

Training Load Metrics and Responses of Flatwater, Ocean and River Marathon Kayakers in Preparation for Competition

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“You’ll have to excuse my lengthiness—”

— Mark Twain —

Abstract

Background:

Regular training improves performance, particularly in activities like marathon kayaking, which require conditioning for both explosive bursts and sustained endurance efforts. Monitoring training load ensures a balance of physiological stress and recovery, which is critical for optimised improvement. However, there are currently no evidence-informed standards for monitoring training load in marathon kayaking.

Aims & objectives:

The aim is to identify the training load measures and metrics relevant to ocean, flatwater, and river marathon kayaking. This involves exploring low-cost, non-invasive monitoring methods and addressing existing gaps in our understanding of monitoring training load in marathon kayaking. The focus is on determining the effectiveness of these metrics in guiding physical conditioning and overall training performance. Ultimately, the goal is to contribute to the development of monitoring methods that are effective and tailored to the specific context.

Methods:

This dissertation had three parts: a systematic scoping review of the literature to identify the extent of the evidence around monitoring practices in marathon kayaking, followed by a more focused narrative review to more precisely highlight the specific demands of marathon kayaking and establish broad areas of importance. Using insights from the scoping and narrative reviews as a framework, a longitudinal repeated measures observational study was conducted with a cohort of marathon kayakers (n=38). The investigation used various low-cost, non-invasive, remotely deployable tools to monitor the kayakers' training for eight weeks before a race.

Primary findings:

Rating of perceived exertion (RPE) was the most sensitive measurement of session intensity. Furthermore, session RPE was considered the most reliable measure of overall training because it is RPE-derived and aligned with other training accumulation measures. Speed and heart rate were useful metrics with context, such as environmental conditions or when used as relative measures. Training stress can be examined by psychometric measures (DALDA and quick POMS). This cohort had relatively low levels of training stress, which had a minimal effect on the psychometric measures. Time trials are an effective performance measure where course environmental impacts can be mitigated.

Conclusions:

At present, there are practical, non-aversive metrics that provide valuable insights into various aspects of kayak training, including total volume, intensity, response, and performance evaluation. When used in the correct context, these metrics can be effective and well-suited to the needs of competitive kayakers.

Dissertation Roadmap

Figure 1 outlines the dissertation structure: Chapter One provides a brief overview, Chapters Two and Three cover the literature search, Chapters Four, Five and Six present the empirical investigation, and Chapter Seven contains the dissertation's conclusions.

Chapter One briefly overviews the dissertation, including the experimental rationale, aims and objectives, limitations, and key terms and concepts. The dissertation then enters the literature search phase. This includes Chapter Two, a scoping review of training load monitoring in marathon kayaking, which reviews the current and past literature relating to practices and an examination of training in kayaking. Chapter Three is a narrative review of the demands of marathon kayaking. This delves into some of the key demands pertinent to monitoring marathon kayaking.

These literature searches were crucial in forming the experimental questions examined in the empirical investigation in Chapters Four, Five, and Six. These Chapters contained the experimental design, the results, and the discussion of a cohort of kayakers in an eight-week observation training study. Chapter Seven summarises the findings, relates them to the reviewed literature, presents the experimental limitations, and suggests further areas of investigation.

— Roadmap —



Figure 1. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed.

— Chapter 1 —

Background and Outline

Experiment Rationale

The sport of kayaking is a widespread activity gaining popularity. In 2021, over 18.6 million Americans tried kayaking at least once. This indicates an 87 per cent increase in participation since 2010, highlighting sustained growth in the sport (1). The sport's governing body, the International Canoe Federation, recognises more than ten distinct disciplines (2). Among the oldest recognised disciplines is marathon kayaking – a long-distance discipline, including races from five to hundreds of kilometres. Additionally, in recent years, the ICF World Ocean racing championship has become a prominent competitive discipline of the sport (3).

The growing competitive field is prompting athletes to exert considerable effort to gain a competitive edge in racing. As is almost universally true in sports, this improvement is achieved through exercise training (4–6). Exercise training acts as a stimulus that triggers a stress response. In the subsequent periods of rest, adaptations occur (5–7). This stress-rest balance must be balanced correctly for optimal adaptation and prevention of non-functional overreaching or injury (8).

Despite many active training participants, marathon kayaking has yet to be studied as extensively as its Olympic counterparts, sprint and slalom. Moreover, marathon kayaking does not have well-defined or scientifically assessed standards of best practice around training load management or training and performance monitoring. Training monitoring is an important part of safe and efficacious training, informing the balance of stress and rest (9).

This potential absence of specific literature might be attributable to the discipline not being an Olympic event, particularly since sports with Olympic status tend to receive more government investment (10). The increased investment will likely result in additional research and implementation of sport-specific tools in these sports. Additionally, despite

the number of competitors in the discipline, the majority are more recreational kayakers rather than professional athletes.

While some tools for measuring stress-rest from sprint or slalom may be relevant to marathon kayaking, athletes may not be willing to incur the additional expenses and complications associated with high-end laboratory-type measures. Before adopting them, testing any of these metrics from the sprint or slalom events on a subset of marathon kayakers is important to ensure they are effective and correctly quantify the athlete's responses (11). The measures need to be calibrated to the demands pertinent to the sport. Ultimately, the most valuable metrics would be the non-aversive and cost-effective measures that the current growing population of marathon kayakers would most likely adopt.

A thorough review of the literature on training load monitoring in marathon kayaking should reveal the state of research in this area. This would allow a more informed view of the topic moving forward. Moreover, this would lead to selecting, developing and validating tools that can effectively monitor load in marathon kayaking. Ultimately, this will help establish best practices for load monitoring in this increasingly popular sport.

Therefore, this research aims to examine the literature related to marathon kayaking training load monitoring. This will help to identify and test non-aversive, cost-effective training measures suitable to the growing class of competitive marathon kayakers.

Aims and Objectives

The objective is to review existing literature on training load monitoring within marathon kayaking and identify, evaluate, and explore the feasibility of current, potential, or novel load monitoring methods. Additionally, conducting on-water testing with a group of marathon kayakers will help advance the field and establish best practices for monitoring schemes.

Objective 1: Conduct a literature review

- Investigate existing literature on training load monitoring in marathon kayaking to comprehend the current state of knowledge in and around this discipline.
- Identify and assess the load monitoring methods currently employed or potentially applicable in marathon kayaking, considering their effectiveness and limitations.

Objective 2: Empirical testing of monitoring methods

- Examine the practical application and feasibility of these monitoring schemes through on-water testing within a cohort of marathon kayakers, aiming to understand their real-world implications and challenges.

Scope, Intended Contributions and Limitations

This research focuses on training load monitoring and performance measurement methods, metrics, and schemes within ocean, river, and flatwater marathon kayaking contexts. The study focuses on measures useful for recreational paddlers. It follows that the measures should be practical, non-aversive and inexpensive. Additionally, these paddlers should be able to understand and apply the outcomes easily. Moreover, the emphasis will be on measures that can be recorded remotely, increasing the study's accessibility to participants. This has the additional consequence of increasing the overall recruitment potential for the study. However, it will limit contact and interaction with participants to virtual means.

The key investigator in this dissertation was in the unique position of being intimately involved in the competition and coaching of marathon kayaking. This enabled the research to benefit from the perspectives of a researcher, practitioner, and coach, providing a nuanced view of the subject and its limitations. Furthermore, it allows the interpretation of the results to be more ecologically valid.

This research aims to expand the existing knowledge in a relatively unexplored area. The goal is to ensure that the benefits of the research reach a broader, underserved population of athletes. Furthermore, the research should lay the groundwork for exploring more detailed and specific questions about load monitoring in kayakers.

Clarification of Terms

Certain terms used in this study are ambiguous, and previous explorations have litigated the correctness of using various terms in a context that does not reflect the strict scientific meaning (12,13). While an effort has been made to avoid using these terms where possible, there are instances where not using them makes the ideas conveyed more challenging to follow and the communication of the material less effective. In such cases, the terms are used.

Training Load

Training load has been criticised for its non-specific use of the term “load,” a mechanical term with a set SI standard definition (14). However, it was felt that the term reflects the meaning behind an all-inclusive accumulation of training more accurately than any similar terms proposed. Furthermore, these terms align with definitions and concepts used in other scientific areas using causal inference (15). Therefore, it is used in the study, with the definition clarified.

Anaerobic and Aerobic Capacity

These terms are often employed to convey the exercise intensity but can be misleading as the specifics of the metabolism, which the term implies, are not known (16). However, the terms are undeniably helpful for a shorthand when referring to intensity. Therefore, in this dissertation the term aerobic capacity refers to the development of adaptations which can sustain endurance-intensive bouts. Moreover, the term anaerobic capacity refers to the development of adaptations which can sustain maximal, explosive or high-intensity bouts. Furthermore, in all but a few cases the authors have opted for the term ‘oxygen-independent’ over ‘anaerobic’.

Marathon Kayaking, Flatwater Marathon Kayaking and Long-Distance Kayaking

These terms appear frequently throughout the dissertation and, while they can be interchangeable, they carry different implications that can cause confusion. Technically, 'marathon kayaking' encompasses all long-distance disciplines—including flatwater, river, and surfski (ocean racing). However, in practice, kayakers often use it to describe flatwater marathon events. To avoid ambiguity in certain instances where the authors deemed it necessary to avoid confusion, the term 'long-distance kayaking' was used as a broader, more inclusive alternative when referring to multiple subdisciplines.

Key Terms and Concepts

A

- **Aerobic Demands:** Refers to the endurance aspects of kayaking, involving sustained physical activity relying on oxidative metabolism.
- **Aerobic Fitness:** The ability of the body's cardiovascular and respiratory systems to sustain prolonged physical activity.
- **Anaerobic Capacity:** Also, *Oxygen-Independent Capacity*. Refers to the development of adaptations which can sustain maximal, explosive or high-intensity bouts.

B

- **Balance:** The ability to maintain a steady and stable position without falling. Important in maintaining control of the kayak and preventing capsizing.
- **Biological Age:** refers to an individual's maturation level, which can impact peak performance in sports like kayaking.
- **Biomarkers:** Biological markers or indicators in blood, urine, or saliva that reflect metabolic status or responses.
- **Brace Stroke:** A kayaking stroke that the kayaker employs to prevent the craft from capsizing or holding a specific position.
- **Burnout:** Mental, emotional, and physical exhaustion from prolonged stress and overtraining.

C

- **Capsizing:** When a kayak overturns in water, often due to a loss of balance or external factors, impacting race outcomes.
- **Catch:** In reference to kayak technique. Refers to the initial phase of the stroke where the paddle enters the water and begins to generate propulsion.

- **Coordination and Kinesiological Coordination:** Refers to the synchronization and precise timing of body movements.

D

- **Downwind Paddling:** Ocean kayak paddling, which goes from one coastal point to another, following the general direction of wind and/or swell and ocean conditions. Requiring specific skills such as swell riding, and navigation to do safely and efficiently.

E

- **Eddies:** Also, *Eddie currents*. Areas of swirling water that are caused by obstacles or changes in water flow.
- **Endurance Capacity:** The ability to sustain physical activity over extended periods without fatigue.
- **Endurance-Strength Sport:** This refers to a sport that combines elements of endurance (aerobic) and strength (oxygen-independent), challenging athletes in both aspects.
- **External Load:** The physical work or stress imposed on an athlete during training, measured through various parameters.

F

G

- **Glide Phase:** This is part of the stroke cycle where the paddle exits the water and prepares for the next stroke. It is important for understanding stroke efficiency.

H

- **Heart Rate Monitoring:** Involves measuring the athlete's heart rate during exercise to assess exercise intensity and training response.

- **Heart Rate Variability (HRV):** Measure of the variation in time intervals between heartbeats, indicating autonomic nervous system function and recovery status.
- **Hydrodynamic Drag:** Resistance encountered by a kayak in water, affecting speed and efficiency.

I

- **Internal Load:** The physiological or psychophysiological response of the body to training stressors.
- **Interference Phenomenon:** Occurs when concurrent training of strength and endurance affects each other's adaptive mechanisms, important in designing training programs for kayakers.

J

K

- **Kayak:** Refers to various types of watercraft designed for different kayaking disciplines. This includes single-person (K1, SS1) and two-person (K2, SS2) variants.
- **Kayaking Disciplines:** Refers to different styles or types of kayaking activities, such as flatwater marathon, surfski (ocean kayak), and river kayaking.
- **Kinetic Chain:** The interconnected series of movements involving muscles, joints, and bones during kayaking strokes.

L

- **Labral Tears:** Injuries to the cartilage around the shoulder joint, common in kayakers due to repetitive motions and force on the joint from high-brace maneuvers.

M

- **Metabolite Build-Up:** Refers to the accumulation of byproducts, such as CO₂, lactate and many others, produced during metabolic processes within an organism.

N

- **Non-functional Overreaching:** A state where an athlete experiences short-medium term performance declines due to excessive training stress.

O

- **Observational or Cross-Sectional Design:** A research design that observes and analyses data at a single point in time, focusing on different data points or conditions.
- **Overtraining:** A condition characterised by excessive training without adequate rest or recovery, leading to chronic fatigue and impaired athletic performance.
- **Over-Stern Rudder:** A rudder system on a kayak where the rudder is attached above the waterline to the kayak's stern.

P

- **Physiological Stress:** The stress placed on the body during physical activity, leading to adaptations and improvements in performance over time.
- **Power Output:** A measure of the mechanical power produced during exercise, often used as an intensity measure in simulated kayaking.
- **Prime Movers:** Muscles primarily responsible for generating movement in a kayak stroke, such as the latissimus dorsi in pulling motions and the deltoids in pushing motions.
- **Psychometric Measures:** These are subjective measures collected through self-reports, questionnaires, or ratings to assess psychological factors such as mood, stress, recovery, and sleep quality in athletes.
- **Psychophysiological Response:** The combined psychological and physiological response of the body to training stressors.

Q

R

- **Race Strategy:** The plan or approach kayakers use during races to optimize performance and achieve their goals.
- **Rating of Perceived Exertion (RPE):** Subjective measures of how hard an athlete feels they are working during exercise.
- **Respiratory Gas Analyzers:** Devices used to measure oxygen uptake and minute ventilation, providing internal load data in exercise physiology.
- **Rudder:** A steering device on a kayak operated by the feet to control direction.
- **Run-Riding:** Also *swell-riding*. The act of catching and surfing open sea wind-swell in an ocean kayak.

S

- **Session Rating of Perceived Exertion (sRPE):** Combines RPE with session time to create a training load measure combining external volume with internal load.
- **Simulated Kayaking:** Refers to kayaking performed in controlled environments, such as kayak ergometers or simulators, used for training and testing purposes.
- **Stroke:** The paddling motion in kayaking, comprising phases like catch, pull, and glide, involving various muscle groups.
- **Stroke Cycle:** The sequence of movements in a complete kayak stroke, including the catch, pull, and glide phases.
- **Stroke Efficiency:** Refers to the effectiveness of each paddling stroke in propelling the kayak forward, influenced by technique and strength.
- **Stroke Force:** The force exerted by the paddler on the water through paddle movements to propel the kayak forward.
- **Stroke Rate:** The number of paddle strokes per minute, serving as an indicator of intensity in both simulated and on-water kayaking.

T

- **Training Load:** Initially mentioned as a combined physiological and psychological stress and then reiterated as a quantification method with external and internal components.
- **Training Load Monitoring:** This refers to the systematic tracking and assessment of the physical demands placed on an athlete during training and competition.
- **Training Intensity:** This refers to the level of effort or workload during a training session, often measured using metrics like heart rate, power output, or perceived exertion.
- **Training Frequency:** This refers to how often a training session or activity is performed within a given timeframe, such as sessions per week or days of rest between sessions.
- **Training Volume:** This refers to the amount of training performed over a specific period, typically measured in hours, distance, or repetitions.
- **Time Trial Testing:** This involves conducting a time trial or performance test to assess an athlete's overall performance under specific conditions, such as completing a designated course as fast as possible in kayaking.

U

- **Under-Stern Rudder:** A rudder system on a kayak where the rudder is attached to the boat below the waterline, on the underside of the kayak's stern.

V

W

- **Wake Riding:** Positioning behind or beside another paddler, using the wake created by another boat to reduce drag and conserve energy, especially important in flatwater marathon racing. Also known as wash-riding, wake-riding, or slip-riding.
- **Water Drag:** Refers to the resistance encountered by a kayak in water, affecting its speed and efficiency.

X,Y,Z.

