak. Furthermore, similar strategies to the present investigation may be implemented during short intervals between competitions since most variables remained stable during the period of the study.

Conclusions

In summary, the present results demonstrated that despite completing large overall training loads, the addition of five weeks of twice weekly RS or HIA interval training induced *trivial to small* performance impairments in on-water 200 and 1000-m Sprint Kayak time trial performance in well-trained kayakers. Despite this, this short intervention in already well-trained Sprint Kayak athletes induced a *small* speeding of the muscle oxygen kinetics at the severe domain in the RS training group whereas whole body oxygen kinetics improved with a *small* change for the moderate and *moderate* change for the severe domain. On the basis of the current findings, it seems that very well-trained athletes may require large increases in specific training stimulus such as RS or HIA; or longer training periods of training to induce larger performance adaptations. Moreover, it would also be interesting if a greater range of outcome measures not assessed here were used. For example, changes in neuromuscular and anaerobic capacities are likely to be important, especially since these are related to 200-m performance. Collectively, these findings can be used to guide coaches in planning training for Sprint Kayak athletes when preparing for competition.

CHAPTER NINE

General Discussion

1. Main Findings

The Sprint Kayak program at the Olympic Games has changed with the inclusion of the 200-m events for both men and women. Up to and including the 2008 Beijing Olympics, male Sprint Kayak athletes had competed over 500 and 1000-m races and women over 500m only. However, at the 2012 games the 200-m for men and women was included at the expense of the men's 500-m program. Due to the larger difference in raced distances in the new program, male athletes were required to focus their training and specialize in either the 200-m or 1000-m event and to date, little is known if women can focus on both the 200-m and 500-m. However, there is presently relatively little available empirical data on the race profiles and physiological demands of these events to inform coaches and scientists to develop evidence-based training programs for young developing athletes to compete in these events.

The physiological demands of Sprint Kayak have previously been estimated in the laboratory setting. Moreover, the predictive power of these physiological variables has been established in athletes from a variety of performance levels although studies investigating well-trained junior Sprint Kayak athletes lacks. This is surprising as athletes from this age group provide the talent pool for future open-age athletes. It is logical that a better understanding of the physical and physiological factors that are best related to performance in both the 200 and 1000-m events can be used to direct training programs, so that athletes may be able to focus their training practices. It has previously been established that whilst higher levels of aerobic fitness benefits athletes in both distances, there are stronger associations between $\dot{V}O_2max$, LT_2 and MAP and 1000-m time trial performance, and anaerobic characteristics are better related to 200-m performance (Fry and Morton 1991, van Someren and Palmer 2003, van Someren and

Howatson 2008). However, due to the fast acceleration and boat speeds required for 200 and 1000-m events, physiological factors not yet investigated such as the oxygen kinetics at both the whole body and muscle level, and muscle oxygenation parameters may provide additional insight into the physiological factors related to Sprint Kayak performance. Such information may be useful for specific training programs for developing Sprint Kayak athletes. Therefore, a series of applied research studies were conducted in order to describe racing (i.e. pacing) and physiological characteristics of well-trained junior Sprint Kayak athletes, to compare for specific training methods for improving physical performance and physiological characteristics important for Sprint Kayak, and to develop methods to monitoring and controlling training for Sprint Kayak athletes.

Racing profile of world-class (pacing) and the physiological characteristics of junior Sprint Kayak athletes.

The results of the pacing analysis of world-class Sprint Kayak athletes (study 1) show that athletes regulate their effort to enhance performance and that a fast start is common practice in world class Sprint Kayak racing. In fact, the results demonstrated that athletes from A finals (top 9) of the 1000-m events for men were superior to their lower ranked counterparts (B final: 10th - 18th). Moreover, between-season variations in pacing strategies were also observed, suggesting that the athletes and coaches may adopt different approaches to training through an Olympic cycle, or that different environmental conditions at each event venue may affect race pacing strategies. It was also observed that the pacing strategy of K1 boats differed from the K4 boats. A variety of factors including fitness levels, racing experience, influences of opponent boats or the athletes training and recovery strategies during regattas may explain such findings.

It is also possible that the hull-water interaction explains part of the differences in pacing strategies between the K1 and K4 boats as the larger four boats are heavier and possess greater 'wetted' area and therefore, higher drag. Each of these factors should be considered when developing training strategies race tactics, and analysing race performance results in Sprint Kayak athletes, especially for the junior athletes that are still developing and learning the best approach to competition.

Results from the study 2 also showed that well-trained junior athletes have similar levels of aerobic fitness as to their senior counterparts, with both maximal and submaximal relative fitness indicators similar to those reported for senior athletes. Similar to previous research on open senior Sprint Kayakers, we also observed very strong relationships between aerobic fitness indicators and performance in both 200 and 1000-m. The first of our original findings was that the athletes who extracted more oxygen from muscle were also faster in the 200-m time trials. In contrast, the well-trained junior Sprint Kayak athletes were lighter, had attenuated maximum power outputs and power output at given $\dot{V}O_2$ or lactate levels, suggesting that their anaerobic characteristics were not yet fully developed. When taken in the context of previous research, the present findings suggest that the development of lean muscle mass, strength, power and anaerobic capacities and maintaining aerobic fitness levels are important for junior Sprint Kayak athletes if they are to be successful in open-age competitions.

A novel finding from the present thesis was the stronger relationships between muscle $O_{2kinetics}$ and 200-m time-trial performance. These results suggest that the ability to extract oxygen for energy production is important for 200-m while reloading

haemoglobin with oxygen is more important for 1000-m performance. These findings could be implemented for designing the training program, where adaptations could be targeted based on these demands. Indeed, Sprint Kayak training interventions that focus on oxygen extraction capacity such as repeated sprint and sprint interval training with efforts from 10 to 30 s may be more appropriate for improving 200-m time-trial performance, whilst interventions that have been shown to improve aerobic fitness and haemoglobin O_2 reloading such as long and short interval training may assist 1000-m time trial performance (Buchheit and Laursen 2013, Buchheit and Laursen 2013).

Methods for monitoring, controlling and examining the training process

The general goal of most athletic training programs is to structure the training stimulus to augment the athlete's technical and perceptual capacities through overreaching and ultimately when unloaded performance is enhanced. Therefore, it is not only important that the training content and loads are appropriate and well-structured, but that these programs are monitored to determine how athletes may be 'coping' with training or if the training responses agrees with what was planned. To achieve this, valid, reliable and cost effective methods for quantifying the training loads should be utilized. The results from the study 4 shows the session-RPE method is valid and practical method for quantifying the internal training load during Sprint Kayak training. Moreover, it was also demonstrated that the athletes rating of perceived exertion to a Sprint kayak session is affected by the perceptual scale used and the training characteristics. For example, the Borg's' (1998) 6-20 scale was designed using linear rating scale, which logically agrees with the characteristics of longer aerobic exercise sessions. This type of exercise is broadly applied in the preparation of junior

Sprint Kayak athletes and often forms the basis of developing aerobic fitness characteristics (Garcia-Pallares, Sanchez-Medina et al. 2009, García-Pallarés and Izquierdo 2011), which are strongly related to performance in all Sprint Kayak events (Fry and Morton 1991, van Someren and Palmer 2003, van Someren and Howatson 2008). The findings of the present thesis also demonstrated that Sprint Kayak athletes with higher fitness levels and better on-water performance also presented lower session-RPE training loads for the same training program and therefore external loads. Combined, these observations show that monitoring session-RPE loads in Sprint Kayak athletes may also be used to inform coaches and athletes on how the athletes are adapting to training. As part of this thesis, a new repeat sprint performance test (SK_{test}) for monitoring training adaptations in Sprint Kayak athletes was developed (study 3). The new SK_{test} was shown to be valid, reliable and sensitive for detecting changes in performance when applied either on-water or in the laboratory. When used together, these tools can be confidently used to monitor the training process in Sprint kayak athletes. In particular, the session-RPE can be used to the athlete's response to training, whilst the SK_{test} can be used to gauge fitness and performance changes in the training environment. When applied in an iterative monitoring model, this process can be used to guide coaches and sport scientists in implementing effective individualized training programs for Sprint Kayak athletes.

Controlling and examining the training process

Traditional training periodization theory suggests that different training goals should be established over the season such that the connecting and sequencing of these loads lead to enhanced performance (Smith 2003). Indeed, coaches usually program specific training micro- and/or macro-cycles, which are sequenced training sessions that combine to elicit training adaptations that meet these pre-established goals (Issurin 2008, Garcia-Pallares, Garcia-Fernandez et al. 2010). However, for coaches to have confidence in their training prescriptions during these training cycles, knowledge of the physiological and perceptual responses to specific training sessions are required. Despite relatively poor knowledge of the specific acute responses to RS and HIA interval training, these sessions are commonly applied to improve characteristics related to the 200 and 1000-m Sprint Kayak events, respectively. Therefore, study 5 examined the acute responses of power output, physiological and perceptual variables of two distinct repeated sprint and two high-intensity aerobic interval training sessions. RS training induced a greater stimulus to anaerobic pathways such as greater mean power output and blood lactate responses while HIA interval training provides a greater stimulus to the aerobic pathways including greater $\dot{V}O_2$ and mean HR responses. However, an important observation for this study was that of the responses to the entire training session was considered, including warm up, main body and cool down, mean session power outputs were similar and there were only a few physiological variables that differed between the different sessions. The practical inferences from these findings are that the coaches should consider the stressors of the whole session and not just the content of main training sets of each work out as the overall stimulus for adaptation whereas the main body of a particular session determines the short term adaptive aim for the training session or even a short period of time. A further interesting observation

from this thesis was the large variation in the times spent in low, moderate and high-intensity training zones for the various physiological markers when related to the same external loads (power outputs) in well-trained junior Sprint Kayak athletes. This highlights the importance of understanding each individual athlete's responses to specific training sessions and the importance of providing individualized training programs in Sprint Kayak athletes training for specific competitive events.