Abbreviated Terms Guide

<i>Abbreviation</i>	<i>Term</i>
<i>%HR</i>	Percentage Of Maximum Heart Rate
<i>%TTS</i>	Percentage of the Best-Reported TT Pace
<i>1RM</i>	One Repletion Maximum
<i>ACSM</i>	American College of Sports Medicine
<i>ANOVA</i>	Analysis of Variance
<i>ANS</i>	Autonomic Nervous System
<i>BMI</i>	Body Mass Index
<i>CSA</i>	Canoeing South Africa
<i>CSV</i>	Comma Separated Values
<i>CV</i>	Coefficient of Variation
<i>DALDA</i>	Daily Analysis of Life Demands for Athletes
<i>ESS</i>	Epworth Sleepiness Scale
<i>FIT</i>	Flexible and Interoperable Data Transfer
<i>GNSS</i>	Global Navigation Satellite Systems
<i>GPS</i>	Global Positioning System
<i>GPX</i>	GPS Exchange Format
<i>HIIT</i>	High-Intensity Interval Sessions
<i>HR</i>	Heart Rate
<i>HRR</i>	Heart Rate Recovery
<i>HRV</i>	Heart Rate Variability
<i>KMCS</i>	Video Camera-Type Kayak Motion Capture System
<i>LSD</i>	Long Slow Distance
<i>macros</i>	Macroinstructions
<i>NID</i>	Non-Invasive Lactate Threshold Device
<i>OTT</i>	Rusko Orthostatic Test
<i>PO</i>	Power Output

<i>Abbreviation</i>	<i>Term</i>
<i>POMS</i>	Profile of Mood States
<i>Quick POMS</i>	Condensed version of the Profile of Mood States
<i>RACE</i>	Racing Type Sessions
<i>RER</i>	Respiratory Exchange Ratio
<i>RMSSD</i>	Root-Mean-Square Difference of Successive Normal R–R Intervals
<i>SD</i>	Standard Deviation
<i>SIT</i>	Sprint Interval Sessions
<i>SPSS</i>	Statistical Package for the Social Sciences
<i>SR</i>	Stroke Rate
<i>sRPE</i>	Session RPE
<i>SSQ</i>	Short Session Questionnaire
<i>tHB</i>	Total Heart Beats
<i>TID</i>	Training Intensity Distribution
<i>TT</i>	Time Trial
<i>TTL</i>	Total Training Load
<i>VO₂</i>	Volume of Oxygen Uptake
<i>VO₂ max</i>	Maximal Oxygen Uptake
<i>VBA</i>	Visual Basic for Applications
<i>VCO₂</i>	Carbon Dioxide Production
<i>VE</i>	Ventilation
<i>YOP</i>	Years of Competitive Paddling

— Roadmap —

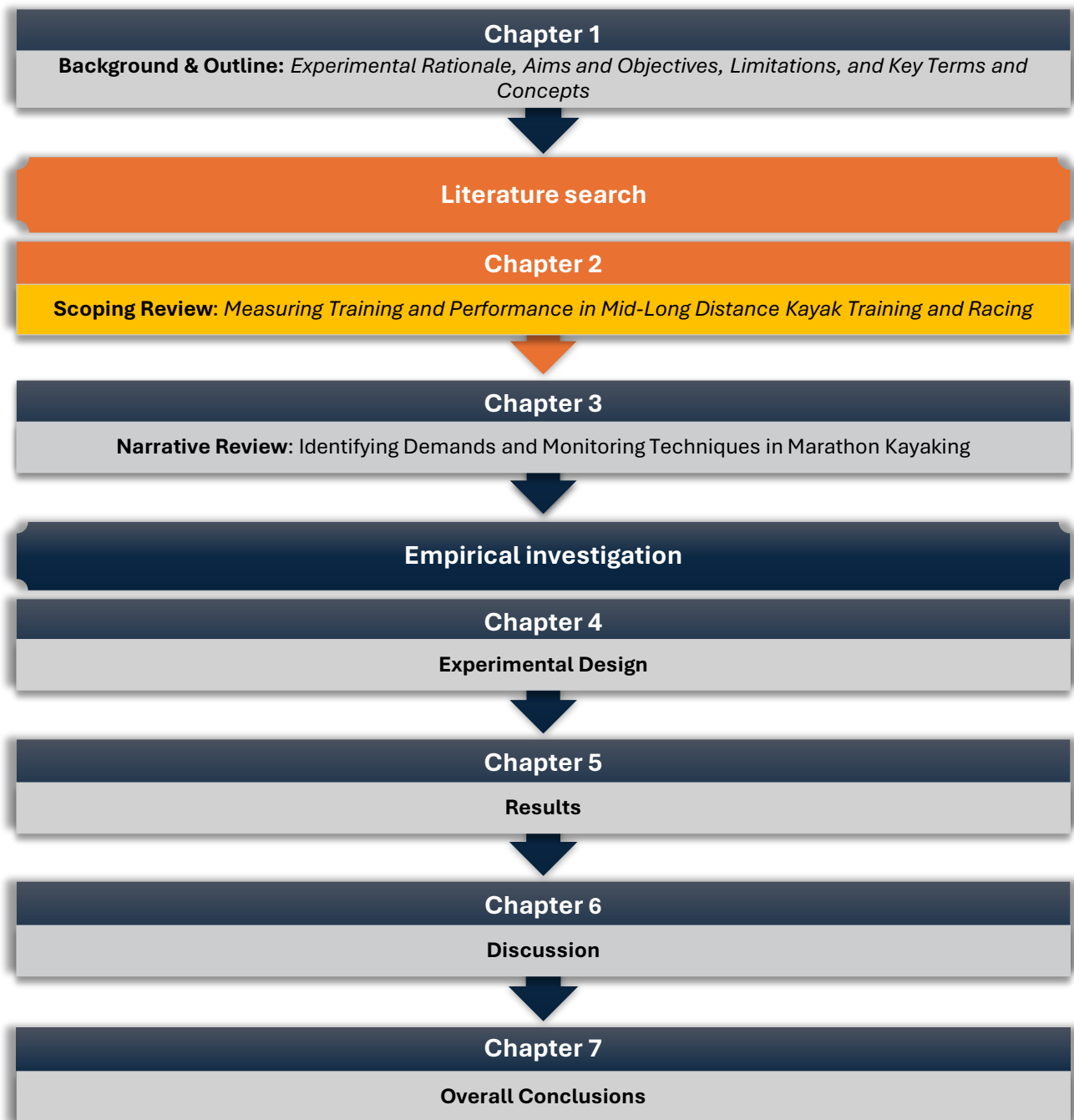


Figure 2. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed.

— Chapter 2 —

Scoping Review: *Measuring Training and Performance in Mid-Long
Distance Kayak Training and Racing*

Objective of the Review:

This scoping review systematically examines the literature on training load monitoring practices in marathon kayak paddling. Gathering and reviewing the available evidence relating to this topic will allow the formation of questions and objectives to elucidate the most suitable training load-monitoring practices for long-distance kayaking and performance monitoring.

Accurately monitoring training loads cannot be overstated; it plays a pivotal role in optimising athletic capabilities across proficiency levels. Its utility extends from allowing individuals to reach peak performance to limiting overtraining or non-functional overreaching. Correctly utilising the training load is vital to obtaining consistently positive training and performance outcomes in long-distance kayaking.

Before refining training load monitoring tools for marathon kayaking, the available literature on the topic must be explored. A comprehensive review of the literature on long-distance kayaking performance and training load measurement is necessary to evaluate relevant evidence systematically. This will also expose the gaps in the literature on marathon kayaking training load monitoring.

Therefore, this scoping review is the first step in pursuing more refined objectives and questions about load monitoring in long-distance kayaking. Moreover, the review will better inform research questions and improve understanding, allowing further research to be more focused.

Introduction

Training exposes athletes to physiological stress, initiating adaptations and contributing to improved performance (17). The challenge lies in determining the optimal balance between stress and recovery, a task complicated by individual differences in training response (8,18). Therefore, establishing a reliable training load monitoring system is crucial for achieving this delicate equilibrium (19). Additionally, each sporting discipline imposes unique stress requirements. For instance, weight-bearing sports like running induce different physiological stress than non-weight-bearing activities like swimming or cycling (20). Recognising these distinctions is essential when designing an effective monitoring scheme.

Training Load Monitoring

Training load measurement is a mechanism for quantifying an individual's cumulative stress across multiple training sessions over time (21). This includes gathering data on each training session's parameters, including the duration, frequency, volume, and intensity. This is referred to as the external load (22). A complete monitoring scheme also includes measuring and evaluating the individual's response to these factors, which is the internal load (11,23).

The amount of exercise outlined in the training plan determines the external load, representing the specified physical work in the training regimen (24). These measures help report and measure the dose of training prescribed and completed. On the other hand, internal load serves as an indicator, reflecting the actual psychophysiological response initiated by the body to cope with the demands imposed by the external load (24). These measures are vital in understanding how an individual reacts to prescribed training.

For a training load monitoring scheme to be effective, it is crucial to have metrics and outcomes that allow quantifying the "dose" of training and measuring the subsequent

"response" to that training (25). Furthermore, these metrics should be tailored to measure the specific stresses encountered in the sport being practised.

Marathon Kayaking

Kayaking has ancient roots. It was a mechanism for transport and fishing for the Inuit people (26). Over the years, it evolved into a racing discipline, with sprint kayaking and canoeing events inducted into the 1936 Olympic Games (27). Many different racing formats have emerged from the original racing form, including marathon kayaking disciplines.

Kayaking involves a participant (kayaker) seated on a craft (a kayak) and propelling it forward with a single dual-bladed paddle. The kayaker submerges the paddle blade into the water, using a cyclic pull-push motion on alternating sides of the craft to move it along the water's surface. The kayaker faces forward in the direction of motion. In most cases, the craft is steered by a rudder operated by the feet with a steering mechanism, foot pedals, or a tiller bar.

Kayaking involves using the paddle as an anchor point to pull the boat through the water. Consequently, it demands a certain level of strength, good oxygen-independent respiration capacity, and high aerobic fitness (28). Moreover, the correct technique should be emphasised, as correctly executing the paddle stroke motion is crucial in propelling the craft through the water (29).

Marathon kayaking shares many fundamentals with other kayaking disciplines. However, distinct demands are likely to arise in each discipline. For example, sprint kayaking requires an increased capacity to sustain high intensity, maintaining a high stroke cadence and power despite the local metabolite build-up (5,30). Marathon kayak racing typically involves longer distances ranging from tens to hundreds of kilometres, which requires improved endurance capacity through distinct training methods (30).

Adequate preparation ensures a proper response of the cardiovascular, pulmonary and muscular systems to the physiological stress of paddling (5,31,32). Consequently, appropriate training will require repeated cycles of kayak training stress and recovery to stimulate the necessary adaptations. The training specifics may vary depending on the individual's needs to elicit the specific adaptations (5,30). Moreover, it is crucial to monitor the individual's response to training to achieve maximal adaptation and avoid overtraining or non-functional overreaching (19). However, for these schemes to be effective, they must adequately capture the training demands of marathon kayaking. Exploration of the available literature on practices specific to marathon kayaking training load monitoring could help to identify appropriate practices.

Therefore, this scoping review examines the current literature on training load monitoring in marathon kayaking. The main aim is to identify the current understanding and gaps in knowledge regarding kayaking's demands. By doing so, this review intends to provide a foundation for future investigations. The goal is to develop efficient training load monitoring schemes for kayaking, enhancing sports performance while reducing the risk of injury and overtraining.

Methods

A scoping review approach was used to explore the topic of training load monitoring in marathon kayaking. This method is appropriate for delving into a new research area with a potentially diverse range of studies. It allows researchers to ask broad research questions, an essential exploratory step in a more comprehensive investigation of the area.

Scoping Review Protocol

This protocol describes a scoping review following the framework of six stages described by Arksey and O'Malley (33). The final step (Stage 6) was not included because it is inappropriate for this research topic.

Stage 1: Identifying the Research Question

The research question was developed using the Population, Context, and Concept (PCC) framework. The population under consideration was marathon kayakers, while the context focused on long-distance racing and training. The concept of interest was training load monitoring. The research question was formulated using this framework to align with the research objectives.

Research question: *“Which monitoring methods are currently used in marathon kayaking?”*

This research question is specific and clear yet broad enough to encompass relevant research outcomes.

Stage 2: Identifying Relevant Studies

The search began by informally searching keywords to determine the types of studies to be collected. This allowed for refining the search terms, helping to catch research that may have otherwise yet to be identified. The search strategy identified all scoping reviews published in the following electronic databases. The relevant databases were identified after consulting with a librarian. Additionally, Gray literature was searched for relevant articles.

Electronic databases

- Africa-Wide Information
- APA PsycINFO
- APA PsycTESTS
- CINAHL complete database
- CINHAL
- Cochrane Library
- EBSCOhost
- Medline
- PubMed
- Scopus
- Web of Science

Search terms

To ensure a comprehensive review, we selected search terms that covered the core aspects of the topic while balancing feasibility. The search process was carried out in stages, which included searches of similar or related terms called strings. These strings contained relevant terms to capture specific populations, concepts or contexts. Initially, each string was searched separately. The strings were then combined using specific operators to refine the search results.

String 1: This was used to select the studies with the relevant population. However, various terms are used for kayaking in different contexts and locations.

S1: Kayaking OR kayak OR Canoeing OR canoe OR surfski OR paddle

String 2: The following string of terms captures the context of the research objective. This review's kayaking context is long-distance or marathon kayaking. These terms tend to be associated with middle-to long-distance kayaking.

S2: Marathon OR endurance OR ultra OR “Long distance”

Strings 3 & 4: The final two strings target the concept being examined in this study. These terms capture literature relating to training load monitoring techniques.

S3: Performance OR training

S4: Load OR measure OR metric OR management OR quantification

Search term combinations:

Each string was searched individually in each database. The searched strings were combined with AND in stages, shown by brackets.

(S1 AND (S2 AND (S3 AND S4)))

Inclusion and exclusion criteria

Study inclusion criteria were based on the research question and objective. For records to be appropriate for this review, they needed to satisfy some conditions:

- I. The review needed to focus on or substantially include kayaking or kayak-related practices (e.g. kayak ergometry).
- II. The study needed to include an outcome measure or performance and/or training measurement.

The studies were excluded if:

- I. The focus population was canoeists, sprint kayakers, ocean canoeists (OC1), stand-up paddlers (SUP) or rowers.

Stage 3: Study Selection

The result from each database search was recorded. The granular specifics of the searches in each database, including specific search terms, dates, and operators, were recorded and can be found in Appendix 1. The searches were conducted for a final time in October 2023 to ensure that any new relevant literature would be included.

The results were then consolidated in a reference manager (Zotero 6.0.29). The process described is summarised in Figure 3. All the records obtained from searching databases were then combined (n=225). The reference manager's software was used to identify and remove the duplicates (n=69).

After compiling the records, an initial screening was conducted to filter out any records that were not relevant to the research questions. Additionally, records collected using search terms related to a different context, such as the word "paddle" referring to a gene polymorphism instead of kayaking, were also identified and removed from the dataset. In total, 19 such records were removed from the dataset. The remaining articles (n=137) underwent a thorough review of their titles, abstracts, and full texts. Decisions to include or exclude records from the study were made based on the research question and objective. Any articles that fell outside the scope of these parameters were excluded (n=109).

The reasons for exclusion were generally based on the population or content focus of the studies or a combination of both. A list of excluded articles and reasons for exclusion can be found in Appendix 1. A sample of the excluded results (n=20) was reviewed by an independent party, who reaffirmed that the articles were not appropriate to include. The remaining records (n=28) were then included in this review.

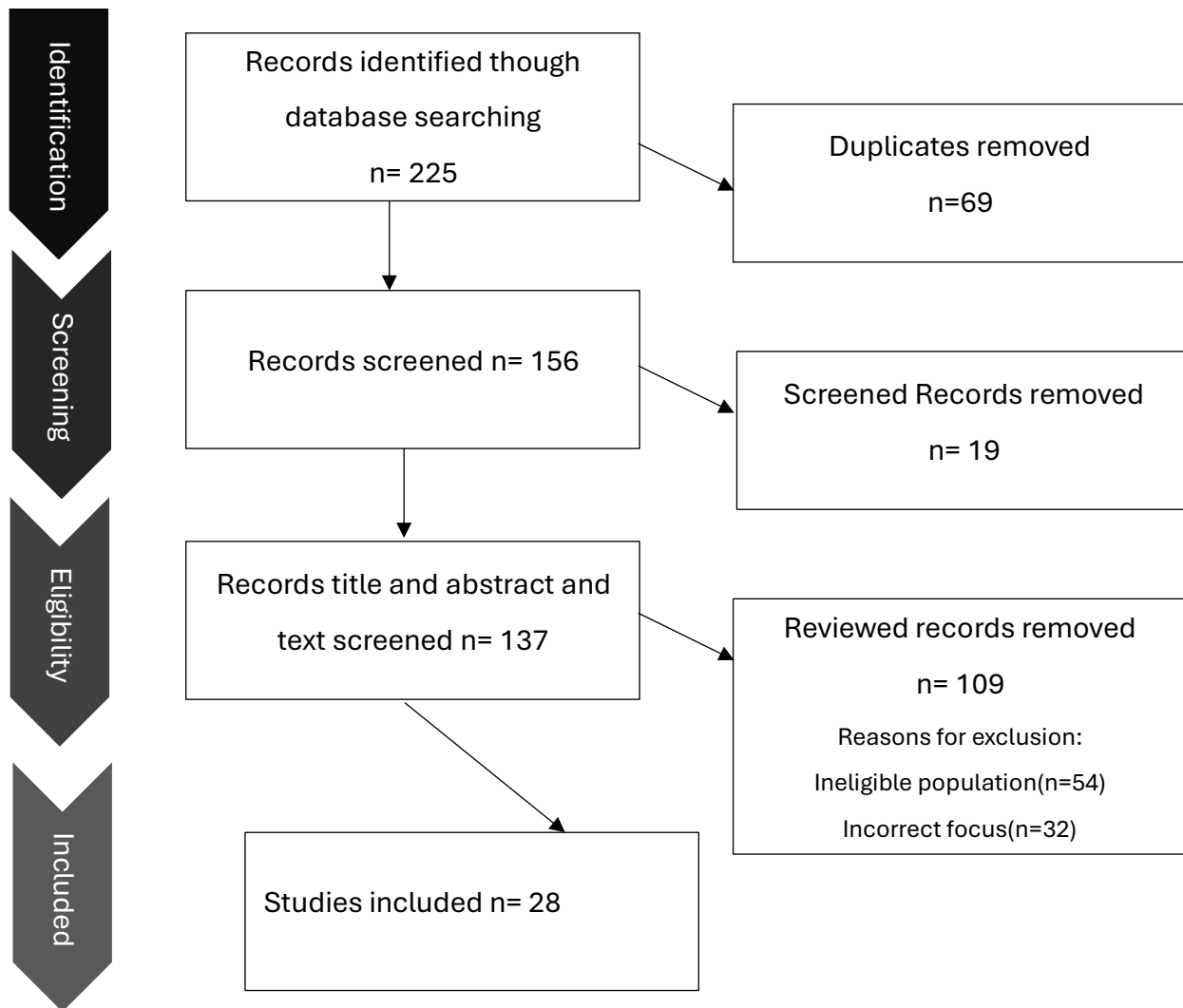


Figure 3. Search results and study selection and inclusion process for the review

Stage 4: Charting the Data

Data extraction and analysis

The remaining records were arranged according to the publishing date to ensure that related papers would be contextualised chronologically. The content of the papers was summarised in a table. The table headings were selected following consultation with a proposed charting form (34). This captured specific and general information about the studies. The initial format and structure of the table were calibrated using the studies that were initially included. Subsequent changes to the table's format, headings or contents were implemented after more studies were assessed.

The papers were summarised into a table with four major headings:

1) Title |Year |Author(s) |Setting

This provides the reader with information about the study, including its setting, whether it was in a laboratory or completed in the field.

2) Aim, Methods and Sample

A summary of the study aims and methods, sample size, and participant characteristics provided the reader with more clarity into the robustness of the study and how appropriate the methodology was for addressing the research question.

3) Outcome measures

The key outcome measures of the study.

4) Key findings relating to the review:

This is a more narrative exercise. The goal is to chart measurements or conclusions relevant to this scoping review's research objectives.