Finally, study 6 examined the effects of five weeks of twice weekly RS and HIA interval training on fitness, oxygen kinetics (muscle and whole body) and on-water time trial performance in well-trained junior Sprint Kayak athletes. The results showed only *trivial* to *small* performance changes in 200 and 1000-m Sprint Kayak time trial performance during short to medium term training focus on either RS or HIA when athletes are already well trained. In contrast, *small* to *moderate* changes observed in whole body and muscle oxygen kinetics characteristics with slightly greater changes elicited by HIA interval training compared to RS training. These results agree with many previous studies in a variety of sports that show that submaximal physiological responses are more sensitive to training stimulus than maximal performance of physiological adaptations. Based on the current findings it seems that very well trained athletes may require large increases in training stimulus or longer training periods of training to larger performance adaptations. Future research should focus on monitoring and controlling the training process in well-trained junior Sprint Kayak for a longer period as it seems well-trained athletes require more time to generate adaptation.

The model applied in this thesis proposes a systematic approach for monitoring and controlling the training process. The findings showed that a thorough description of the

pacing and physiological demands of competition can aid in the development and implementation of training methods that can improve the processes of training. Indeed, designing training sessions based on known responses to specific stimuli and understanding how longer term application of such stimuli affect physiological and performance outcomes for athletes. Moreover, the training process can also be improved by using specific validated tools that are sensitive to typical training approaches used in a specific sport, both the SK_{test} and session-RPE method can be used together to improve the training processes in Sprint Kayak.

2. Limitations

This thesis has taken an applied approach to understanding the racing and competition demands of Sprint kayak competition. Moreover, the acute and longer term performance and physiological responses to specific training approaches in Sprint Kayak were also examined. New methods for quantifying training load and assessing physiological and performance adaptations in the field were also developed. However, with the exception of study 1, each of these studies was conducted in well-trained, young developing Sprint Kayak athletes. Therefore, care should be taken in extending these findings to other age groups.

Study 1 only analysed official split and total times from major international events. Unfortunately, the relatively crude data (250 m time splits) did not allow describing precisely the actual pacing strategy adopted. Nevertheless, this study provided new information on real competition without any experimental manipulation of the pacing or racing condition. Additionally, in study 2 controlled laboratory based time trials over the 200 and 1000-m were not accomplished, which limits further insights on the basis of

these findings and actual physiological response of well-trained Sprint Kayak athletes. In Study 3 the Sprint Kayak on-water testing will be affected by environmental conditions such as wind speed and direction, water and ambient temperature. During testing the weather conditions were similar for all on-water sessions as it was decided to not test if the wind speed was greater than 3 m·s^{-1}, which is likely to have contributed to the good level of reliability observed in these tests. Nevertheless, from a practical point view, it is important to apply the SK$_{test}$ under consistent weather conditions, to reduce the noise in the measurement. Furthermore, in study four a greater sample of paddlers of various ages and fitness level would increase the generalization of our findings. However, since the data was collected in a real training environment in highly trained junior kayakers, these data have strong ecological applicability. The study 5 presented difficulties when comparing the responses between the different training sessions completed in this study was that it was difficult to match each session for each internal and external training load. Initially it was intended to match training sessions for external load using mean power output. Clearly the physiological responses to these sessions are dependent upon many factors such as session duration, work interval intensity, work interval duration, between-effort relief characteristics, work/relief ratio and exercise mode. Finally, the relatively low sample size for study 6 may lower the statistical power of the study. However, well-trained junior Sprint Kayak athletes are a very specific and small population in Australia, and the group that participated in this study was representative of highly trained young Sprint Kayak athletes. Indeed, 18 out of 20 of the athletes in the present study had competed at national championships with 10 being selected for the national team to compete internationally. A further limitation of the study as the short duration of the intervention period which may not have been sufficient to elicit greater training adaptations in well-trained athletes. Moreover, the time trials being conducted

on-water only and not in the laboratory may have masked any effects in 200 and 1000-m performance. However, due to the invasive nature of the study on the training routines of these athletes, we were unable to interfere with their training programs for a greater duration. Future studies should investigate the efficacy of the RS and HIA interval training over longer training periods. Additionally, methodological issues with measuring NIRS data during sprint kayaking may have created measurement 'noise' that could have affected the results. Indeed, the nature of testing NIRS whilst paddling on a kayak ergometer is that the power production varies according to the tension implied to the paddle. These characteristics seems to have generated noise in the NIRS data, evidenced by wide spread of the confidence limits in the data.

3. Practical Applications

This thesis identified practical recommendation regarding monitoring and controlling training that can be implemented in Sprint Kayak training:

- Coaches and sport scientists should consider using this pacing profile information as a reference when organizing their training programs or when defining racing strategies. The K4 in particular requires a well-planned pacing strategy, as it has a different profile to the K1. Such strategy would include practicing even pace strategies at targeted race performance. Moreover, the team boats may receive different training approach including fast starts, even pacing and perhaps the end spurt in order to distribute the effort over 1000 m and 500 m better.

- Training programs that for talented junior athletes should continue developing general aerobic fitness as these characteristics may be required if athletes are to specialise in either the 200-m or 1000-m event. However, general strength and lean muscle mass should be developed to meet the demands of under 23 and senior level.

- Coaches and sport scientists can confidently use the SK_{test} as a monitoring tool over the training season. Meaningful changes of 2-3% can be considered for the ergometer and on-water tests, respectively.

- Coaches and sport scientists can be confident in quantifying training loads using the session-RPE method, regardless of the RPE scales used. However, coaches should be aware that aerobic fitness and Sprint Kayak performance are related to athletes perception of training intensity during training, suggesting that better performing and fitter athletes may have perceived the same training session to be easier than their poorer performing or less fit counterparts. Coaches could use this information as a simple monitoring tool to assess how athletes within a training squad are adapting to training

- The main body of the RS and HIA interval training sessions seems to be responsible for adaptation. Therefore, coaches may focus on the main part of the training session when planning the short term adaptations of smaller training cycles. However, the entire training session is recommended to gauge the overall strain on a daily basis. Finally, more individualized training content is

recommended to be implemented, as athletes respond differently to the training loads.

- The application of RS training provides greater activation of the anaerobic glycolytic system whilst HIA interval has greater energetic cost and aerobic system.

- Coaches and sport scientists may use the training dose applied in this study as a reference to guide for developing optimal training strategies for training in Sprint Kayak. Furthermore, a monitoring training loads and performance system may be implemented during short intervals between competitions since most variables remained stable during the period of the study.

CHAPTER TEN

Summary and Recommendations

1. Thesis Summary

This thesis consisted of a number of applied studies that addressed various problems that improved our understanding of the physiological and racing demands of Sprint Kayak competition, training techniques for improving Sprint Kayak performance and methods for monitoring and controlling Sprint Kayak training. Specifically, the studies in this thesis investigated the profile of pacing strategies used by world-class kayakers during world championships (Study 1); profiled the physiological characteristics of developing junior Sprint Kayak athletes and established the relationships between these physiological variables ($\dot{V}O_{2kinetics}$, $M_{O2kinetics}$, paddling efficiency and Sprint Kayak time-trial (Study 2); developed a valid, reliable and sensitive field-based test for Sprint Kayak athletes that could be applied to athletes on a regular basis (Study 3); determined the validity of the session-RPE method using the three different scales of perceived exertion compared to common measures of training load (Study 4).; described the power outputs and acute physiological responses to common RS and HIA training sessions in well-trained young Sprint Kayak athletes (Study 5); and examined the effects of RS compared with HIA interval training on physiological variables and performance indicators in well-trained junior Sprint Kayak athletes (Study 6). A summary of the findings from the series of investigations conducted as part of the thesis is shown in Table 10.1.

Table 10.1: Summary of the investigations conducted as part of the thesis.

Study (Number, Chapter, Title)	Subjects	Study Design	Training	Performance and Physiological Tests	Findings
1 Chapter 3 Pacing characteristics of international Sprint Kayak athletes	Competitors of seven years of world championship (n = 486 finals)	Observational design	n/a	n/a	The 1000-m Sprint kayak competition has a reversed-J shaped pacing profile, whilst a fast start strategy is common in both the 1000 and 500-m competitions. The pacing profile in Sprint Kayak depends on boat (individual, double or four-set) and race level (final A or B).
2 Chapter 4 Physiological characteristics of well-trained junior Sprint Kayak athletes	21 well-trained junior Sprint Kayak athletes (13 males, 8 females).	Cross-sectional design	n/a	On-water 200 and 1000-m time trials; Incremental step test; Square wave tests	Well-trained junior athletes have similar levels of relative aerobic fitness compared to older counterparts. General aerobic fitness is better related to 1000-m performance whereas muscle oxygen kinetics relates better to 200-m performance.
3 Chapter 5 A new field test for assessing and monitoring Sprint Kayak athletes	Part A: 11 well-trained junior Sprint Kayak athletes; Part C: 8 well trained young Sprint Kayak athletes (n=19)	Cross-sectional design	n/a	On-water 200 and 1000-m time trials; Incremental step test; SKtest	The repeat-sprint SK_{test} is a valid and reliable measure of Sprint Kayak performance. The test is also for detecting meaningful changes in Sprint Kayak performance either in the laboratory or in the field.
4 Chapter 6 Methods for quantifying training in Sprint Kayak	10 well-trained junior Sprint Kayak athletes	Longitudinal observational design	Specific preparation period	On-water 200 and 1000-m time trials; Incremental step test	Session-RPE is valid for quantifying training loads of junior Sprint Kayak athletes. The level of validity of the session-RPE method is affected by on the RPE scale used and nature of the training completed

SKtest = Sprint Kayak test; **RPE** = Ratings of perceived exertion.

Table 10.1 (cont.): Summary of the investigations conducted as part of the thesis.

Study (Number, Chapter, Title)	Subjects	Study Design	Training	Performance and Physiological Tests	Findings
5 Chapter 7 Comparison of the acute physiological responses of repeated sprint and high-intensity aerobic training sessions in Sprint Kayak athletes.	11 well-trained junior Sprint Kayak athletes (m=9; f = 2)	Randomised, Cross-over design	4 training sessions (2 RS – 10 s and 30 s; 2 HIA 3 min and 2km)	Incremental step test;	Mean power output, blood lactate, perceptual, HR and $\dot{V}O_2$ responses for main body of RS, compared to HIA – TSI were similar. Similar responses for s-RPE, TSI, mean power output and HR; $\dot{V}O_2$, distance covered; and lactate for the entire RS compared to HIA training session. Athletes significantly differed in the responses in the time spent in low, moderate and high-intensity zones for the power output and $\dot{V}O_2$, for the same training sessions.
6 Chapter 8 Comparison of repeat sprint and high-intensity aerobic interval training on physiological variables and performance in junior Sprint Kayak athletes.	20 well-trained junior Sprint Kayak athletes (m=12; f = 8)	Matched-groups, pre-post parallel control design	5 weeks of regular training with twice weekly RS or HIA interval training in addition to usual training	On-water 200 and 1000-m time trials; Incremental step test; Square wave tests	5 weeks of training presented impaired responses of on-water performance, general fitness indicators, whole body and muscle oxygen kinetics. Well-trained junior Sprint Kayak athletes may require greater loads and longer periods to adapt than the doses used in the present study.