Stage 5: Collating, Summarising, and Reporting the Results

The data were systematically examined to identify and interpret recurring themes or patterns. The findings were presented through tables and textual descriptions. The reported results from various sources were anticipated to include multiple measurement types. In instances where the measurements significantly differed, direct comparisons were deemed either impractical or inappropriate. Consequently, certain papers were excluded from specific summaries if their inclusion was incompatible with the intended characterisation. Summaries indicated the number of included papers.

The included 28 studies are summarised in Table 1. The table briefly describes the studies and their relevance to the review.

Stage 6: Feedback

This did not apply to this style of systematic review.

Results

Table 1. Summary of included studies, including characteristics, aims, methods, outcome measures and key findings. Clarification of abbreviations can be found below the table.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Physiological characteristics of elite kayak paddlers 1983 Tesch Laboratory Observational	To determine elite kayak paddlers' (n=6) anthropomorphic and physiological characteristics and how they compare to other athletes and non-athletes.	Measurement of Physical and Anthropomorphic features, muscle strength and endurance indices, maximal oxygen uptake, HR and [La].	Kayaking requires aerobic capacity measured by VO ₂ max, heart rate, and [La], as well as muscle strength and endurance measured by an isokinetic dynamometer.
Muscle metabolite accumulation following maximal exercise: A comparison between short-term and prolonged kayak performance 1984 Tesch and Karlsson Laboratory Quasi-experimental crossover.	Muscle biopsies were obtained from the mid-portion of m. deltoideus immediately pre and post-exercise from elite flat-water kayakers (n=5). Looked at differences in muscle metabolites in short vs prolonged kayaking.	The concentrations of adenosine triphosphate (ATP), creatine phosphate (CP), glucose-6-phosphate (G-6-P), glycogen, glucose, and lactate were compared before and after short-term and prolonged kayaking.	The intensity difference in short vs long-duration kayaking results in different metabolic outcomes. These can be measured with a muscle biopsy and subsequent biochemical analysis.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Physiological and kinanthropometric attributes of elite flatwater kayakists 1991 Fry and Morton Laboratory and field Observational	Investigated the physical and psychological factors affecting performance in races (500m to 42 000m) of competitive male kayakers of varying abilities (n=38).	The performance (race time) measured in the WA state canoe championships was compared in a linear regression to subsequent measurements of physiological, kinanthropometric characteristics such as pulmonary function, strength, flexibility, body mass, height, anaerobic capacity, power maximal oxygen consumption, efficiency, and ventilatory threshold.	Long-distance racing performance (measured by race time) strongly correlates with isokinetic strength during a simulated kayak movement. Specifically at a speed of 120 degrees per second ($r=0.67$ for the left side and $r=0.69$ for the right; $p<0.05$). Similarly, the 60s all-out power, VO_2 max and time to exhaustion (incremental aerobic performance test) correlated with performance. The authors concluded that changes in these variables from training might give insight into performance.
Ventilatory threshold and work efficiency during exercise on cycle and paddling ergometers in young female kayakists 1994 Bunc and Heller Laboratory Cross-sectional	To assess the effects of increasing specific (paddling ergometer) and non-specific (cycle ergometer) exercise on parameters relating to the ventilatory threshold (V_T) and work efficiency in young female flat-water kayakers (n=11).	Comparison of functional variables and work efficiency measures on the cycle and the paddling ergometer at various intensities. Measured VO_2 max, V_T , V_E , HR, [La] and power output.	The results of physiological variables sensitive to training status in non-specific submaximal and maximal exercise modality testing should be interpreted cautiously.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
The use of critical power as a determinant for establishing the onset of blood lactate accumulation 1994 Clingeffer et al. Laboratory Cross-sectional	To determine the relationship between critical power (CP) and the onset of blood lactate accumulation (OBLA) in highly trained kayakers (n=8). Assessed via measurements from incremental ergometer paddling trials over four days, including two critical power tests, a lactate-HR profile and a sub-max lactate test.	Measurement of power output, work done, [La], and HR in multiple trials to determine critical power (W), lactate-HR profile, submaximal [La] and submaximal power.	Although accurate biochemical means of determining exercise intensity exist and are appropriate for lab settings, non-invasive measures of similar factors are more suitable for everyday training prescription and monitoring.
A comparison of time to exhaustion at VO ₂ max in elite cyclists, kayak paddlers, swimmers and runners. 1996 Billat et al. Laboratory Cross-sectional	To compare the time to exhaustion at the power output (or velocity) (v) at VO ₂ max for different exercise's VO ₂ max values. Comparing elite sportsmen by timing how long they could sustain v at vVO ₂ max in an activity. Kayakers (n =9).	Comparison of physiological parameters such as [blood lactate], HR and t at vVO ₂ max, following a time to exhaustion at vVO ₂ max.	VO ₂ max can indicate kayaking's physiological demand and how it may differ from other sports. ANOVA revealed cycling and kayaking had significantly different times to exhaustion.
Anaerobic contribution to the time to exhaustion at the minimal exercise intensity at which maximal oxygen uptake occurs in elite cyclists, kayakists and swimmers 1997 Faina et al. Laboratory Cross-sectional	The contribution of the anaerobic energy system to the time to exhaustion (tlim) at the minimal exercise intensity (speed or power) at which maximal oxygen uptake VO ₂ max occurs in elite males (n=23). Assessed by analysing the relationship between tlim and accumulated oxygen deficit (AOD).	Participants' physical characteristics, VO ₂ max, heart rate, and blood lactate concentration [La] were measured, and the AOD was subsequently calculated.	VO ₂ max can demonstrate Kayaking's physiological demand. At higher intensity, kayaking has a lower aerobic demand than cycling, swimming, or running, which should be considered when monitoring and using aerobic markers.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Importance of wash riding in kayaking training and competition 1998 Pérez-Landaluce et al. Laboratory and field Quasi-experimental crossover	To quantify the energy savings when a kayaker is "wash riding." Male international flat-water kayakers (n=8) performed a field test of 2000 m in each of the four wash-riding positions.	The time, stroke rate, [La], HR, and rating of perceived exertion (RPE) at different wash riding positions were recorded and compared. Additionally, the recorded intensities of wash positions were performed on a kayak ergometer under laboratory conditions, allowing HR, VO ₂ max, [La], mean power output (W), and RPE measurements.	Energy savings exist in different wash riding positions. These may vary between 18% (right and left wave) and 32% (V-wash). These energy savings influence group TT or race times of participants independent of fitness status and should be noted in monitoring.
Energetics of kayaking at submaximal and maximal speeds 1999 Zamparo et al. Field Cross-sectional	The energy cost of kayaking per unit distance (C_k , kJ/m) was assessed in middle- to high-class athletes (n=8, m=3; f=5). At submaximal speed, C_k was measured by dividing the steady-state oxygen consumption by the speed, assuming an energy equivalent of 20.9 kJ /L O ₂). At maximal speeds, C_k was calculated using the ratio of the total metabolic energy expenditure to the distance.	Anthropometric characteristics, individual VO ₂ max and maximal anaerobic alactic capacity (AnAl). The measures were used to calculate energy cost at submaximal and maximal speeds.	The longer distances rely on aerobic metabolism. Therefore, training and monitoring should target these systems to improve efficiency and monitor oxygen uptake improvements over time.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
The validity of physiological variables to assess training intensity in kayak athletes 2004 Bishop Laboratory Cross-sectional	To examine whether the relationship between HR, [La] and intensity determined during a kayak graded exercise test (GXT) remained stable during constant-intensity kayak exercise. Trained kayakers (n=16) performed GXT and a subsequent 20-minute constant-load test on a wind-braked kayak ergometer at a power output corresponding to their lactate inflexion (LI) intensity.	The peak oxygen uptake (VO ₂ max), HR and lactate parameters, lactate inflexion, and lactate threshold were measured during the GXT (n=16) and the constant-load test(n=8).	These results suggest that HR, but not [La], is similar during a GXT and constant-load exercise at the lactate turn-point intensity and, therefore, a more reliable measure of kayaking intensity.
Determination of anaerobic threshold based on the dynamics of the heart and stroke rates estimated in the upper body progressive test 2004 Sitkowski et al. Laboratory Cross-sectional	To analyse the course of the power output (PO)/HR, PO/stroke rate(SR), and SR/HR relationships in the progressive incremental exercise and evaluate the accuracy of determining the anaerobic threshold (AT) based on the above three relationships. The Conconi test (CT), the 30-min test (PET) with PO at the deflection point (PODP), the critical power test (CP), and the GXT until exhaustion were performed on an ergometer (n=12).	Measurement of SR, HR, PO, and [La]. The progressive incremental exercise tests examined PO/HR, PO/SR, and SR/HR relationships. Subsequently, the AT, MLSS, CP, and DP were determined. PO at the AT and PO Dmax were determined based on [La].	SR/HR/PO measures are associated in ergometry p<0.05, with SR changes affecting PO/HR. Additionally, the determination of AT based on the analysis of the three DPs is comparable to [La] testing.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle 2009 <i>García-Pallarés</i> et al. Laboratory and Field Longitudinal repeated measures	To analyse changes in cardiovascular and neuromuscular variables in elite kayakers (n=11) across a 12-week periodised cycle of combined strength and endurance training.	Anthropomorphic changes (such as body mass, skin fold, and chest circumference), physiological and performance changes (VO ₂ max, peak lactate, VT2), and peak speed, heart rate (HR), and stroke rate (SR) relative to the physiological factors over time.	Changes in kayaking peak speed over time can be related to improvements in physiological variables.
Antioxidant status, oxidative stress, and damage in elite kayakers after 1 year of training and competition in 2 seasons 2009 Teixeira et al. Laboratory Longitudinal repeated measures	Examining the effects of chronically high training loads on a range of kayakers' (n=9) lipoproteins, antioxidant status, lipid peroxidation, muscle damage, inflammation, and physiological stress markers were measured during three periods in two consecutive seasons.	Data on dietary intake, physical activity, estimated energy expenditure, body composition, and anthropometry were measured. The changes in lipoproteins, antioxidant status, lipid peroxidation, muscle damage, inflammation, and physiological stress markers were compared longitudinally during the competitive period (T1), the precompetitive (T2), and the subsequent competitive (T3) period.	Longitudinal measurement of training load status provides evidence that individuals are reacting appropriately to the training. However, certain markers, such as antioxidants, are inconsistent, therefore, less volatile markers might be preferable.
Physiological effects of tapering and detraining in world-class kayakers 2010 <i>García-Pallarés</i> et al. Laboratory	To analyse changes in neuromuscular, body composition, and endurance markers during 4 wk of tapering and subsequent 5	Examining changes in physiological markers from the tapering and subsequent RT or TC. Including body composition, muscle	Changes related to training reduction can be measured with changes in performance measures such as 1RM and speed,

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Longitudinal, repeated measures	wk of reduced training (RT) or training cessation (TC) in world-class kayakers (n=14).	strength and maximal aerobic power.	45% 1RM in BP or PBP, and maximal aerobic power.
Reversed drift in heart rate but increased oxygen uptake at fixed work rate during 24h ultra-endurance exercise 2010 Mattsson et al. Laboratory Cross-sectional	To investigate the reverse drift in heart rate (HR) but increased oxygen uptake (VO ₂) during ultra-endurance exercise. Well-trained male athletes (n=9) performed 24-h exercise in a controlled laboratory setting, with alternating blocks of 110min kayaking, running and cycling.	V _E , VO ₂ , and HR were measured. The RER was then determined. Blood samples were taken at specific intervals, and biochemical analysis revealed catecholamine, haemoglobin, and haematocrit levels and changes in blood volume. These were compared at 6-hour intervals over 24 hours.	The sole use of HR to determine exercise intensity and energy expenditure would not give accurate results for ultra-endurance exercises. Drifts (changes) in HR and VO ₂ should be considered.
Physiological responses to kayaking with a swivel seat 2010 Michael et al. Laboratory Quasi-experimental crossover	To compare the physiological characteristics of flat-water kayaking using two different seating conditions. The traditional fixed seat and novel swivel seat on an air-braked kayak simulator in elite kayakers (n=15).	The expired air, HR and PO were continuously measured, and gross efficiency (GE _{kayak}) was calculated. [La] was recorded directly after each test to compare the variables of both conditions were compared.	Kayaking intensity markers HR, SR and VO ₂ uptake remained similar in both conditions, while PO showed a significant difference between conditions, showing its sensitivity to changes in ergometer kayaking intensity.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Changes in biochemical parameters after a 20-hour ultra-endurance kayak and cycling event 2011 Suárez et al. Field Longitudinal repeated measures	To analyse blood biochemistry changes in creatine kinase (CK), urea, triglycerides, haemoglobin (Hb), creatinine, creatinine clearance and lactate in a 20-hour ultra-endurance kayak and cycling event. Participants' Biomarkers (n=16) were measured before and after the 100km kayak and 65 km mountain biking events.	Changes between the pre- and post-race biomarkers.	Biochemical markers CK and urea seem to be sensitive to ultra-endurance kayaking. The authors reported significant increases in the biochemical markers of muscle damage (CK, urea; $p<0.05$) in response to the event.
Haematological changes in elite kayakers during a training season 2012 Borges et al. Laboratory and Field Longitudinal repeated measures	The study was conducted to see if the variations in training load during the season could affect the haematological markers in elite male kayakers (n=8) and if these changes were severe enough to cause clinically relevant changes in the blood counts. Collecting and testing blood samples taken at four time points, one before and three throughout the training season.	Changes in the haematological parameters over the four time points: leukocytes (WBC), erythrocytes (RBC), granulocytes, lymphocytes, monocytes, platelets, mean platelet volume, platelet distribution width (PDW), Hb, mean corpuscular volume (MCV) and MCHC, Ht, red blood cell distribution width (RDW), and mean corpuscular haemoglobin (MCH), with a full cell count in addition to plasma volume changes.	Monitoring the athlete's haematological parameters during the training season is a mechanism for identifying potential health risks such as anaemia and increased susceptibility to upper respiratory tract infections. However, such measures likely have much day-to-day variation.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Urine citrate and 6-sulfatoxymelatonin excretion during a training season in top kayakers [2012 Nuñez Laboratory and Field Longitudinal, repeated measures	To evaluate the influence of a training program on citrate and 6-sulfatoxymelatonin (^a MT6S) excretion in elite kayakers (n=12). Urine samples were collected at specific training periods.	Urine values of ^a MT6S in the morning and evening in different training periods and the rate (morning/evening), total sum (morning plus evening), and nocturnal increment (morning minus evening) of citrate and ^a MT6S.	Urine citrate and ^a MT6S obtained by noninvasive techniques may be used as markers to evaluate metabolic recovery and stress produced by the training season workload in elite kayakers. However, with biological systems, there is natural variation. Therefore, using such measures will require experienced personnel to interpret nuanced results correctly.
No effect of upper body compression garments in elite flat-water kayakers [2013 Dascombe et al. Laboratory Crossover Randomized Controlled Trials	To determine the effects of wearing upper body compression garments (UBCG) on selected performance responses during simulated flat-water kayaking in elite kayakers. Additionally, to identify changes in the physiological responses during simulated kayaking that may be responsible for changes in performance. Elite flat-water kayakers (n=7) performed both an incremental and 4 min performance test (4minPT) in separate control	Physiological and performance responses (mean ± sd) across the incremental flat-water kayaking exercise in the control and upper body compression garment conditions. This is done by measuring oxygen uptake, HR, [La], RPE, power, distance, SR, and work.	UBCG did not affect kayaking performance. The training load measures used in the study might be suitable for measuring performance in marathon kayaking.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
	and UBCG conditions in a randomised crossover order.		
A pilot study on how do elite surfski paddlers manage their effort and hydration pattern in the heat 2014 Hue et al. Field Observational	To investigate thermal response, hydration behaviour, and performance during flatwater kayaking races in tropical conditions. Core temperature (Tcore), HR, fluid intake, perception of temperature, and comfort measurements were taken from elite paddlers at a 2012 ocean racing WC (n=5).	Comparison of Race performance (1/s) and DTcore, mean HR, fluid intake, body water loss, and perceived thermal sensation and comfort.	Athletes racing at high intensities (i.e. higher rate of work) resulted in greater DTcore, which correlated with better performance ($r=0.87$, $p < 0.05$). Thus, DTcore relates to kayaking intensity in hot/humid conditions. Notably, the study has a small sample size.
Neuromuscular profile of top-level women kayakers assessed through tensiomyography 2015 <i>García-Pallarés et al.</i> Laboratory Cross-sectional	To assess neuromuscular characteristics and the lateral symmetry percentages of the trapezius, deltoideus, and latissimus dorsi muscles in top-level women kayakers (n=21), establishing reference values in the recovery period, and to determine the influence of gender and specific training in the assessed parameters.	The tensiomyography (TMG) parameters of the deltoideus, trapezius, and latissimus dorsi were compared across different groups.	Using muscle TMG parameters such as those from the trapezius can show the influence of specific training. This can be used to assess whether adequate load is being placed on training in these areas. However, such measures are unlikely to be useful outside of high-level environments, owing both to cost and aversiveness.
Self-hydration and thermoregulatory	To investigate thermal response, hydration	Comparison factors include race performance (1/s) and	No significant correlations were found

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
processes of average-level paddlers during international surfski events in a tropical climate 2015 Hue et al. Field Cross-sectional	behaviour, and performance in flatwater kayaking races in tropical conditions. Core temperature (Tcore), HR, fluid intake, perception of temperature, and comfort measurements were taken from average-range paddlers (n=8) at a 2012 ocean racing WC.	DTcore, mean HR, fluid intake, body water loss, and perceived thermal sensation and comfort.	between any factors, except DTcore before was positively associated with DTcore after the race. ($r=0.77$, $p < 0.03$)
Sport-specific physiological adaptations in highly trained endurance athletes 2015 Lundgren et al. Laboratory Cross-sectional	To compare certain physiological characteristics, in international-level endurance athletes primarily exercising with the whole body (cross-country skiing n=17), lower body (orienteering n=15), or upper body (flatwater kayak n=11) to identify differences resulting from training adaptations between groups.	Comparing the maximal oxygen uptake (VO_2 max), blood volume (BV), haemoglobin mass (Hbmass), and brachial endothelial function, measured as flow-mediated dilatation (FMD) and the training intensity distribution of the different groups.	Kayakers had greater brachial arterial diameters and lower BV than athletes in lower-body sports, likely the result of training adaptations. Endurance sports of different modalities result in unique physiological adaptations, which are relevant for monitoring or comparing sports. However, this specific measure of FMD is unlikely to be used in kayak monitoring.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Kayaking performance is altered in mentally fatigued young elite athletes 2019 Staiano et al. Laboratory Quasi- experimental crossover	This study tested whether 60 minutes of a highly demanding cognitive task inducing mental fatigue reduces a simulated 2000 m kayaking performance test in young elite athletes. Moreover, the second aim was to determine if mental fatigue would affect performance in a population of young, under-17 elite athletes (n=13) at the national level.	Measuring and comparing performance time, HR, [La], RPE, the psychological markers of subjective workload (NASA-TLX), mood (BRUMS), and motivation in the mentally fatigued condition vs. rested condition.	Sixty minutes of a cognitively demanding task-induced mental fatigue and affected kayaking performance in elite young athletes. Thus, cognitive markers may have merit in assessing longer-duration performance and training.
Strength training intensity and volume affect performance of young kayakers/canoeists 2021 Gäbler et al. Field Longitudinal repeated measures	To compare the effects of moderate intensity, low volume (MILV) vs. low intensity, high volume (LIHV) strength training on sport-specific performance, measures of muscular fitness, and skeletal muscle mass in young kayakers and canoeists. Semi-elite young kayakers and canoeists (n = 40) performed either MILV (70–80% 1-RM, 6–12 repetitions per set) or LIHV (30–40% 1RM, 60–120 repetitions per set) strength training for one season.	The changes in 250m and 2,000m time trials (TT), handgrip strength, underhand shot throw, average bench pull power over 2 min, and skeletal muscle mass between the two conditions.	The measures that significantly improved over time were the 2,000 m TT, shot throw, handgrip strength, and skeletal muscle mass ($t \geq 2.1$, $p < 0.05$). Moreover, excellent test-retest reliability (ICC > 0.93) for the time trials was observed. While these strength measures correlate with sprint performance in a 2000m TT, the TT alone in marathon kayaking is likely the more reliable holistic measure of

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
			performance readiness for longer distances.
Optimal and freely chosen paddling rate during moderate kayak ergometry [2022] Gam et al. Laboratory Cross- sectional	To investigate whether, in moderate paddling there is a U-shaped relationship between oxygen uptake and stroke rate, and whether elite kayakers apply a freely chosen stroke rate, which is energetically optimal. Young male elite kayakers (n=11) performed moderate kayak ergometry at pre-set target stroke rates of 65, 75, and 90 strokes/min and at a freely chosen stroke rate, while physiological responses, including oxygen uptake, were measured.	Maximal oxygen uptake, power, HR, pulmonary ventilation, RER, and stroke rate were recorded. The physiological measures for the different SRs were compared.	Measures of oxygen uptake, power, HR, pulmonary ventilation, RER, and SR are suitable for assessing kayaking intensity.