RS = Repeated sprint; **HIA** = High-intensity aerobic training; **HR** = Heart rate; **TSI** = Tissue saturation index; **RPE** = Ratings of perceived exertion; $\dot{V}\mathbf{O_2}$ = Oxygen consumption; m = male; f = female

This thesis provided new knowledge on racing demands of Sprint Kayak. The results showed that under actual competition, world-class athletes apply a fast start strategy in both 1000 and 500-m events for all individual, double and four seat boats. Individual boats adopt an end spurt towards the end of the race, whilst the larger crew boats tend to adopt an even pacing strategy after the starting phase after start. Moreover, higher ranked athletes employ a more "aggressive" pacing approach than their lower ranked counterparts. The results from the thesis also showed that well-trained junior Sprint Kayak athletes have similar levels of aerobic fitness when expressed relative to body mass as their older counterparts competing at senior level. Moreover, it was also observed that general aerobic fitness indicators had stronger relationships related to 1000-m on-water time-trial performance, whilst the muscle oxygen kinetics were related better with 200-m on-water time-trial performance.

The junior Sprint Kayak athletes are the talent pool for future open-age athletes that may compete in International competitions. Accordingly, it is important that both training content and athlete monitoring systems are used to maximise athlete development during the developmental stages of their careers. This thesis provides appropriate tools to quantify both training, with the validation of the session-RPE method for junior Sprint Kayak and monitor performance using the new SK_{test}. This new field test was developed to be implemented as part of standard training session, and designed to be able to be implemented in relatively confined spaces with a group of athletes. Bothe session-RPE method and the SK_{test} were shown to be valid for use in Sprint Kayak, and the SK_{test} was shown to be reliable and have sufficient sensitivity for detecting changes in performance that are commonly observed with Sprint Kayak training in well trained young athletes.

Study five of thesis presented new findings on acute responses of short and long RS and HIA interval training sessions in a controlled laboratory setting. It was shown that the responses to the RS sessions are more similar to the competitive demands of the 200-m event, whilst the HIA sessions are similar to the demands of the 1000-m time trial. Moreover, the results also demonstrated the potential impact of the warm-up and cool down on the overall sessions' stimulus that should be taken into account when planning training. It might be that the energetic cost of high-intensity interval training sessions contribute to the cardiopulmonary adaptations whilst the higher power outputs achieved during the main body of each session is the drive the changes in neuromuscular adaptations. Finally, a large between-athlete variation in the physiological stimulus was observed, even when external loads were controlled in these sessions. Collectively, these findings suggest that as athletes may respond differently for same training sessions, and highlight the importance of individualized training plans for Sprint Kayak athletes. Finally, five weeks of short and long RS or HIA interval training in addition to ordinary Sprint Kayak training had unclear effects on both on-water Sprint Kayak performance over 200 and 1000-m and physiological variables including $\dot{V}O_2max$, lactate threshold, maximal aerobic power, whole body and muscle oxygen kinetics. Taken together, the findings of this thesis provide novel information on the racing characteristics as well as the physiological profile of well-trained junior Sprint Kayak. Moreover, methods for monitoring and controlling the training process of well-trained junior Sprint Kayak is provided. Nonetheless, further research is still required on this topic.

2. Directions for Future Research

To expand upon the findings of this thesis, and develop a greater understanding of the specific demands Sprint Kayak racing, the monitoring and controlling the training in Sprint Kayak, it is recommended that further research investigate the following:

- Racing profiles of world-class junior and under 23 athletes is required to better understand the evolution of pacing aspects of Sprint Kayak;

- Future pacing studies in Sprint Kayak should use more data points to gain greater insight into the work distribution during each event – new technologies such as GPS systems may be used to provide more sensitive pacing data in such studies;

- The career evolution in physiological and performance profiles of Sprint Kayakers, for both the 200- and 1000-m events is required.

- Examine the proportional body segments and neuromuscular characteristics of senior athletes with junior and under 23 athletes to better understand the anthropometrical factors that might be important for Sprint Kayak performance.

- Determine the physiological demands of on-water performance over 200, 500 and 1000-m. Additionally, examine the relationships between neuromuscular and anaerobic capacities with time-trial performance over these distances.

- Determine the role of strength and power for junior developing Sprint Kayak athletes and performance.

- Dose-response studies for RS and HIA interval training on physiological (i.e. aerobic, anaerobic, and neuromuscular characteristics) and performance (i.e. 200-m and 100-m time-trials) characteristics;

- Longer-term (i.e. 6 months to 4 years) monitoring of responses to Sprint Kayak training in junior athletes through systematic monitoring training characteristics, fitness, fatigue and performance relationships.