Title Year Author(s) Setting study design	Aim, Methods & sample	Outcome measures	Key findings relating to the review
Development of a video camera-type kayak motion capture system to measure water kayaking 2023 Miyazaki Laboratory Cross-sectional	To compare the kinematic data between KMCS and an optical motion capture system (OMCS) in kayaking and to determine the accuracy of the KMCS analysis in elite junior female kayakers (n=5).	The trunk angles (tilting, turning, and rotation) were examined using KMCS and OMCS simultaneously, and the differences between these systems were evaluated.	The ICCs for tilting, turning, and rotation showed excellent reliability (0.97, 0.99, and 0.97, respectively). The newly developed KMCS effectively measured the trunk motion with reasonable accuracy in kayaking.

1RM = 1 repetition maximum

ANOVA = analysis of variance test

AnAl = Maximal aerobic alactic activity

AT = anaerobic threshold

BP = Bench Press

BRUMS = Brunel Mood Scale

CK = creatine kinase

C_k = energy cost of kayaking per unit distance

CP = Critical power

DP = Lactate deflection point

GXT = kayak graded exercise test

HR = Heart rate (bpm)

Hb = haemoglobin

LI = Lactate inflection intensity

MLSS = Maximal Lactate steady state

ONBL = Onset of blood lactate accumulation

PODP = Power output at the deflection point

PBP = Prone bench Pull

PO = Power Output

RER = Respiratory Exchange Ratio

RPE = rating of perceived exertion

RT = reduced training

SR = Stroke rate

T_{core} = core temperature

TC = training cessation

TMG = Tensiomyography

UBCG = upper body compression garments

V_E = Minute Ventilation

VO₂ = Volume of oxygen uptake

VO_{2 max} = maximal oxygen uptake

V_T = ventilatory threshold

VT2 = Ventilatory Threshold 2 or Anaerobic threshold

WA = western Australia

[la] = blood lactate concentration

^aMT6S = citrate and 6-sulfatoxymelaton

Overview of the Search Results

After executing the search and filtering criteria, 28 studies from 1983 to 2021 were eligible for inclusion in the review. These studies had different formats, participants, and measurements. Each study varied in terms of evidence and relevance to the review. Of the 28 studies, 18 were laboratory experiments involving restricted movement or simulated kayaking. Six studies were conducted in the field, where sensors measured on-water kayaking. The remaining four studies combined measurements in the field with controlled measurements from a laboratory.

Scope and Diversity of Included Studies

Most of the studies ($n = 16$) were cross-sectional or observational in design. Five studies employed a quasi-experimental or randomised controlled design to compare conditions. An additional seven studies were longitudinal with repeated measures. Only three studies included field-based measurements. The characteristics of the longitudinal studies are detailed in Table 2.

Table 2. The characteristics of longitudinal studies (n = 7)

Title Year Author(s) Setting	Format Duration
Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle 2009 <i>García-Pallarés</i> et al. Laboratory and Field	Longitudinal, 4 repeated measures 12 weeks
Antioxidant status, oxidative stress, and damage in elite kayakers after 1 year of training and competition in 2 seasons 2009 <i>Teixeira</i> et al. Laboratory	Longitudinal, 3 repeated measures 1 year
Physiological Effects of Tapering and Detraining in World-Class Kayakers 2010 <i>García-Pallarés</i> et al. Laboratory	Longitudinal, 3 repeated measures 9 weeks
Changes in biochemical parameters after a 20-hour ultra-endurance kayak and cycling event 2011 <i>Suárez</i> et al. Field	Longitudinal, 2 repeated measures 24 hours
Haematological changes in elite kayakers during a training season 2012 <i>Borges</i> et al. Laboratory and Field	Longitudinal, 4 repeated measures 31 weeks
Urine citrate and 6-sulfatoximeatonin excretion during a training season in top kayakers 2012 <i>Nuñ ez</i> Laboratory and Field	Longitudinal, 3 repeated measures 22 weeks
Strength Training Intensity and Volume Affect Performance of Young Kayakers/Canoeists 2021 <i>Gäbler</i> et al. Field	Cross-sectional and Longitudinal, 2 repeated measures 1 year

Monitoring Methods of the Included Studies

The 28 studies had varying designs, the most common being observational or cross-sectional. These studies focused on different measurements at a single point in time. Other longitudinal designs compared variations in conditions and/or composition of athlete groupings contiguously or repeatedly over time.

The studies utilised different measurement techniques to obtain the desired outcomes. Laboratory techniques were used to measure performance outcomes. The laboratory approach provides accurate and sensitive results in a controlled setting. Additionally, researchers relied on measurements taken in the field. Where such measures were precise, they gave a more realistic view of the desired outcomes. Both measurement types have advantages and challenges. Most studies in this review examined the impact of protocols, practices, or conditions on performance or training. The review focused on examining the measurements used to monitor continuous training load and scrutinising their effectiveness.

Most laboratory studies were highly controlled, measuring individuals on kayaking simulators or kayak-related movements on specialised machines. While these studies provide accurate data on specific movements, they struggle to replicate the nuances of real-world kayaking. Other studies opted for direct or indirect measurement of on-water kayaking. However, such measures had challenges in controlling confounding factors. External load metrics describing exercise output were a staple of the reviewed literature. For instance, speed, distance, and duration measured with Global positioning system (GPS) devices were consistently featured (6,35–43). These measures were widely used in on-water kayaking to assess volume and intensity. Moreover, they are indispensable for performance evaluations such as time trials or race simulations (42). Another significant external measure highlighted across various studies was stroke rate (6,36,44–48). This metric is an indicator of intensity in both simulated and on-water kayaking (36).

Simulated kayaking, such as performed on a kayak ergometer, approximates distance and speed. Power output, derived from the rotational speed of the kayak ergometer flywheel, was almost universally adopted as an intensity measure in studies of simulated kayaking (36,44–53). Additionally, featured simulated kayaking external measurements include isokinetic force measurement (force measured at an artificially set constant speed),

measured by an isokinetic dynamometer (28,35). These measurements allow for the determination of force production at different phases and speeds of the stroke cycle.

A novel approach to technical monitoring appeared within the reviewed literature—a video camera-type kayak motion capture system (KMCS) (54). Uniquely tailored for kayaking, the KMCS focuses on, among other aspects, on-water trunk motion, a crucial element of proper kayaking technique that other monitoring methods cannot directly measure. Although this method was not widely used, it was a new technique at the time of this review.

Internal measures were used to quantify the response to the stress encountered. These include physiological or psychophysiological measurements. Many laboratory studies included a measure of oxygen uptake and/or a ventilatory measure (6,28,35–38,44,46–49,51,52,55). These measures were also used to compare across disciplines (49,51,52). Additionally, blood, saliva or urine biomarkers were measured in both on-water and laboratory testing (6,28,36–39,42,44–47,49–52,55–59). Assessment of lactate levels was a common occurrence. Other blood biomarkers included concentrations of adenosine triphosphate (ATP), creatine phosphate (CP), glucose-6-phosphate (G-6-P), haematological parameters, citrate and 6-sulfatoxymelatonin, glycogen and glucose, to name a few. These measures assess aspects of the metabolic response to the workload.

Heart rate measures were widely used (6,28,36,38,40–42,44–52,55). They can be measured via electrocardiography using a chest heart rate strap in both on-water kayaking and a simulated setting. Therefore, these measures were used to assess exercise intensity indirectly. They were also valuable in comparing on-water and simulated kayaking (6,35,36).

Measurement types and techniques were not used in isolation. A recurring feature was combining measures to ensure some redundancy or create new metrics (38,44,45,50).

Psychometric measures have been used on various occasions to assess internal state. Across the review, the rating of perceived exertion was used (36,42,47). It is another example of a metric that can be used in both on-water and simulated kayaking. The Brunel Mood Scale and the success motivation and intrinsic motivation scales were other featured psychometric tools (42).

Discussion

The studies discussed involved various methods, each with its own advantages and disadvantages within the context of the reported studies. The studies included multiple measures of internal and external training load (11). External measures are typically those of volume, duration, and some measures of intensity. Moreover, Internal load refers to the psychophysiological and physiological response to the training (22). This discussion evaluates these measures through the lens of ease of use, financial sustainability, and effectiveness in assessing kayaking-specific demands to inform the design of the experimental section of the dissertation.

External Load Measures

Speed and Distance

The most common external load measures in kayaking were speed, distance, and duration, measured with Global Positioning System (GPS) devices (6,35–43). The speed of kayaking, similar to the speed of a runner, was also regarded as a measure of intensity (60). However, the speed measured in kayaking does not account for the movement of water relative to the ground speed. This is also inconsistent across racing disciplines, as while flatwater kayaking might have moderate variation, river or ocean kayaking is likely to have more variation. However, there does not seem to be an appropriate metric to replace this method, which is currently widely used for kayaking training, racing, and testing (37,61,62).

Moreover, these GPS measures are essential for performance assessments such as time trials or race simulations (42). Furthermore, GPS sports watches are gaining popularity among the active population, especially runners (63). It is reasonable to assume they will become integrated into monitoring kayakers despite the limitation in measuring speed independent of water flow.

Stroke Rate

Stroke rate is a kayak-specific metric measure included in much of the reviewed literature (6,36,44–48). Stroke rate is used to assess the intensity of kayaking in both simulated and on-water kayaking. It is analogous to the role of cadence in running and cycling (64).

Cadence impacts measures such as the rating of perceived exertion in cycling. In kayaking, stroke rate is more closely related to speed and effort (65). It is a valuable tool for contrasting modalities (36). The measure may be affected by paddling conditions but is less compromised than speed or distance measures when the conditions change (36).

Power

Power output was universally adopted as an intensity measure in simulated kayaking in the reviewed literature (36,44–53). It is less influenced by environmental conditions than speed or the stroke rate. The data for power metrics in the examined studies was derived from the rotational speed of the flywheel. A more direct measure of force or power has previously been determined by direct measures of force from load cells at various locations (66). This has value in determining how the kayakers produce the stroke forces, and useful in probing technique. Previously, paddle power sensors have shown promising results in slalom kayaking (67). However, the measure is restricted chiefly to simulated kayaking due to the lack of affordable and robust stroke power sensors. In simulated kayaking studies, the measure is used as an intensity measure, which has application in assessing improvements in simulated kayaking performance following a training intervention (6). Moreover, it has an application in comparison across sports modalities.

Video Analysis

A recent development in kayak monitoring is the video camera-type kayak motion capture system (KMCS) (54). This system employs motion capture to capture a kayaker's paddling technique directly. This tool occupies a previously vacant spot as no other methods directly measure kayaking technique. A kayaker's technique significantly influences overall

ability and performance (29). The KMCS may provide unique insight into kayaking stroke, addressing the monitoring gap and accelerating targeted improvements in stroke.

Internal Load Measures

Internal measures quantify the response to encountered stress, encompassing physiological or psychophysiological metrics that provide insight into the individual's internal state (11,22). These assessments are vital for understanding the physiological response to training.

Oxygen Uptake & Minute Ventilation

Oxygen uptake and minute ventilation were frequently used in the literature under review (6,28,35–38,44,46–49,51,52,55). Due to their cost and specialised nature, respiratory gas analysers are used primarily in laboratory settings. Despite the availability of portable alternatives, adoption is hindered by costs, discomfort, and the expertise needed to calibrate and interpret results (68,69). Consequently, while not exclusive to laboratories, the practical use of these tools remains confined to specialised settings (51).

Biomarkers

The reviewed literature primarily examined biochemical status (6,28,36–39,42,44–47,49–52,55–59). These investigative approaches encompassed sampling blood, urine, saliva, or other bodily fluids to evaluate concentrations of pertinent substrates, often associated with metabolic stress. As the literature establishes, blood lactate concentration tends to increase in response to exertion in normal individuals (70). Consequently, it can be a useful metric measured in various exercise contexts to ascertain the metabolic status of individuals.

Within the reviewed literature, lactate concentrations are pivotal in informing assessments related to the lactate turn point, lactate threshold, onset of blood lactate accumulation, lactate steady state, or maximal alactic capacity (37,44,45,50). The application of measuring these in the field remains a challenge.

The exploration of other metabolites is also evident in the literature, including adenosine triphosphate (ATP), creatine phosphate (CP), glucose-6-phosphate (G-6-P), glycogen, glucose, and various haematological parameters assessed from blood (56,58).

Additionally, citrate and 6-sulfatoxymelatonin were examined in urine (59). These measurements aimed to evaluate the metabolic consequences of exercise on homeostasis, offering insights into the specific metabolic impacts of various exercise intensities in kayaking. Notably, blood, urine, saliva, or other bodily fluids measurements can be done in laboratory settings and on-water kayaking scenarios. However, it's worth noting that the interpretation and application of these assessments still predominantly reside within higher-level contexts. Also, the expense makes these methods impractical for a routine monitoring programme.

Heart Rate

Heart rate measures featured prominently in the studies under review (6,28,36,38,40–42,44–52,55). Heart rate during exercise is related to perceived effort in most activities. Heart rate assessment is feasible using electrocardiography with a chest heart rate strap in both on-water and simulated settings. Furthermore, numerous wrist-based GPS sports watches have photoplethysmography (PPG) capabilities that capture heart rate data. However, it's important to note that the accuracy of wrist-based heart rate measurements is likely compromised during kayaking due to water and movement-related artefacts, hindering reliable heart rate detection (71). Moreover, gripping the paddle likely affects cutaneous blood flow and alters the contact pressure of wrist-worn devices. Since PPG signals rely on detecting local blood volume changes, both reduced perfusion and inconsistent contact pressure can degrade signal quality and compromise heart rate accuracy(72,73).

Heart rate measurement is commonly used for recreational sportspeople, especially runners (63). Therefore, despite its potential limitations, its cost-effectiveness and ease of use among kayakers make it a practical choice for both on-water and simulated kayaking scenarios.

Psychometrics

Psychometric measures were used on various occasions to evaluate athletes' internal state. The rating of perceived exertion (RPE) was used most consistently (36,42,47). RPE is applicable in both on-water and simulated kayaking. The Brunel Mood Scale and the success motivation and intrinsic motivation scales were other psychometric tools seen in use (42).

However, the studies examined did not include a combined measure suited to the load monitoring constraints of kayaking, such as the Session Rating of Perceived Exertion (RPE)(74). This measure combines the product of the rating of RPE (in arbitrary units) with the session duration (minutes). This provides a training load measure incorporating an external training volume measure with an internal load metric. It is also likely less affected by conditions than other volume measures, such as distance, or intensity measures, such as speed.

Another absent measure that has shown utility in various sports was the Daily Analysis of Life Demands for Athletes (DALDA) (75). The measure is associated with specific biomarkers and deemed sensitive to stress in basketball players (76). Moreover, it has the advantage over similarly sensitive psychometric tests, having only 34 items, making it one of the shorter psychometrics and improving ease of use (77).

Combining Multiple Metrics

While the discussed monitoring methods have been considered individually, an effective monitoring scheme should not rely on a single measure of training load. Instead of viewing each training load metric in isolation, it should be viewed as a component of the complete picture. Accumulating various measurements provides a more comprehensive understanding of the external and internal loads.

Examples of combining metrics were seen in Mattsson *et al.* and Staiano *et al.* The former used a combined metric approach to measure intensity, including measures like minute ventilation, oxygen uptake, heart rate (HR), and biomarkers (38). Similarly, researchers in the latter article measured heart rate, blood lactate concentrations, and perceived exertion ratings to better measure the level of exertion during kayaking (42).

Evaluating multiple training load markers provides a comprehensive monitoring picture and allows overlapping measures to cross-check, reducing the likelihood of misinterpreting incorrect measures. While the specific metrics employed in this example may not apply to our research objective, the practice of overlapping measures can be applied to any suitable set of metrics.

The data from two or multiple measures can be integrated to create a new and unique measure. This creates single measures that can be compared across multiple time points while covering different kayaking training or racing characteristics. Moreover, the relationship between the combined measures in different contexts might provide additional insight. Sitkowski *et al.*, in looking at heart rate (HR), stroke rate (SR) and power output (PO) in estimating anaerobic threshold, created ratios of PO/HR, PO/SR and SR/HR in progressive incremental exercise tests (45). These combined measures can be compared over time to measure kayaking efficiency.

These combinations of metrics are also helpful in determining how multiple metrics relate to each other. For instance, Bishop *et al.*, Sitkowski *et al.*, and Mattsson *et al.* examined the relationships between HR, blood lactate concentrations, oxygen uptake, and kayaking intensity (38,44,45). Chiefly, these measures provide insights into physiological status, offering information about the internal load. Furthermore, examining such relationships enhances our understanding of how known physiological states relate to one another in kayaking. While these specific measures remain cumbersome due to the need for blood sample testing, the principle can be applied to any suitable metrics (78).

For instance, new devices, such as the non-invasive lactate threshold device (NID), are under development and testing. These devices have the potential to make testing more accessible and consistent. However, they are currently relatively expensive and reasonably inaccessible tools (79). Although it is important to consider metrics that provide a clearer picture of the relationship between physiological training markers and intensity measures, these metrics should be non-aversive and inexpensive to be more widely adopted.

Identified Themes

In this review, four key themes related to effective load monitoring have been identified.

Firstly, different metrics or combinations of metrics are suitable for distinct settings. When examining outcomes in marathon kayaking, it is crucial to consider associated factors that can enhance the effectiveness of measures.

Moreover, it is valuable to identify some key features that are necessary for effective load monitoring tools. Although there have been no direct studies on the efficacy of measures, the metrics used should possess certain qualities. They should be effective in producing consistently reliable and valuable information. They should also be easy to use and affordable. The ease of using a measurement usually depends on how invasive, tedious, or time-consuming the metric is.

Furthermore, an effective measure is not necessarily a novel concept. However, evaluating it in the context of marathon kayaking may be considered novel. When a measuring instrument is used frequently, the likelihood of bias becomes significant. Additionally, expensive technology is needed for some measures.

Finally, balancing these factors is challenging, as optimising one often limits another. Finding a middle ground where all aspects are appropriately weighted and considered leads to a well-rounded measurement.

Conclusions

Limited literature is available on the effectiveness of monitoring training in marathon kayaking. Most studies are cross-sectional and laboratory-based, with many studies using simulated kayaking rather than kayaking on the water. Measuring performance accurately while kayaking on water and controlling confounding factors in water is difficult. Nuances of paddling, such as balance, water interaction, and environmental factors like wind or temperature, cannot be simulated in kayaking (40,80,81).

In summary, monitoring kayakers' training load and responses is an understudied area. Studies with on-water measurement over longer durations would make a valuable contribution to improving the topic. A comprehensive understanding of the monitoring methods' advantages, disadvantages, and effectiveness is crucial for informed decision-making in kayaking research to ensure the studies are robust and the findings are reliable and applicable.

— Roadmap —

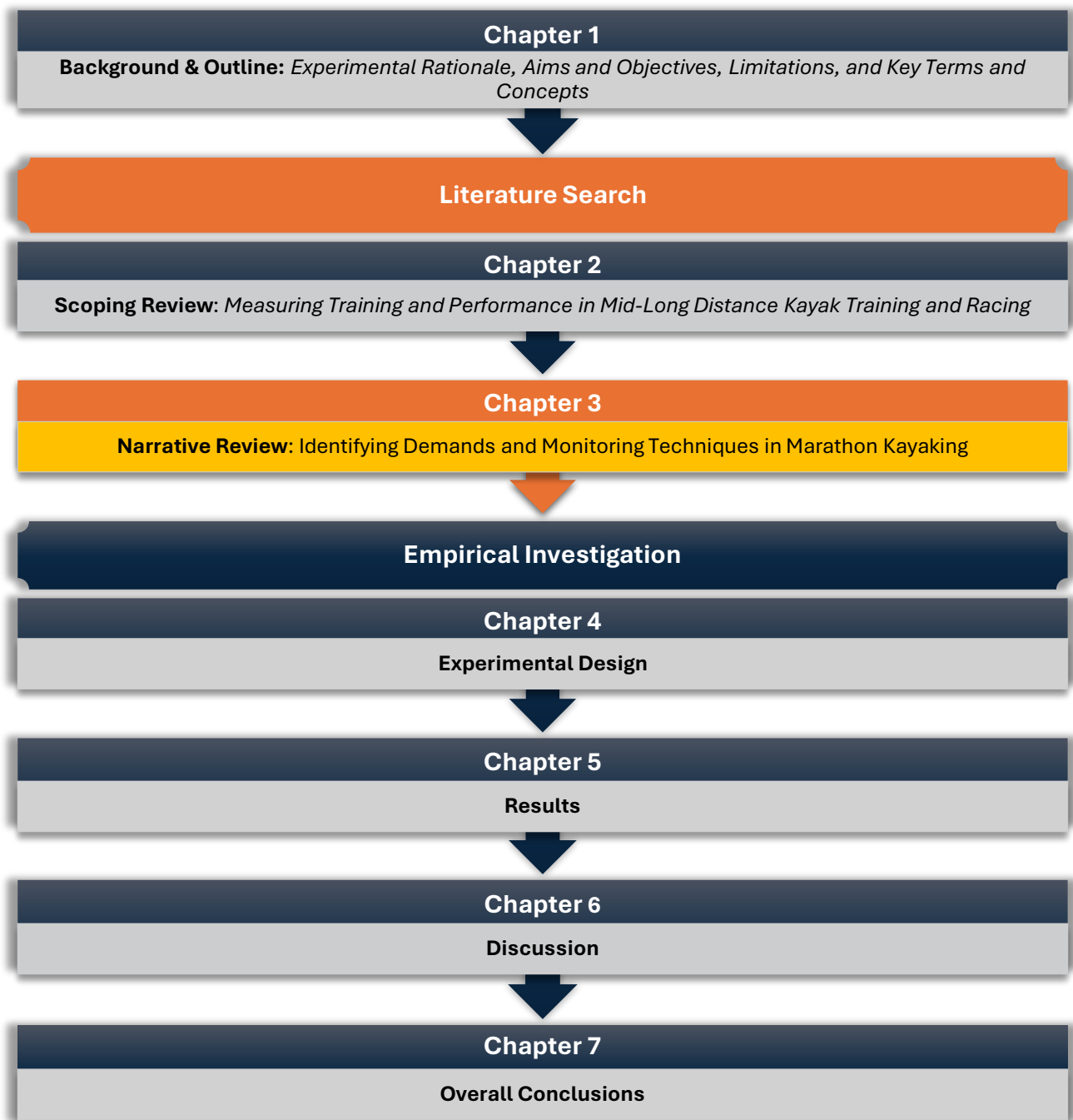


Figure 4. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed.

— Chapter 3 —

Narrative Review: *Identifying Demands and Monitoring Techniques in
Marathon Kayaking*

Introduction

Purpose of Review

This narrative review thoroughly examines kayak paddling and the critical aspect of training load monitoring. Our particular focus centres on the discipline of marathon kayaking, with the goal of elucidating the most suitable training load monitoring practices for addressing its particular challenges in kayak training.

Monitoring training loads plays an essential role in optimising the athletic capabilities of individuals across various proficiency levels. Its utility ranges from achieving peak performance to safeguarding against overtraining or non-functional overreaching.

This review explores various metrics, methodologies, tools, and technological applications used in monitoring training loads to identify those most suitable for kayak paddling. The review follows the scoping review completed. Although it stands alone, its purpose is to highlight some critical aspects of training load measurement. These aspects were not covered as they were beyond the scope of the previous review.

Understanding the sport's characteristics and prerequisites while exploring the available monitoring techniques should help offer valuable insights. These insights, in turn, will empower practitioners with the discernment required to select the most appropriate training load measures tailored to the distinctive demands of kayak paddling.

A nuanced understanding of load monitoring could enhance the precision and efficacy of tools in the hands of practitioners. Ultimately, it is a step that should lead to refinements in training regimens and performance outcomes, all while concurrently mitigating the risk of injury. Therefore, this review uses the systematic approach to evaluate and understand the training load monitoring appropriate for marathon kayaking.

Marathon Kayaking

The Kayak craft was developed by the Inuit people to carry and transport goods and people through waterways. Additionally, smaller variants were used for fishing and setting of nets (26). The formal canoe-kayak sport originated later, with more formal canoeing competitions from the mid-19th century (82). In this review, kayaking, paddling, canoeing, and surfski will refer to the formal kayak racing modality unless otherwise specified.

Kayaking is an activity involving a participant (kayaker) who is seated on a craft (a kayak). A single dual-bladed paddle is used to propel the kayak forward. The kayaker uses the paddle in cyclic motions, ‘gripping’ the water on either side of the boat, thereby pulling it through the water. The kayaker is faced forward, in the direction of motion. In most cases, the craft is steered by a rudder, operated by the feet with a steering mechanism, foot pedals or a tiller bar. The craft used depends on the specific kayaking modality. When competitors are racing in a flatwater race, they typically use a flatwater kayak. If racing downriver, they would be in a more robust river kayak with an over-stern rudder mechanism. In offshore Ocean racing, an ocean kayak or surfski is most appropriate (Figure 5). This craft can handle offshore conditions that other variants cannot. Each craft type has specific qualities that suit it to a particular medium.



Figure 5. Surfskier (Ocean kayaker) catching a wave in a single ski (SS1).

Each craft for the specific disciplines will vary in design and features. Although each modality has unique demands, there is a marked overlap between the kayaking modalities.

The objective of kayaking competitions is to compete on a specified course and achieve the fastest time. In sprint distance events, each kayaker is allocated their lane to ensure they have open water, not dissimilar to short-distance track athletics. In contrast, white-

water kayaking involves participants individually racing through a stretch of white water in a time-trial format (83).

In the marathon kayaking format, the focus shifts to racing over longer distances, ranging from 10 to hundreds of kilometres. The racecourses traverse various terrains such as flatwater (e.g., lakes or dams), offshore, or down rivers. Mass starts or, in some instances, batch starts are commonplace, with all competitors racing the same course simultaneously (84). The kayaker who finishes the course first or achieves the quickest time is the winner. The best kayakers have excellent discipline-specific skills, paddling technique and aerobic fitness. Purposeful training is essential in improving any of these aspects (85).

Training Load Monitoring

Improving in any activity, especially sport, involves repeated deliberate practice to acquire and perfect a specific skill (85). Kayaking is no exception. Productive training should create sufficient stress to trigger metabolic and physiological changes necessary to induce adaptations in the rest phase (86). The specific quantities and intensities of exercise are tailored to produce the desired outcomes (87). Informed training promotes optimal adaptation and skill acquisition while avoiding overtraining or non-functional overreaching (8,88,89). Training load monitoring is an essential part of informing training (8). However, training measures are required to capture the training load adequately.

Training measures must be either a direct measure or an approximation of the work done (external load) or the physiological stress associated with the training session (internal load) (90). External load measures such as speed, distance, power, and duration are independent of internal characteristics. Internal load can be assessed by measuring heart rate, VO_2 max, lactate and Rating of Perceived Exertion (RPE)(91). Multiple measurement methods are used to measure the vast array of athletic demands.

Moreover, the best measures are those specific to a sport's demands, non-invasive, and easy to use and interpret (90). Therefore, it is crucial to understand a sport's demands, both in practice and competition, to best inform which load monitoring measures best capture the demands and are practical for regular use.

Aims of Review

To improve the effectiveness of load monitoring in marathon kayaking, we need to focus on two main areas:

- (i) Understanding the unique characteristics and demands of marathon kayaking to gain a deep understanding of this sport.
- (ii) Evaluating the metrics, practices, tools, and technologies used for load monitoring.

This review is focused on achieving these two objectives. It will provide invaluable insights to inform the selection of training load measures tailored to kayaking's unique demands. This will inform the selection of measurements which will be used in the empirical investigation in Chapter Four.

Demands of Marathon Kayaking

Introduction to Demands

Marathon kayaking requires a high level of aerobic fitness and the ability to sustain physical activity for a prolonged period, utilising predominantly oxidative metabolism. This characteristic is similar to other endurance sports. The endurance demand for kayaking requires an adequate response of the cardiovascular, pulmonary and muscular systems to fulfil the energy demands (5,31,32). However, the novel aspect of water sports, such as kayaking, is that the force from the athlete is applied via the paddle to a fluctuant element (the water) (92).

Therefore, in addition to endurance conditioning, a marathon kayaker must have certain fundamental skills. These include the physical strength to exert force to pull the kayak through the water, the ability to coordinate movements accurately and with correct timing, and sufficient balance to prevent the craft from capsizing. The latter two aspects culminate in the proper paddling technique, referred to as “stroke” (29).

The force to propel the kayak is primarily generated with the upper body (arms and torso). However, the limbs help produce and hold the stroke force necessary for forward thrust. Similarly, an emphasis on physical strength is described in rowing, albeit with more significance placed on lower limb strength (93). The strength is complimented by good stability, which relies on the abdominal and oblique muscles of the torso acting on proprioceptive feedback. Increased stability improves freedom of movement. This is crucial as a high degree of rotational range of motion of the torso increases distance per stroke. Moreover, poor range of motion in this faculty could increase injury risk (94).

The proprioceptive capability is important for coordinating motion (95). This coordination, in turn, is vital for correct stroke and paddler stability. The coordination, range of motion, and stability allow the stroke force to be efficiently transferred to forward thrust.

The velocity the craft moves through the water depends on the physical conditioning and ability of the athlete to apply adequate forces, as well as how efficiently that force is converted into forward thrust. Consequently, the latter two fundamentals, proprioceptive and kinesiological coordination and craft stability, culminating in proper technique, are paramount to performance (96–98). Moreover, correct technique dramatically improves the ability of the kayaker to accelerate the kayak, regardless of endurance capacity or physical strength (99).

Figure 6 demonstrates the interconnected nature of the fundamentals underpinning kayaking performance. Where one area is compromised, strength in the related areas will be undermined. For instance, poor kayaker endurance will negatively affect paddler stability and, therefore, stroke execution.

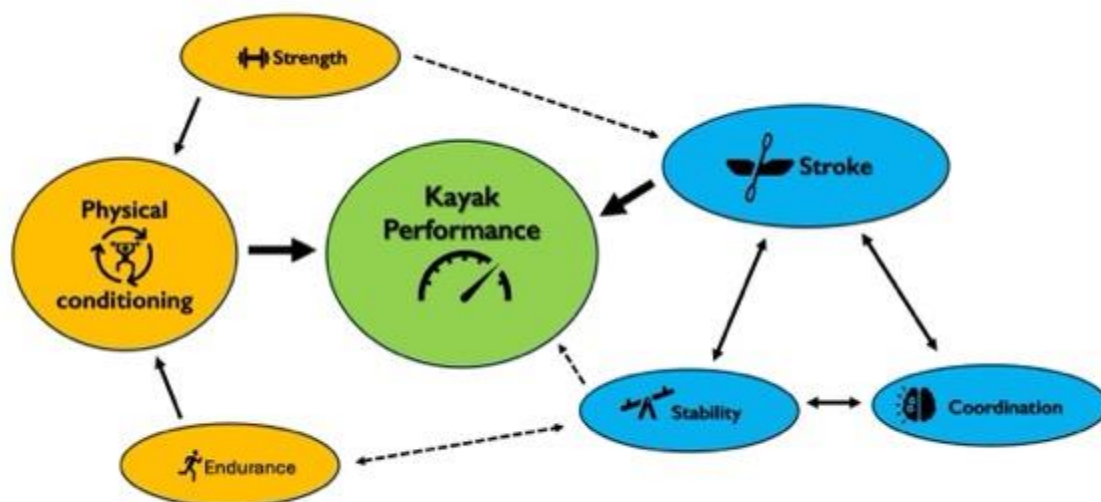


Figure 6. The interconnected nature of different fundamentals of kayaking and their relationship to performance. The arrows demonstrate the direction and magnitude of the aspects effect. Note how there are both bidirectional and unidirectional effects.

Kayaking Technique and Skill

Correct technique, or stroke, involves performing the cyclic arcs of the paddle in a highly coordinated manner. The blade of the paddle needs to enter the water at the correct angle in two planes and with sufficient force and speed to generate the forward propulsion. A kayaker's ability to perform the correct stroke requires many hours of practice to perform with any degree of proficiency. The paddle stroke transfers the force generated by the kayaker via the paddle into forward thrust, which pushes the craft forward. A good stroke involves making this transfer of force as efficient as possible.

Stroke Cycle

Start setup

The kayaking stroke has been numerously described as a cycle with various phases (26,62,99–103). The starting point has the kayaker seated, legs extending forward, knees moderately bent, and feet resting against a foot plate or bar. The upper body is rotated so that one shoulder points forward and one shoulder points towards the craft's rear. The arm corresponding to the leading shoulder is in flexion abduction (extended forwards) and horizontal to the legs. The rear-facing shoulder is in abduction, extension, and external rotation. The arm corresponding to the rear shoulder is bent at the elbow at $\sim 90^\circ$, the hand positioned slightly higher than the kayaker's head. The paddle is gripped with both hands, the shaft almost parallel to the boat, sloping down from the rear towards the leading hand. This described starting position is shown in Figure 8.

Catch-pull phase initiation

The stroke cycles start and end from this described starting point. The cycle is further broken down into “Catch”, describing the entry of the paddle into the water; “Pull phase”, where the paddle is pulled while in the water; and finally, the “glide phase”, where the paddle exits the water and is positioned for the next cycle. Note that the stroke cycle is

repeated on the alternating sides (left and right) of the boat. The left-hand portion of this cycle is shown in Figure 8.

From the aforementioned start point, the leading blade arm begins to adduct and initiate extension, moving the leading blade of the paddle down and into the water. This is known as the “catch”.

The catch initiates the “pull phase”, where the paddle is pulled through the water (103). The leading arm goes from flexion abduction to extension adduction. Simultaneously, the trailing arm flexion is initiated by internal rotation and forward flexion of the rear-facing(retracted) shoulder. The leading elbow is flexed while the trailing elbow is extended. The torso is rotated about the sagittal plane so that the front-facing shoulder moves posteriorly, and the rear-facing shoulder moves anteriorly. Thus, the paddle is arced through the water, initially parallel to the boat and then in a parabolic arc away outwards. These movements continue until the forearm (of the initially leading arm) is flexed to approximately 90 degrees, and the hand passes the hip (according to the coronal plane). The external rotation of the shoulder then initiates the paddle exit from the water.