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APPENDIX

UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I _____ *(participant's name)* agree to participate in the research project "**The relationship between physiological characteristics and performance in Olympic distance sprint kayak events**" being conducted by Thiago Oliveira Borges at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney.

I understand that the purpose of this study is to determine the relationships between physiological variables ($\dot{V}O_2max$, $\dot{V}O_2kinetics$, anthropometry, muscle strength and power) and race performance in Olympic distance sprint kayak events (1000-m and 200-m events). I understand that my participation in this research may involve up to 20 h of my time over a two week period. I also understand that there are possible risks in participating in this study. These possible risks are:

1.   Risk of Infection from Capillarised Blood Sample: There is a very small risk of infection from the capillarised blood sample (approximately 1 drop [50   However, all capillarised blood]) during the sampling will be undertaken by a trained personal under sterile conditions using standard procedures. This procedure is standard in sport science laboratories.

2.   Fatigue from Training: The exercise protocols in the present study will be demanding. It is anticipated that you may feel general fatigue from physical training completed in this study. However, this fatigue will be no greater than you normally endure during training for your sport.

3.   Muscle Strains: There is a minor risk of suffering a muscular strain during the exercise being completed during the studies. As the testing in some instances involves maximal force production, it is important for the subject to warm up prior to exercise and warm down at the completion. Leading up to the maximal tests, you will perform activities that gradually increase muscle temperature to ensure that injury risk is minimised during testing.

I understand that UTS attempts to ensure that the greatest of care will be taken by the researchers during the testing and training sessions. However, I acknowledge that UTS, its agents and employees will not be liable for any loss or damage arising directly or indirectly from these testing and training sessions. I acknowledge and accept that there are risks involved, including but not limited to discomfort, injury and, in extremely rare circumstances, death. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty. I am aware that I can contact Thiago Oliveira Borges (phone: 02 9514 5846 or _____) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Thiago Oliveira Borges has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____   ____/____/____

Signed by

_____   ____/____/____

Witnessed by

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Manager, Susanna Gorman (ph: 02 - 9514 1279, Susanna.Gorman@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I _____ *(participant's name)* agree to participate in the research project "**A field-based test to assess aerobic and anaerobic fitness in Sprint Kayak**" being conducted by Thiago Oliveira Borges at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney.

I understand that the purpose of this study is to establish test standards for Sprint Kayak and also determine validity and reliability for this test in the laboratory and on water. I understand that my participation in this research may involve up to 14 h of my time over a three week period. I also understand that there are possible risks in participating in this study. These possible risks are:

4. <u>Risk of Infection from Capillarised Blood Sample</u>: There is a very small risk of infection from the capillarised blood sample (approximately 1 drop [50   ]) taken from an earlob However, all capillarised blood sampling will be undertaken by a trained personal under sterile conditions using standard procedures. This procedure is standard in sport science laboratories.
5. <u>Fatigue from Training:</u> The exercise protocols in the present study will be demanding. It is anticipated that you may feel general fatigue from physical training completed in this study. However, this fatigue will be no greater than you normally endure during training for your sport.
6. <u>Muscle Strains:</u> There is a minor risk of suffering a muscular strain during the exercise being completed during the studies. As the testing in some instances involves maximal force production, it is important for the subject to warm up prior to exercise and warm down at the completion. Leading up to the maximal tests, you will perform activities that gradually build up their muscle temperature to ensure that injury risk is minimised during testing to minimise this risk.

I understand that UTS attempts to ensure that the greatest of care will be taken by the researchers during the testing and training sessions. However, I acknowledge that UTS, its agents and employees will not be liable for any loss or damage arising directly or indirectly from these testing and training sessions. I acknowledge and accept that there are risks involved, including but not limited to discomfort, injury and, in extremely rare circumstances, death. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty.

I am aware that I can contact Thiago Oliveira Borges (phone: 07 5576 4386 or   ) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Thiago Oliveira Borges has answered all my questions fully and clearly.
I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____   ____/____/____

Signed by

_____   ____/____/____

Witnessed by

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics manager, Ms Susanna Gorman (ph: 02 - 9514 1279, Susanna.Davis@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

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UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I _____ *(participant's name)* agree to participate in the research project "**Quantifying training dose in Sprint Kayak**" being conducted by Thiago Oliveira Borges at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney.

I understand that the purpose of this study is to determine the validity of the session-RPE method for quantifying training loads using three different RPE scales and training impulse measures from individual lactate and GPS-determined velocity curves. I understand that my participation in this research may involve up to 90 h of my time over a five week period, which corresponds to the time I will spend during my training routine. I also understand that there are possible risks in participating in this study. These possible risks are:

7.   <u>Risk of Infection from Capillarised Blood Sample</u>: There is a very small risk of infection from the capillarised blood sample (approximately 1 drop [50 μL] taken from an earlobe). However, all capillarised blood sampling will be undertaken by trained personal under sterile conditions using standard procedures. This procedure is standard in sport science laboratories.

8.   <u>Fatigue from Training:</u> The exercise protocols in the present study will be demanding. It is anticipated that you may feel general fatigue from physical training completed in this study. However, this fatigue will be no greater than you normally endure during training for your sport.