Paddle exit: Glide phase initiation

The paddle exiting the water initiates the glide phase (103). The previously trailing arm is now the leading arm in the stroke cycle starting point (as previously described) in flexion abduction (extended forwards) and horizontal to the legs. However, the new trailing arm is out of position for the next cycle. The new trailing shoulder thus continues external rotation until the hand is superior to the elbow and then abducted and extended posteriorly. This action lifts the paddle and sets up the new trailing arm for the next stroke. It is deemed the “glide phase” as there is no paddle contact with the water.

Role of the legs

In the pull phase, the leg corresponding to the leading arm pushes against the footplate (or bar), the knee going from moderate flexion at the “catch” to moderate extension by the exit of the paddle. The knee extension pushes the corresponding hip backwards, increasing the overall range of rotation that the trunk can achieve. In the “glide phase,” the knee (corresponding to the new leading arm) is moderately flexed in preparation for the “pull phase” extension.

The stroke cycle is rapidly repeated on alternating sides. This can be described in terms of the paddle phases (beginning on the left side): Left side “pull phase,” “glide phase,” right side “pull phase,” “glide phase,” then again left side “pull phase,” and so on. The paddle interface with the water transfers the force generated by the movements described into forward thrust, propelling the kayak forward through the water.

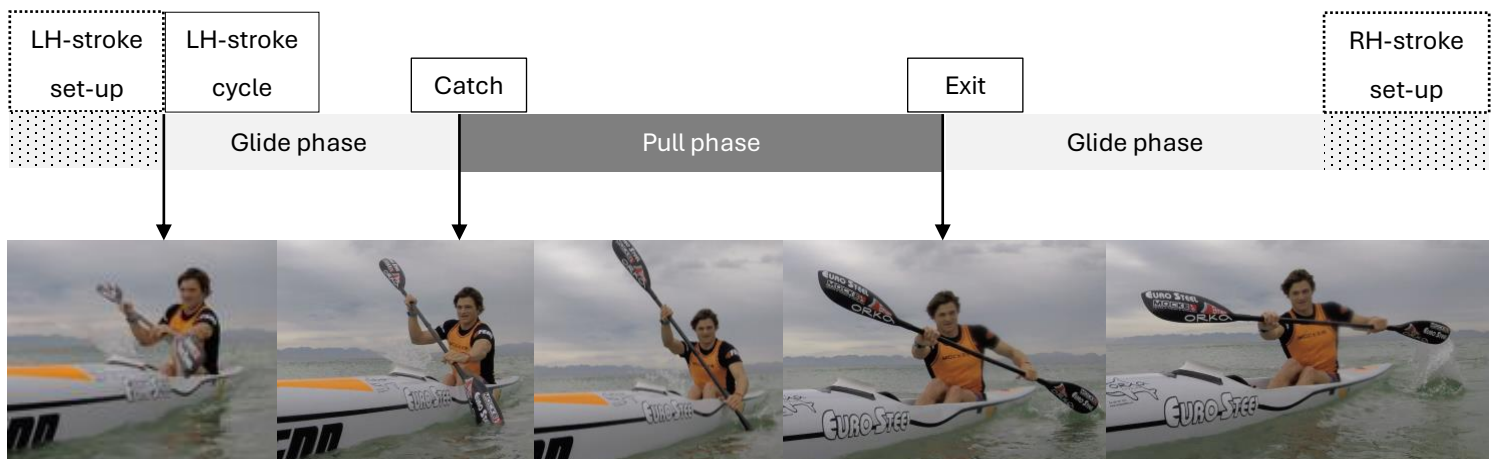


Figure 8. A series depicting the different paddle and body positions throughout the left-hand side kayak stroke. The right hand-side repeat of the cycle is not shown.

Biomechanics of Stroke

The kayaking stroke involves an interplay of muscles in the arms, shoulders, torso, and legs, from the prime movers to the synergists and stabilisers. The specific patterns of muscle activation and timing of the motions will depend on the paddler's technique. However, in general, the following movements need to be performed.

Pulling the paddle- through the water

Firstly, there is a pulling motion from the stroke's previously defined starting point. The arm begins from a stretched-out position horizontal to the body and directly ahead. In the pulling motion, the arm is moved down and back towards the corresponding hip. In this phase of the stroke, the blade closest to the leading hand enters and is pulled through the water. This movement requires the highest force as the arm is closest to the load (water/blade interface). In kayaking, the pulling motion is primarily driven by the latissimus dorsi muscles in the back, with key contributions from the Trapezius, Teres major, and Biceps brachii muscles. These muscles work in concert to ensure a stable and effective stroke and prevent injury such as shoulder dislocation (104,105). These are, therefore, important in the initial part of the stroke, referred to as “catch”, and the subsequent pull. Moreover, the power with which a kayaker can perform prone bench pull has been shown to significantly correlate to maximum kayaking speed ($r = 0.80$, $p < 0.01$) (106).

Pushing the paddle- through the water

Additionally, a pushing motion beginning superior and 10-20cm outside of the shoulder directly forwards to end with the arm horizontally stretched out in front of the body. In this phase, the blade furthest from the pushing hand is pulled through the water and exits by the completion of the motion. This movement must cover a greater distance than the simultaneous pulling motion of the other arm and, therefore, needs to be performed at a higher speed. This motion is facilitated by the Deltoids (anterior), which are responsible for the flexion and medial rotation of the arm, (medial) abduction of the arm, (posterior)

extension and lateral rotation of the arm. Additionally, the pectorals major which is responsible for flexion, adduction, and medial rotation of the humerus. Finally, the triceps brachii are responsible for the extension of the forearm and resisting shoulder dislocation (104,105).

Lifting the paddle- out of the water

Subsequently, there is a lifting motion, pulling the hand up from the hip until it is superior to the shoulder. In this phase of the stroke, the paddle exits the water and is completely airborne (referred to as the “glide phase”(103)). The motion has little load but needs to be performed at high speed. This motion is facilitated by the rotator cuff muscles responsible for stabilisation and external rotation of the shoulder, as well as the (medial) deltoid, for abduction of the arm.

Upper body rotation

Concurrent rotation around the medial plane facilitates pulling and pushing. The kayaker must rotate their torso about the medial plane to enable longer strokes on alternating sides. This increases the distance per stroke by the maximum force produced. This is facilitated by the e Rectus Abdominis, which flexes the torso forwards, and the external and internal oblique muscles, which rotate the torso around the medial plane. These muscles are also vital components in the kinetic chain of motion and the craft's stability (107).

Bracing with legs

Lastly, a vital part of an efficient, powerful stroke is holding the body in place by bracing the legs against the footplate. The quadricep muscles facilitate the counterforce between the lower limbs and corresponding arms, stabilising the paddler in the boat. These are important for stabilising the lower body in the boat, helping generate and transfer the thrust force of the paddling. Therefore, the legs have a critical role in the kinetic chain (99,108).

Marathon Kayaking Subdisciplines

Kayaking proficiently involves employing the correct technique. This is the only way to create and transfer stroke force to forward thrust efficiently. The stability of the kayaker in the craft is critical to them having the freedom of movement to perform correct strokes. Stability in kayaking is a learned skill. However, different kayak variants have differing levels of stability. A broader hull on a kayak makes it more stable but can create more drag as the craft moves through the water (36). The kayaks are produced for different mediums (river, ocean, flat water). A kayak is chosen to suit the medium on which the kayaking takes place and the proficiency of the kayaker. The medium on which the kayaking takes place will affect how well a kayaker can perform a kayaking stroke. Kayak racing on the ocean, flat water, and downriver poses various technical challenges that are unique to each discipline. Therefore, while good stroke and aerobic fitness are prerequisites of success, a discipline-specific skill can be equally important.

Ocean racing (Surfski) technique

In kayak ocean racing (surfski), race courses are generally point-to-point, similar to what is seen in certain types of yacht racing, albeit on a much smaller and simpler scale (109). At least some wind, swell, tides, or currents are typically on open ocean courses. The ability to navigate these elements successfully is a vital part of racing. The wind and swell provide energy, which experienced paddlers can use to aid them in completing a course faster and with less physical effort than less experienced ocean kayakers. The ability to do this successfully takes a specific skill, which takes time and effort to cultivate. This type of paddling technique is termed “Downwind” (110).

Paddling downwind involves “catching” the open ocean wind swell referred to in the sport as “runs” or “runners”. The kayak is paddled downwind (thus the name), i.e. in the same direction as the prevailing swell and wind. To catch the wind swell, the kayaker needs to accelerate the craft while facing down the steepest section of the swell. The acceleration must be precisely the right time, or the wind swell will be missed. When a wind swell is

successfully caught, the kayaker can surf down the face of the swell (110). This is depicted in Figure 9. This gives the paddler a considerable speed boost as the swell typically moves faster than a kayaker can paddle. Successful downwind paddlers can catch these runs more consistently and with less physical effort than less experienced paddlers. This primarily results from timing their attempt to catch the wind swell more effectively.

Additionally, with the ability to link one wind swell to the next, skilled paddlers can link multiple wind swells in succession. The nature of paddling in the ocean is that the waterscape is unpredictable. This means paddlers must be able to adapt to sudden changes in the water quickly. Thus, ocean kayaking strokes are generally



Figure 9. Surfski's racing side-by-side downwind race on the Columbia river, Oregon, USA. The kayakers are seen taking advantage of the waves produced by the wind blowing up-river.

shorter, with a higher cadence. Shorter strokes further forward may be necessary for both rapid acceleration to catch a swell or to brace against the force of wind or water at any point in the stroke. Although this decreases stroke efficiency, it is necessary to mitigate the risk of capsizing while not limiting acceleration (111). Moreover, any efficiency lost in a stroke is more than gained by catching the swell.

Therefore, success in surfski paddling requires not only the execution of good technique and the endurance capacity or aerobic fitness to sustain high-intensity endurance effort, but also the skill of downwind paddling and the focus to keep anticipating and reacting to the everchanging waterscape.

River kayaking

Marathon river kayaking involves racing along a stretch of river for several hours or even multiple days. Participants must navigate through rapids and select the most efficient

channels to complete the course as quickly as possible. River padding is classified as an extreme adventure sport (112). This is not without reason, as it is dangerous, with the risk of severe injury or even death (113). Therefore, river-specific kayaking skills are crucial to ensure participants are not only competitive but safe. Paddling down rapids requires the kayaker to navigate between rocks and other obstacles. This entails choosing the correct path downriver, which should be the fastest possible without severe risk of capsizing.

In river kayaking, a splash cover is used. This prevents water from sinking the craft but can limit the range of motion of the kayaker. Paddling downriver means paddling in moving water, which changes the drag of the paddle through the water and affects water resistance (111). This is an over-and-above anomaly, like eddies and waves, which collectively lead to a shortening of the stroke to deal with the decreased range of motion and vulnerability to capsizing. As in surfski, this decreases stroke efficiency, but the trade-off is worth ensuring the paddler remains upright (111). Experienced river kayakers can position themselves excellently on the river to avoid obstacles and find the fastest-flowing water. Figure 10 shows K2 kayaking crews navigating down rapids on the Fish River in the Eastern Cape of South Africa.

Another vital aspect of river racing is portaging, which entails carrying the kayaks over land. Portages are sometimes necessary to avoid dangerous obstacles, such as large rapids or waterfalls, and other times, it is quicker to portage than follow the course of the river. In races, kayakers need to run effectively while carrying the boat. Furthermore, paddlers must be capable of exiting and re-entering the craft quickly and without incident in varying terrain. Excellent balance, boat positioning, and control are fundamental to the portaging technique (80).



Figure 10. Kayakers in K2's navigating down rough water in Keith's flyover rapid in South Africa's Fish River Marathon, 2021. The kayakers can be seen employing shorter brace-strokes to stay upright in the rapids.

In summary, success in marathon river races requires balance, coordination, and aerobic fitness to perform correct techniques on varyingly rough water at high intensity for several hours. Additionally, specific skills and concentration are required to navigate the “big water” sections of the river safely and quickly and execute portages without incident (114).

Flatwater marathon

A flatwater marathon is a set-distance race with eight laps and seven portages for senior males (one fewer for females). The laps are approximately 3.8 km, with one short lap making the total distance about 30km. The laps are punctuated with a portage between 30 and 150 meters, occurring at a predetermined point in the lap. The race typically takes slightly over two hours, depending on the competitors and conditions (84).

This format of kayaking requires the least understanding and skill of water conditions but relies on a high kayaking speed and acceleration, strength of endurance, and tactical acumen. Acceleration, speed, and aerobic fitness are important in endurance racing, but tactics such as wash riding, buoy turns, and portages also play a significant role. The largest contributor to performance is boat wake riding, where athletes conserve energy by positioning themselves on the boat wake of a competitor, similar to drafting cycling races (115).

Drafting involves strategically positioning oneself behind another competitor to reduce environmental drag, leading to energy conservation. While not unique, there are some key differences in kayaking drafting. Specifically, larger groups enhance the drafting benefit in sports, where the benefit is found in reducing air resistance (e.g., cycling). However, the most effective energy-saving positions in kayaking are directly beside or behind the lead paddler.

According to Pérez-Landaluce *et al.*, the V1 position directly behind the lead paddler can achieve an energy saving of up to 32% (Figure 11) (36). This creates a situation where

kayakers are constantly competing for the wake of the lead paddler, known as the “first wake”, while trying not to become the lead paddler until it's advantageous. Moreover, it means that in kayaking, a group size of 4 is the ideal group size where everyone has the best possible gain from wave riding and no real possibility of being bumped off. It is common in a marathon race for a small breakaway group of 2-4 paddlers to get away early in a race without being caught by a bigger chasing group—something uncommon in cycling.

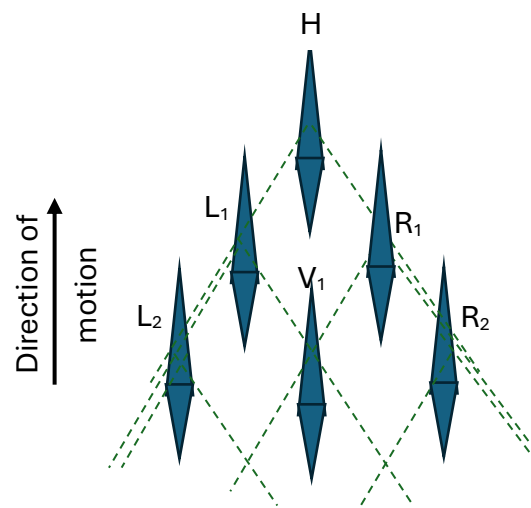


Figure 11. A typical wash riding configuration of a bunch of kayakers. H= Head paddler, then L1 = Left first wave, R1 = Right first wave, L2 = left second wave, R2 = right second wave and V1= First V directly behind head paddler. The dashed line represents the boat wave. The positions closest to the head paddler (L1, R1 and V1) have optimal energy saving, the energy saving decreases on positions further away (L2, R2).

Success in a flatwater kayak race depends on efficiently holding onto the best wash. To achieve this, a kayaker needs to have excellent aerobic fitness, speed and acceleration, which is vital to both challenge and fend off challenges from other kayakers for the position. Moreover, they also need tactical acumen to get the most wash riding with the least effort. Therefore, in this format, having good technique becomes of utmost importance. Even if a paddler possesses the strategic insight to comprehend how to respond in a specific situation, it proves futile without the necessary acceleration and

speed to execute the desired move. Finally, being strong in portaging is important, as this often contributes to kayakers breaking away in a race.

To summarise, this section highlights that while the different water formats vary, they share certain key elements crucial for success. These include proper balance and coordination to execute strokes accurately and robust aerobic fitness to sustain high-intensity paddling over extended periods.

Craft Types

Each kayaking discipline has unique challenges, so specific kayaks are designed for each to navigate conditions as quickly as possible. A kayak's speed is largely determined by the power generated by the paddler through the paddle, which must overcome the drag force acting on the hull (111,116). Manufacturers aim to minimise water drag at racing speeds by designing long, narrow kayaks (81,117). However, more streamlined designs can be less stable, so within the mandated specifications, manufacturers design craft to be efficient at high speeds and stable enough to allow maximum effort (81).

Each craft variant has single-person (K1, SS1) or two-person (K2, SS2) variants. The letter designates the craft: K=kayak and SS = surfski. The number designates the number of crew (2). The craft is designed to suit the unique demands of each kayaking modality. Albeit there is notable overlap between the modalities. Figure 12 and Figure 13 are examples of SS1 and SS2 surfskis and K1 kayaks.

Different types of kayaking have their own unique challenges, and the kayaks used for each discipline are specifically designed to tackle these challenges while ensuring maximum speed, performance, safety, and dependability. Although there may be variations in kayaks for different disciplines, basic principles guide the ideal design of the craft and allow kayakers to navigate the challenges of the water.

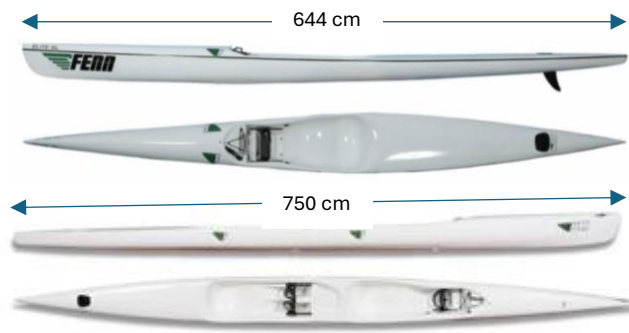


Figure 12. A single (top) and double (bottom) surfski, the ocean kayaking variants of K1 and K2 respectively. These are sit-on-top crafts with under stern rudders controlled by foot pedals. The boats are not to scale, but lengths are shown alongside.

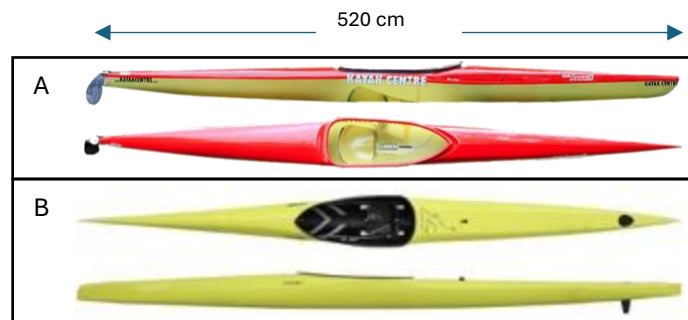


Figure 13. A- river K1 with an over-stern rudder system; B- Marathon K1 with under-stern rudder system.

Physical Characteristics of Kayakers

Kayaking is a seated activity that places significant emphasis on upper body and core strength, which is essential for generating the necessary thrust for forward motion.