9.   <u>Muscle Strains:</u> There is a minor risk of suffering a muscular strain during the exercise being completed during the studies. As the testing in some instances involves maximal force production, it is important for the subject to warm up prior to exercise and warm down at the completion. Leading up to the maximal tests, you will perform activities that gradually build up their muscle temperature to ensure that injury risk is minimised during testing to minimise this risk.

I understand that UTS attempts to ensure that the greatest of care will be taken by the researchers during the testing and training sessions. However, I acknowledge that UTS, its agents and employees will not be liable for any loss or damage arising directly or indirectly from these testing and training sessions. I acknowledge and accept that there are risks involved, including but not limited to discomfort, injury and, in extremely rare circumstances, death. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty.

I am aware that I can contact Thiago Oliveira Borges (phone: 02 9514 5846 or [redacted]) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Thiago Oliveira Borges has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____   ____/____/____

Signed by

_____   ____/____/____

Witnessed by

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Manager, Susanna Gorman (ph: 02 - 9514 1279, Susanna.Gorman@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I _____ *(participant's name)* agree to participate in the research project "**The acute response of repeated sprint-based and high-intensity aerobic training sessions on sprint kayak athletes**" being conducted by Thiago Oliveira Borges at the School of Nursery, Midwifery and Health, University of Technology, Sydney.

I understand that the purpose of this study is to verify the acute response of two different training regimes on physiological variables in well trained Sprint kayakers. I understand that my participation in this research may involve up to 30 h of my time over a five week period. I also understand that there are possible risks in participating in this study. These possible risks are:

10.   Risk of Infection from Capillarised Blood Sample: There is a very small risk of infection from the capillarised blood sample (approximately 1 drop [50   the] study. However, all capillarised blood sampling will be undertaken by a trained personal under sterile conditions using standard procedures. This procedure is standard in sport science laboratories.

11.   Fatigue from Training: The exercise protocols in the present study will be demanding. It is anticipated that you may feel general fatigue from physical training completed in this study. However, this fatigue will be no greater than you normally endure during training for your sport.

12.   Muscle Strains: There is a minor risk of suffering a muscular strain during the exercise being completed during the studies. As the testing in some instances involves maximal force production, it is important for the subject to warm up prior to exercise and warm down at the completion. Leading up to the maximal tests, you will perform activities that gradually increase muscle temperature to ensure that injury risk is minimised during testing.

I understand that UTS attempts to ensure that the greatest of care will be taken by the researchers during the testing and training sessions. However, I acknowledge that UTS, its agents and employees will not be liable for any loss or damage arising directly or indirectly from these testing and training sessions. I acknowledge and accept that there are risks involved, including but not limited to discomfort, injury and, in extremely rare circumstances, death. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty. I am aware that I can contact Thiago Oliveira Borges (phone: 02 9514 5846 or ⬛⬛⬛⬛⬛) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Thiago Oliveira Borges has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____   ____/____/____

Signed by

_____   ____/____/____

Witnessed by

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Manager, Susanna Gorman (ph: 02 - 9514 1279, Susanna.Gorman@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I _____ *(participant's name)* agree to participate in the research project **"The effects of repeated sprint- and high-intensity aerobic-based training on oxygen uptake kinetics in Sprint Kayak**" being conducted by Thiago Oliveira Borges at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney.

I understand that the purpose of this study is to test the effects of two different training regimes on aerobic and anaerobic fitness characteristics in Sprint Kayak athletes. I understand that my participation in this research may involve up to 200 h of my time over a ten week period. I also understand that there are possible risks in participating in this study. These possible risks are:

1.   <u>Risk of Infection from Capillarised Blood Sample</u>: There is a very small risk of infection from the capillarised blood sample (approximately 1 drop [50   However, all from an earlob capillarised blood sampling will be undertaken by a trained personal under sterile conditions using standard procedures. This procedure is standard in sport science laboratories.
2.   <u>Fatigue from Training:</u> The exercise protocols in the present study will be demanding. It is anticipated that you may feel general fatigue from physical training completed in this study. However, this fatigue will be no greater than you normally endure during training for your sport.
3.   <u>Muscle Strains:</u> There is a minor risk of suffering a muscular strain during the exercise being completed during the studies. As the testing in some instances involves maximal force production, it is important for the subject to warm up prior to exercise and warm down at the completion. Leading up to the maximal tests, you will perform activities that gradually build up their muscle temperature to ensure that injury risk is minimised during testing to minimise this risk.

I understand that UTS attempts to ensure that the greatest of care will be taken by the researchers during the testing and training sessions. However, I acknowledge that UTS, its agents and employees will not be liable for any loss or damage arising directly or indirectly from these testing and training sessions. I acknowledge and accept that there are risks involved, including but not limited to discomfort, injury and, in extremely rare circumstances, death. I acknowledge and accept that my participation is entirely voluntary, and that UTS has accepted my participation in good faith without express implied warranty.

I am aware that I can contact Thiago Oliveira Borges (phone: 02 9514 5846 or ▮▮▮▮▮▮▮) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason.

I agree that Thiago Oliveira Borges has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

_____   ____/____/____

Signed by

_____   ____/____/____

Witnessed by

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer, Susanna Gorman (ph: 02 - 9514 1279, Susanna.Gorman@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

20 July 2011

Associate Professor Aaron Coutts
School of Leisure, Sport and Tourism
KG01.06.78
UNIVERSITY OF TECHNOLOGY, SYDNEY

Dear Aaron,
UTS HREC 2011-162 – COUTTS, Associate Professor Aaron, BULLOCK, Dr Nicola, et al (for BORGES, Thiago Oliveria PhD student) – "The relationship between $\dot{V}O_2$ kinetics and performance in Olympic distances of Sprint Kayak"

Thank you for your response to my email dated 25/05/11. Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics clearance is now granted.

Your clearance number is UTS HREC REF NO. 2011-159A

Please note that the ethical conduct of research is an on-going process. The *National Statement on Ethical Conduct in Research Involving Humans* requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

If you have any queries about your ethics clearance, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,

Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee

20 July 2011

Associate Professor Aaron Coutts
School of Leisure, Sport and Tourism
KG01.06.78
UNIVERSITY OF TECHNOLOGY, SYDNEY

Dear Aaron,
UTS HREC 2011-161 – COUTTS, Associate Professor Aaron, MURPHY, Professor Aaron, et al (for BORGES, Thiago Oliveria PhD student) – "A field-based test to assess aerobic and anaerobic fitness in Sprint Kayak"

Thank you for your response to my email dated 25/05/11. Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics clearance is now granted.

Your clearance number is UTS HREC REF NO. 2011-159A

Please note that the ethical conduct of research is an on-going process. The *National Statement on Ethical Conduct in Research Involving Humans* requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

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If you have any queries about your ethics clearance, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,

Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee

20 July 2011

Associate Professor Aaron Coutts
School of Leisure, Sport and Tourism
KG01.06.78
UNIVERSITY OF TECHNOLOGY, SYDNEY

Dear Aaron,
UTS HREC 2011-159 – COUTTS, Associate Professor Aaron, MURPHY, Professor Aaron, et al (for BORGES, Thiago Oliveria PhD student) – "Quantifying training dose in Sprint Kayak"

Thank you for your response to my email dated 25/05/11. Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics clearance is now granted.

Your clearance number is UTS HREC REF NO. 2011-159A

Please note that the ethical conduct of research is an on-going process. The *National Statement on Ethical Conduct in Research Involving Humans* requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

If you have any queries about your ethics clearance, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,

Professor Marion Haas

Chairperson
UTS Human Research Ethics Committee

Dear Applicant,

Thank you for your response to the Committee's comments for your application titled, "The acute response of repeated sprint-based and high-intensity aerobic training sessions in sprint kayak athletes".

Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics approval is now granted. Any conditions of approval as stipulated in the Committee's comments will be noted on our files.

Your approval number is UTS HREC REF NO. 2012000241

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au)

To access this application, please follow the URLs below:
* if accessing within the UTS network: http://rmprod.itd.uts.edu.au/RMENet/HOM001N.aspx
* if accessing outside of UTS network: https://remote.uts.edu.au , and click on "RMENet - ResearchMaster Enterprise" after logging in.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,
Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney
T: (02) 9514 9645
F: (02) 9514 1244
E: Research.Ethics@uts.edu.au
I: http://www.research.uts.edu.au/policies/restricted/ethics.html
P: PO Box 123, BROADWAY NSW 2007
[Level 14, Building 1, Broadway Campus]
CB01.14.08.04

20 July 2011

Associate Professor Aaron Coutts
School of Leisure, Sport and Tourism
KG01.06.78
UNIVERSITY OF TECHNOLOGY, SYDNEY

Dear Aaron,
UTS HREC 2011-160 – COUTTS, Associate Professor Aaron, BULLOCK, Dr Nicola, et al (for BORGES, Thiago Oliveria PhD student) – "The effects of repeated sprint- and high-intensity aerobic-based training on oxygen uptake kinetics in Sprint Kayak"

Thank you for your response to my email dated 25/05/11. Your response satisfactorily addresses the concerns and questions raised by the Committee, and I am pleased to inform you that ethics clearance is now granted.

Your clearance number is UTS HREC REF NO. 2011-159A

Please note that the ethical conduct of research is an on-going process. The *National Statement on Ethical Conduct in Research Involving Humans* requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

If you have any queries about your ethics clearance, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,

Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee

Table B: – Downs and Black (1998) criteria for Quality of Reporting in Research.

No.	Author(s)	Reporting Quality											
		Hypothesis stated	Main outcomes	Participant characteristics	Intervention described	Confounders	Main Findings described	Variability of estimates	Adverse events	Describes subjects lost	Probability values		

Obs: 1 = yes; 0 = N

Table B(Cont.): – Downs and Black (1998) criteria for Quality of Reporting in Research.

No.	Author(s)	External Validity	Internal Validity (bias)					Internal Validity (selection bias)					TOTAL SCORE (%)
		Representative Sample	Blinding	Researchers blinded	Unplanned analyses identified	Appropriate statistical tests	Accurate outcome measures	Same population recruitment	Recruited at same time	Randomisation	Concealed randomisation	Power	

Obs: 1 = yes; 0 = N