Kayakers' physical characteristics play a role in their ability to improve the generation of the necessary force, equating to better performance. Numerous studies have investigated the determinants of kayaking performance and have identified certain anthropomorphic features that correlate with certain performance measures (118,119,26,120).

Height, Arm Span, and Mechanical Advantage

Height and upper limb length are notable characteristics that can impact kayaking performance. Visualising the paddle as a lever, with the water acting as the fulcrum and the hands functioning as both the load and effort points (see Figure 14), we can understand how greater seated height and longer arms provide a mechanical advantage. Specifically, an increased seated height and longer arms allow for a longer effort arm (Figure 14, E-L), the distance between the top hand (E) and the water. The load arm (Figure 14, L-Fc), the distance between the bottom hand (L) and the water, is relatively shorter. This

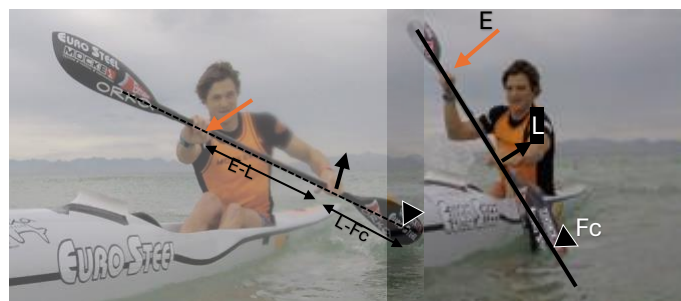


Figure 14. Shows how the paddle in a kayaking stroke can be seen to act as a lever, upon which the kayaker pulls the kayak through the water. The figure shows how the lever moves from start to finish of the pull phase of the stroke. The hand furthest from the water is the Effort (E). The hand between acts as the Load (L) and the water acts as the Fulcrum (Fc). E-L is the distance between the hands, and F-L is the distance from hand to water.

advantageous configuration is often associated with increased height, as a strong positive correlation exists between adult height and upper limb length (121,122).

Research by López-Plaza et al. in 2017 demonstrated significant positive correlations between height ($r=0.45$, $p<0.01$), sitting height ($r=0.51$, $p<0.01$), body mass ($r=0.41$, $p<0.01$), and time trial performance (119). Additionally, Fernandes et al. found that a higher sitting position positively correlated with higher velocity in younger kayakers (118). Shepard also noted associations between coach ratings and athlete height, indicating that taller stature was prevalent among the studied kayakers (26). However, it is important to note that excessive height may introduce challenges such as craft instability and additional weight, suggesting the existence of an upper limit to the benefits of height. It can be concluded that having a taller seated height can be an advantage in kayaking, particularly when combined with other beneficial characteristics.

Body Mass and Kayak Efficiency

Body mass and skeletal muscle mass are additional factors to consider in relation to kayaking performance. It is known that increased weight contributes to higher hydrodynamic drag, which in turn makes paddling at high speeds more challenging (111). However, weight gain can be beneficial if it leads to a relative increase in power. A study examining both sprint and long-distance kayakers revealed significant positive associations between body mass, skeletal muscle mass, and measures of maximal and relative power during single-stroke kayak tests (120). This suggests that additional weight from skeletal muscle can be a worthwhile trade-off for flatwater kayaking performance.

It is also worth noting that the choice of kayak plays a role in the impact of a kayaker's weight. Although flatwater and river kayaks are restricted to a shorter length, they are otherwise optimised for heavier paddlers. In ocean paddling, surfskis are used. These have no such length restrictions and are thus longer with greater efficiency, meaning that the kayaker's weight becomes less consequential (81).

In summary, the physical characteristics of kayakers have an impact on their performance. High height, upper limb length, and body mass can influence speed and efficiency. While certain traits provide advantages, there are limits to their benefits. The choice of kayak also plays a role in mitigating the impact of kayaker weight. Understanding and optimising these physical attributes contribute to the overall success of kayakers in their pursuit of speed and performance on the water.

Physiological Demands

This section explores the diverse physiological systems challenged by kayaking's demands. It aims to offer a comprehensive exploration of systems and key factors relating to these fundamental demands, drawing insights from a wide array of literature sources. Kayaking is a combined endurance-strength sport that challenges both aerobic (endurance) and oxygen-independent (strength and power) systems (28). This section will examine these divergent demands, including which physiological systems are involved and how they may need to adapt. It will also look at other areas of unique impact in kayaking, including balance and biological age.

Strength and Power

A kayaker uses the paddle to propel the kayak through the water. A closer examination of the kayaking stroke (see *Stroke Cycle*) revealed that it is unquestionably a highly resisted movement. Hence, kayakers' strength and, more importantly, their ability to generate force are integral to an effective kayaking stroke. The literature has supported direct links between strength measures and kayaking performance (123–125).

A study of endurance kayak performance found that the number of hanging dips completed in a minute and race time were significantly correlated ($r = -0.58$, $p=0.003$) (123). Moreover, a longitudinal study conducted over three years on male and female elite kayakers showed a significant correlation between strength gain scores and performance time over the study period ($r = 0.59$ $p<0.01$ for Pull-up 1RM; $r = 0.64$, $p<0.01$ Bench press 1RM) (124).

Furthermore, a study of elite sprint kayakers found strong correlations between maximum power output in exercises such as the bench press, prone bench pull, and a modified 10-second Wingate kayaking test ($r = 0.83$ – 0.98) and peak power in the Single Kayak Stroke Test (125). These findings suggest that muscular strength and power are key contributors to kayaking performance. The ability to generate high force during resistance-based exercises appears to be consequential to on-water kayaking performance measures.

Furthermore, a study aiming to optimise strength gains found that strength-training groups substantially improved sprint performance, in contrast to trivial or small changes in the control group (126). However, the study was focused on improvements within the first 15m of a sprint. Another study found no strong association between one repetition maximum (1RM) in various upper body exercises and 1000m performance in sub-elite sprint kayakers between the measures ($r > 0.7$; $p < 0.01$) (127). This may suggest that the high strength is more consequential for shorter distances. Ultimately, this highlights that kayaking performance is multifactorial. While strength is important, it alone is insufficient for optimal performance. Therefore, relying solely on strength metrics to predict on-water marathon kayaking performance has limited applicability.

Aerobic Fitness

The ability to sustain physical activity relying on oxidative metabolism for a prolonged period is crucial for success in long-distance events, including kayaking (31). A study on elite kayak paddlers demonstrated a maximal $\dot{V}O_2$ uptake of $4.30 \pm .29$ L/min, accompanying high blood lactate levels after races (14.0 ± 4.1 mmol/L) (28). Additionally, a study on long-distance kayakers found a strong correlation between their race time and peak VO_2 max during arm ergometry ($r = -0.81$; $p > 0.001$) (123). These findings indicate that the activity requires high aerobic and oxygen-independent metabolism levels.

In a study comparing time to exhaustion at a velocity of VO_2 max among world-class athletes in cycling, running, swimming, and kayaking, kayakers exhibited a lower mean VO_2 max incremental test (53.8 ± 6.1 ml/min/kg), approximately 74% of that seen in cyclists in discipline-specific VO_2 max testing. However, they demonstrated a longer time to exhaustion at their velocity of VO_2 max (*Kayak Mean $\pm$ SD = 376 ± 134 s vs Cycling Mean $\pm$ SD = 222 ± 91 s*) (51). This can be attributed to the lower energy cost of kayaking at the velocity of VO_2 max compared to cycling. Nevertheless, it underscores that kayaking demands a significant aerobic capacity.

Interference phenomenon

Strength and endurance training prompt distinct and occasionally divergent adaptive mechanisms. Therefore, concurrent strength and endurance training could compromise the adaptations for improving muscle strength, especially muscle power (128). Kayaking necessitates resistance and endurance training, so structuring kayaking training to minimise interference might be consequential. However, a more recent review disputes the severity of interference with non-eccentric sports such as cycling or kayaking (129). Notwithstanding, where catering to prevent interference is not challenging, it could be adopted. A study on interference in sprint canoeing and rowing concluded that periodisation of training into short blocks, wherein a specific adaptation is elicited, would be optimal (130).

Cardiovascular System

Engaging in kayaking, an endurance-strength exercise, for an extended duration places specific demands on aerobic capacity. Two primary demands emerge within the cardiovascular system in this context. First, the classic requirement is for increased blood flow to muscles and lungs, facilitating the delivery of essential metabolites and removing metabolic by-products. Second, the cardiovascular system must contend with high peak systolic blood pressure observed in combined endurance-strength activities (131). These demands force the adaptation of the cardiovascular system to cope with the sustained increases in haemodynamic load (132).

The literature has observed that long-term athletic training of both endurance and resistance results in cardiac changes. Specifically, there is increased left ventricular cavity dimension and cardiac wall thickness in endurance and strength training, respectively. Additionally, there is increased cardiac mass in both cases (133,134). Understanding that these adaptations should occur can inform the type of training that needs to take place. Furthermore, it underscores the importance of specific regiments of both resistance-type training and endurance training (6).

Considering this difference might be important from a measurement context. Heart rate (HR) is often used to evaluate session intensity. A study on sprint kayakers found that HR and stroke rates were mismatched when recorded during a prescribed intensity zone based on power output. Furthermore, HR could not differentiate training demands across high-intensity (135). However, this should not underscore heart rate measures, as they are still extremely useful monitoring tools, particularly at intensities more common in marathon kayaking. However, more context could enhance their interpretation.

Oxygen Uptake

In a study on time to exhaustion in various sports, the incremental VO_2 max test result for kayaking was 53.8 ± 6.1 ml/min/kg, which is only 74% of that achieved by cyclists in modality-specific testing (51). This discrepancy is likely attributed to the reduced demand placed on the larger muscles in the lower limbs during kayaking compared to cycling.

While not reaching the levels described in cycling or running, this highlights the substantial aerobic demand inherent in kayaking, necessitating robust support from the cardiovascular and pulmonary systems. Kayakers must possess ample ventilatory capacity to meet the energetic requirements of the activity, a factor particularly crucial at submaximal intensities where a larger proportion of the demand is met through aerobic respiration (37).

Furthermore, in marathon kayaking, where races approach the limits of aerobic exertion, ensuring sufficient ventilatory capacity becomes paramount. Moreover, the inherent tensioning and twisting of the upper body, integral to a correct kayaking technique (see Figure 8), may influence respiratory capabilities. Considering these factors may be necessary for a nuanced view of kayaking demands.

Balance

Kayaking involves manoeuvring a craft on moving water affected by various forces such as winds, tides, and gravity. This challenges kayakers who must maintain balance and control while navigating these water disturbances (136). A study on the postural response of rowers and kayakers to imposed optic flow (a virtual background which gives the impression of movement) showed these populations to be less impacted than a non-athlete group (80). Thus, by practising on-water kayaking and facing balance-related challenges related to the medium, kayakers have likely tuned up their balance along with other skills.

Balance is a factor in paddling with the correct technique (see Figure 6). Moreover, the kayaker needs to balance the craft without capsizing, particularly in rough conditions encountered in the ocean or downriver. Even on flat water, the fastest crafts are narrow to reduce drag and thus unstable (81). Moreover, this is a consideration when interpreting data related to simulated kayaking (on kayak ergometer), where the on-water balance demand is challenging to replicate.

A kayak set up in a way that best suits the kayaker's anthropomorphic features aids optimal performance (137). However, while the cockpit set up in a kayak, specifically seat height, can improve paddling efficiency, it can also make the craft less stable by raising the centre of mass (138). Consequently, understanding and optimising these factors results in better craft stability, ultimately improving performance.

Biological Age and Peak Performance

Biological maturation influences the peak sporting performance of individuals. The ideal biological age for excelling in a specific sport can vary depending on the physical demands and technical expertise required (139). A study of Olympic athletes showed a range of biological maturation across different sports. The study utilised regression trees as a

statistical tool (140). It revealed that male and female canoeists peaked in the fourth (age:26.9-29.2y) and fifth (age:27.0-29.0y) oldest groupings of Olympic sport athletes, respectively (141). However, these findings were specific to sprint canoeing, which relies on explosive power and speed. In sports that depend on endurance, like marathon kayaking, athletes tend to perform at their best at later ages. In addition, athletes who acquire advanced skills and knowledge can offset the decline in performance that comes with ageing (139). As a result, marathon kayaking disciplines such as river and surfski tend to favour older, experienced athletes who have honed their skills through deliberate practice.

Psychological Demands

There is a cognitive load associated with kayaking. For example, a study found that performing a cognitive task before kayaking decreased the speed of skilled kayakers (142). Moreover, a study on cognitive load on kayaking performance in young elite athletes showed that a high cognitive load task harmed performance (42). Interestingly, in the time trial following the cognitive task, the athletes reported higher Rating of Perceived Effort scores (RPE) despite lower average heart rates and average speeds (42).

Although previous studies found that acute bouts of aerobic cyclic exercise (e.g., treadmill running or walking) can improve cognitive ability, these improvements are typically seen in connection with moderate-intensity exercise or after the exercise bout (143). Moreover, maintaining correct balance, form, and coordination of stroke, all while sustaining a substantial physical effort constitutes a considerable cognitive load (142).

In marathon kayaking, athletes face unique cognitive challenges. Ocean kayakers (surfski paddlers) must stay focused to maintain their course and ride the wind swell effectively. River marathon paddlers must remember the correct river channels and accurately navigate rapids. Flatwater marathon paddlers need to maintain high-intensity effort while making tactical decisions.

In marathon kayaking, cognitive demands are likely heightened, particularly in ocean and river conditions. Consequently, this could influence ratings of perceived exertion (RPE) during both racing and training, a phenomenon previously associated with mentally fatiguing tasks (142). Acknowledging these factors adds valuable context to the interpretation of psychometric scores.

Ergogenic Aid Intake

It is generally accepted that using an ergogenic aid in longer (> 60 minutes) races is beneficial for sustaining a high-intensity output (144). The specific concentrations and macronutrient makeups may vary, but the literature supports a guideline of 60g/h of carbohydrate intake (144,145). Kayaking is unlikely to be an exception, as it has both endurance and power demands (146).

Consuming ergogenic aids during kayaking presents a challenge as the hands remain occupied throughout the exercise. As a result, using a bottle as a delivery system is impractical. Instead, kayakers typically opt for drinking systems with tubes or drinking pipes, essentially long rubber straws, that require minimal hand involvement. Mastering this technique is essential to avoid time and position loss during a race, especially when athletes are under pressure. Being skilled at quickly and seamlessly using ergogenic aids without disrupting their race strategy is likely beneficial. Athletes should also avoid excessive reliance on consuming aids at specific times, such as those recommended for athletes, to ensure flexibility and versatility in different race situations (147). A study on surfski paddlers found that high performers tended to drink less (40). While this could indicate drinking ergogenic aids is less important in kayaking, it is more likely that the mechanics of paddling, which limits easy access to drink, leads to a constraint on *ad libitum* drinking for athletes racing more seriously.

These strategies also need to be adapted based on conditions (as with most sports), particularly with increases in environmental temperature (148). Kayak races are often unassisted, so the athlete may need to take enough juice to be self-sufficient for longer periods (149). Ultimately, consideration of such factors in racing might benefit performance.

Prevalent Injuries

Understanding the common injuries associated with a specific sport can help understand its overall physical impact and give insight into the demands of that activity on specific areas of the body. Kayaking, for the most part, is a low-impact sport in this context, meaning that regular engagement in the sport does not excessively strain connective tissues. Conversely, Coaches and sports scientists often consider the high levels of connective tissue strain in contact sports (150). Although kayaking does entail multiple cycles of repetitive loads, the loads are not as substantial as running, where a single stride leads to high ground impact forces and injuries resulting from repetitive loads that exceed the tissue's specific load capacity (20,151).

Kayaking is, however, not without risks. In the relevant literature (26,100,152–157), there are both acute and nonacute injuries which can result. The majority of injuries were of the soft connective tissues, such as muscle, ligaments and tendons (152). Non-acute injuries, or injuries not arising from a specific incident, are related to repetitive loads on the joints. Afflicted anatomical areas include shoulders and wrists, likely from holding and handling the paddle, and lower back injuries, which likely relate to a kayaker's seated position. Among reported pathologies related to kayaking are rotator cuff injuries. These are likely due to the rotator cuff being overused. It likely stems from its involvement in the kayaking stroke motion and the repetitive nature of the kayak stroke. Moreover, the rotator cuff abnormalities are about twice as common in marathon vs sprint kayakers (100,153). This underscores the nature of the injury as related to repetitive use as opposed to high acute strain. Wrist tendon issues such as tenosynovitis had reported a prevalence of 23% in a study on kayakers partaking in marathon kayaking events (156). However, these were more attributed to rough water conditions altering kayak stroke.

Acute injuries tend to arise from “brace-strokes”, where a kayaker reacts to a water event and prevents themselves from capsizing. Labral tears requiring surgical reconstruction were reported concerning shoulder dislocation (153). These injuries are more common in

river paddling, where brace strokes are more common. Trauma from striking an object was also reported, which is more prevalent in river paddling (154). Additionally, prolonged paddling has been shown to increase blood levels of creatine kinase and C-reactive protein, not unlike that reported in long-distance sporting events (157).

There are certain dangers related to the medium in which kayaking takes place. The obvious danger is drowning. However, there are some less obvious dangers. The water can be cold, leading to hypothermia, cardiac arrest, and ventricular fibrillation. Moreover, repeated immersion in unsanitary water can soften the skin. This can lead to blistering, paronychia infections, sinusitis, and otitis. Severely contaminated water can also cause diarrhoea, vomiting and gastrointestinal distress (26).

In conclusion, kayaking is generally considered a low-impact sport. However, it does come with inherent risks and the potential for injuries, particularly in the shoulders, wrists, and lower back, due to the repetitive stroke motion. Awareness of these potential injuries and their patterns enables athletes to implement effective training, monitoring, and prevention strategies. With proper risk management, kayaking is considered a safe activity, allowing enthusiasts to continue enjoying the sport well into their later years.

Demands of Marathon Kayaking: Summary

Marathon kayaking hinges on two fundamental pillars. First, it necessitates robust physical conditioning, encompassing endurance (i.e., fitness) and the ability to generate ample force (i.e., strength). Second, it demands top tier kayaking technical acumen, well-developed balance, proprioception, and motion coordination, ensuring precise stroke implementation. Mastering kayaking demands a blend of physical conditioning and precise biomechanical execution to propel the kayak efficiently through the water.

The superior kayaking technique begins with a stroke. The stroke is a nuanced cycle comprising distinct phases. The catch initiates the pull phase when there is paddle contact with the water. This is followed by the glide phase, initiated by the paddle exiting the water and identifiable by no paddle contact with the water. The correct stroking technique needs to be complimented by adequate force generation.

The stroke cycle engages the major muscles of the back, shoulders, arms, core and legs, including the latissimus dorsi, trapezius, Teres major, biceps brachii, deltoids, pectoralis major, triceps brachii, rectus abdominis, obliques, quadriceps and the rotator cuff including many other associated muscles associated muscles. Precise technique maximises the engagement of these major muscles, yielding optimal force generation for each stroke.

When the correct technique aligns with sufficient strength and endurance capacity, it forms the foundations of an outstanding marathon kayaker. Oxygen-independent fitness enables repetitive, high-intensity stroke cycling, critical for starts, finishes, and various racing stages across all disciplines. Furthermore, aerobic fitness is the cornerstone of marathon racing, achieved through targeted training adaptations in major bodily systems.

The cardiovascular system must adapt to handle increased haemodynamic load in kayaking, a combination of endurance and strength activities. It is important to ensure

sufficient ventilation during the kayak stroke, despite the contortion of the upper body. Additionally, because kayaking requires both strength and endurance, training programs should consider the potential for interference between these adaptations.

The physical attributes of kayakers, such as seated height and body weight, significantly impact their kayaking performance. Essentially, kayakers use the paddle as a lever, so greater seated height and longer arms provide a mechanical advantage, enhancing force generation and stroke efficiency. However, increased weight results in higher drag forces on the craft, diminishing efficiency. Therefore, these factors should be considered in training routines and how the kayak is configured.

The type of kayak chosen should also align with the kayaker's physical characteristics. For ocean kayaking, longer crafts excel in high-speed travel, making kayaker weight less critical. However, in river and marathon kayaking, where shorter crafts and portaging are typical, excess body weight can hamper efficiency, especially in longer races.

Kayakers must prepare for various aspects beyond just paddling technique. They need to master specific subdisciplines-related skills, requiring high precision throughout a race. Tasks like navigating channels in a river or efficiently wind swell riding in surfski demand unwavering concentration. A lapse can significantly affect race outcomes. Also, portaging, where kayakers must exit the craft and carry it on land before returning to the water, is a specific skill. Even efficient ergogenic aid intake is a crucial skill in kayaking. Since kayakers constantly use their hands to propel the kayak, reaching for supplements or fluids can consume valuable time during a race. Therefore, these skills should be well-practised to avoid instability and potential capsizing.

Owing to many of these unique procedures, ensuring practice with a racing boat on the racing condition is also important to ensure that the athlete can perform these practices smoothly and has tuned up their balance correctly. Capsizing in a kayaking race will have a

severe negative impact on the race outcome. The experience gained from many years of racing is invaluable in improving all these race-related skills, thus allowing more age-advanced individuals to use their experience and refined skills to mitigate age-related performance decline.

Looking at injuries prevalent in kayaking can enlighten the areas under the most strain in kayakers. The shoulders tend to take the most strain due to the repetitive nature of kayaking strokes. The prevalence of such injuries should inform the training done to mitigate the occurrence of such injuries.

In conclusion, marathon kayaking has both technical and physical demands. Effective training should encompass the intricate interplay of these demands while acknowledging the physiological and psychological challenges they pose. Furthermore, training should consider how these numerous stresses might interact and prioritise the practices most important to the subdiscipline.

Monitoring Practices in Kayaking

Objectives of Monitoring Load

In kayaking, training aims to enhance an athlete's ability to excel in the sport. Achieving optimal performance hinges on striking the right balance between training stress and subsequent recovery (8). Monitoring training load is pivotal in achieving this equilibrium by quantifying an individual's cumulative stress across multiple training sessions (21). This monitoring typically involves collecting data on various training aspects, such as duration, frequency, volume, intensity, and the individual's response to these factors (23). These measures can be broadly categorised as external or internal load, referring to measurable factors occurring externally or internally within the athlete (11).

The quantity of exercise delineated in the training plan dictates the external load, encapsulating the designated physical workload within the training regimen (24). These metrics are valuable for reporting and quantifying the prescribed and completed training dose. In contrast, internal load functions as indicators that mirror the authentic psychophysiological response triggered by the body in response to the demands imposed by the external load (24). These measures are indispensable for understanding how an individual responds to the prescribed training.

West et al. (158) propose a comprehensive approach to monitoring, stipulating that data collected should provide data on three essential pillars. Firstly, monitoring should involve acquiring measurements capable of revealing the demands or expected load during competition. Secondly, it should utilise metrics to shape and guide the design of training regimens (i.e., the training dose), thus aligning them with specific goals and objectives. Lastly, it should incorporate metrics or measures to evaluate individual responses to training, facilitating necessary adjustments.

Simply put, effective training load monitoring requires metrics and outcomes that enable the quantification of the "dose" of training and the measurement of the subsequent "response" to that training (25).

Objectives to Monitor

In marathon kayaking, the foremost goal is straightforward. To win a race by completing the designated course faster than fellow competitors. Moreover, given that in most races, all participants start together simultaneously, the winner will be the first to cross the finish line. While the objective remains simple, numerous unpredictable elements, including weather conditions, shifting water dynamics, and course differences, can profoundly influence race outcomes.

However, successful marathon kayakers consistently exhibit outstanding technical skills, astute tactical judgment, and peak strength and fitness conditioning to secure their finest performances despite these volatile elements. These attributes contain measurable objectives, which load monitoring tools can evaluate.

The load monitoring in kayaking has traditionally been centred around the demands of sprint races. However, marathon kayaking introduces a distinct set of challenges. Marathon kayaking, characterised by prolonged endurance exercise, places a more substantial demand on aerobic metabolism. Yet, it's worth highlighting that specific measures, initially designed for sprint kayaking, can still be relevant and valuable in the context of marathon kayaking. However, it's crucial to recognise that the unique demands of each sport during competition may necessitate adjustments in how we apply these monitoring measures.

Therefore, when assessing current load monitoring practices and objectives in kayaking, it's imperative to contextualise them within the previously established goals. This

evaluation seeks to identify the measures that make the most significant contributions to enhancing these pivotal performance factors.

Improvement of Kayaking Skills and Technique

Enhancing kayaking skills encompasses discipline-specific expertise and proficiency in executing the kayak stroke. To refine discipline-specific skills, kayakers typically need to practice in the actual conditions they will encounter. This hands-on experience is vital for developing the ability to respond effectively to various situations. In simple terms, improving a skill, i.e., downwind paddling, involves repetitive practice paddling downwind conditions. Monitoring such skills involves evaluating improvements in mean speed or energetic efficiency during specific segments of the conditions. However, it can be challenging to separate these skill enhancements from improvements in physical conditioning.

On the other hand, improving the kayaking technique necessitates deliberate and repetitive practice to master the coordinated motion of the kayak stroke (29). Specific drills and technical exercises on land and water are designed to enhance the stroke. Additionally, technical training may be supplemented with feedback from video analysis and in-session coaching intervention. Despite its critical role in overall kayaking success, continuous tracking of the kayaking technique has yet to be a widespread practice. However, it's important to note that these techniques are typically more crucial in sprint kayaking. A single missed stroke can dramatically influence the race's outcome in sprint races. Conversely, in marathon kayaking, the focus leans more towards efficiency throughout a longer race.

Techniques for tracking kayaking skills encompass video analysis of kayak strokes (159), ensuring the stroke's coordination aligns with a two or four-phase model (29). These methods may also involve tracking the stroke and calculating the distance covered per stroke. Implementing these techniques requires technical equipment and associated

costs. Furthermore, like tracking discipline-specific skills, enhancing kayaking stroke efficiency can provide insights into technical proficiency. However, isolating the progression of kayaking technique or skills improvement from improvements in physical conditioning remains challenging.

Improvement of Strength and Fitness Conditioning.

Broadly, optimal physical strength and aerobic fitness improvement will include specific training or stresses occurring at carefully considered durations, frequencies and intensities (87). The training prescription specifics should align with the discipline's demands. As previously described, Kayaking places a combination of endurance and strength demands on athletes (5,32). Training regimens for kayakers will inevitably vary, yet the overarching goal remains enhancing the physical capacities of athletes and, thus, their ability to meet these demands.

Kayak training encompasses various on-water paddling sessions with diverse emphases. While individual sessions will vary broadly, they will focus on improving oxygen-independent (strength and power) or endurance (aerobic capacity). The sessions are set up with specific duration and intensity targets, depending on the goals of the training phase (160). The specific compositions are the subject of academic studies (43). Moreover, incorporating resistance training into an exercise regimen can bolster strength and power output (161). Furthermore, the timing of training may be important, as studies have shown that structuring training into blocks (periodisation) can effectively enhance performance in sprint kayaking (6).

Implementing such a training regimen effectively is assisted by choosing and using the appropriate training monitoring tools. Firstly, the efficacy of a training load measure hinges on its capacity to encapsulate the demands of training and competition. Moreover, the measures must accurately quantify the diverse intended and completed training (21). Furthermore, the metric should accurately depict how an athlete reacts to an individual

session and the entire training regime (158). This quantitative approach of assessing the demands, quantifying specific training prescriptions and evaluating training responses proves valuable in assessing training progression (158). Such practices provide insights into athlete responses, enabling precise and individualised training prescriptions.

Training Load Monitoring Tools

In the studies focusing on training and performance, various tools were utilised to measure factors relevant to kayaking. Various technologies have emerged to monitor both internal and external loads of athletes. Many of these measures, particularly the internal ones, are applicable across different sports. At the same time, others are specific to certain sports but have been adapted for kayaking. Table 3 presents a list of variables measured in the literature. It includes those variables used to quantify training loads, examine performance and gauge the training response of individuals.

Table 3. The internal and external training load measures employed in kayaking studies

	Variable	Units	Studies
<i>Internal</i>	Maximal O ₂ uptake	L O ₂ /min/kg	(28,37,51,123,162,163)
	Blood lactate concentration	Mmol/L	(28,36,42,51,162,164)
	Heart rate	bpm	(28,36,42,51,162,164)
	Session RPE	AU	(163)
	Rating of perceived exertion (RPE)	AU	(36,42,163)
<i>External</i>	Force (SSKT, Paddle, leg)	N	(99,120,125)
	Power (SSKT, Paddle, leg)	W	(36,42,99,120,125,164)
	Stroke length	m	(120)
	Stroke rate	Strokes/min	(36,42,99,164)
	Speed	m/s	(37,42,123–125,163,164)
	Duration	s	(37,42,123,124,163,164)
	Distance	m	(37,42,123,124,163,164)
	Stroke form (Video analysis)	-	(159)

AU = Arbitrary units

bpm = beats per minute

L O₂/min/kg = Litres oxygen per minute per kilogram bodyweight

m = metre(s)

m/s = metres per second

Mmol/L = Millimoles per litre

s = second(s)

Session RPE = Session Rating of Perceived Exertion

SSKT = Single-stroke kayak Test (also Single kayak stroke test (SKST))

Strokes/min = strokes per minute

RPE = Rating of Perceived exertion

W = Watt

Training Intensity, Volume and Frequency

The training load monitoring tools discussed here align with West *et al.*'s pillars (158). They specifically address the first two pillars: measures to delineate the anticipated load in both training and competition and the ability to clearly describe the intended training prescription. The metrics associated with these pillars exhibit some overlap, prompting a collective examination. Collectively, these tools of the first two pillars can be employed to assess the intensity, volume, and frequency of training. These are mostly external load measures.

GPS sports watches

Measures that are more commonly used to monitor day-to-day training in kayaking are wearable GPS (Global Positioning System), which can track speed, distance and acceleration, among other variables, depending on the device used (165). These devices are commonly used in sports like distance running or road cycling to track these variables reliably (165). These devices are becoming increasingly common among recreational runners (166). The devices (such as GPS sports watches) are also commonly fitted with additional sensors to measure physiological variables such as heart rate (bpm)(167). However, as kayaking takes place on a free-moving, fluctuating element, many unbalanced forces are acting to affect the speed of a kayak. Marathon kayaking races occur on rivers, flat water (such as dams or lakes) and open ocean. This is a challenge as the exact effect of the conditions on the speed and distance is difficult to determine. Even if training is done on the same body of water, there can be changes in water depth, wind, current or flow. Therefore, there can be a disconnect between the speeds measured and the distance covered compared to kayakers' effort or intensity. It may be necessary to get additional information about the water conditions. For example, providing the location of a training session, like including information about elevation in running or hiking, could help make informed judgments about the training data. Alternatively, a more direct measure of intensity might be better appropriate.

Heart rate

This internal load measure can assess both intensity and training response. Variations in heart rate during exercise are shown to correlate with changes in exercise intensity (168). Furthermore, heart rate is related to your metabolic state, where the metabolic demand is increased heart rate increases to meet the demand in an attempt to maintain homeostasis (131). Therefore, the measurement of heart rate in exercise can inform the intensity of the exercise. Moreover, as the athlete engages in endurance exercise in repeated and sustained bouts, the heart will adapt to pump larger volumes of blood more efficiently, with the adaptations relating to the nature of the exercise (131). Thus, tracking heart rate relative to other intensity markers (such as the speed of kayaking) over time might indicate efficiency improvements. Moreover, the ubiquity of sports watches with heart rate monitoring capability makes the measure convenient. However, it must be considered in the context of other factors, such as the state of recovery and stress, which can influence heart rate independently of effort.

Power and stroke rate

Cycling has widely adopted mechanical power meters; these sensors measure cyclists' power output. This is a direct measure of the physical output of a cyclist propelling the bicycle forward and is commonly used to quantify cycling intensity (169). In cycling, the power meters comprise a strain gauge, which measures the force, as the crank is a fixed length, and rotation is about a fixed point the distance and time measures (169). In contrast, kayaking power is more difficult to measure. The movement of the paddle is less restricted when compared to a bicycle crank, making the determination of power more complicated. Moreover, even where a power meter is successfully mounted to a paddle, the power loss occurring in the paddle-water interface is difficult to determine. Ultimately, using measures of power might be desirable. It has shown promising results in slalom and sprint kayaking (170,171). However, this technology is still expensive and not widely integrated into the sport—the current commercially available power meter costs just under USD 900 as of August 2023 (172).

Stroke rate is another measure which could be incorporated as a measure of kayaking intensity. A study of stroke efficiency at different stroke rates in sprint kayakers found a strong positive correlation between stroke rate and mean velocity ($r = 0.904$, $p < 0.001$) (102). At present, counting strokes accurately in kayaking requires additional sensors. Although sports watch accelerometers can measure similar actions. Garmin® and Finis Swimsense® use watch actigraphy to count the number of strokes a swimmer takes for a pool length. They were accurate to within one stroke of the actual stroke count 62% of the time (173). Unfortunately, the kayaking modes often don't have such features. However, with the correct software installed, this might be a cost-effective way to add monitoring capability without incurring a substantial cost. It might be particularly useful when combined with other measures such as speed or power.

Training Response Measures

Measurement tools aligned with the third pillar described by West *et al.* are used to evaluate individual responses to training (158). These can range from a response to a training interval, session, or block. These are generally internal load measures.

High-level tools

Among the more advanced tools are sophisticated laboratory devices like breath gas analysers. They possess the capability to measure crucial parameters such as ventilation ($\dot{V}E$), Volume of oxygen uptake ($\dot{V}O_2$), Volume of carbon dioxide production ($\dot{V}CO_2$), and the respiratory exchange ratio (RER). This wealth of data offers valuable insights into an individual's metabolic rate and energy expenditure, proving useful for evaluating fitness levels and endurance performance (174). Furthermore, there are testing kits available that enable researchers to analyse capillary whole blood samples, for instance from an earlobe or fingerpick. These kits can provide essential information regarding hormone concentrations and specific metabolic by-products, such as lactate, related to oxygen-independent metabolism (175). These metrics unveil the inner workings of an athlete's

physiological state and metabolic condition. However, the practical application of these measures often remains limited to controlled research settings or use by elite practitioners. This limitation arises from the intricacy of correct utilisation and analysis of outcomes, in addition to the associated costs.

Psychometric tests

Psychometric measures are valuable tools for both researchers and sports practitioners. They are generally subjective measures collected via self-report (e.g. Questionnaire or rating on a numeric scale) (9). The questionnaires assess mood states, perceived levels of stress and recovery, other physical and behavioural indications, or a blend of these factors (77). Psychometric measures are more sensitive to training and consistent across disciplines than physiological markers (176). Therefore, besides being lower cost than other physiological measures, they may be favourable in certain situations (177).

Many different psychometric measures have been developed to measure various facets of psychology. Some measures have multiple items that need to be answered to get a result, while others are simpler with direct questions. The Rating of Perceived Exertion (RPE) is a subjective measure where the athletes rate the difficulty of an exercise effort on a scale (178). RPE has been well-validated as an effective measure of exercise intensity across various populations (179). Moreover, RPE can be appended with a duration metric to create a versatile training load score, Session RPE (sRPE) (74). For instance, a study on monitoring fatigue in sprint kayak training showed that the sRPE measures correlated strongly with distance and heart rate training load measures (180).

Additionally, more complex measures seek insight into more multifaceted aspects, such as mood or overall baseline stress. One such questionnaire-based measure is the Profile of Mood States (POMS), which contains 65 items to answer and provides general insight into the mood states of an athlete (181). Moreover, the POMS test, effective in identifying mood-affected states, was demonstrated as a promising tool for the early diagnosis of

overtraining syndrome in endurance athletes (182). This tool could have profound implications of athletes' long-term wellbeing. Another shorter tool, with only 34 items, is the Daily Analyses of Life Demands for Athletes (DALDA), which examines the overall stress of an athlete and its possible causes (75). Each tool seeks to understand one or multiple areas of athlete psychology or psychophysiological state.

Psychometric measures help understand an individual's sleep habits, behaviour and chronotype. The Horne-Ostberg "morningness-eveningness" questionnaire indirectly measures the chronotype of individuals (183). The Epworth sleepiness scale is a tool to measure daytime sleepiness (184). Sleep impacts well-being and mood considerably, with poor sleep being associated with poor performance, reduced recovery from exercise and increased injury risk (185). Therefore, it is an important measure to consider when understanding response to training and recovery.

Psychometrics are effective tools for training load monitoring. Many validated psychometric tools provide a systematic framework to assess an athlete's psychological state, including stress levels, mood, and sleep. The effectiveness of these tools depends on their correct use. Consideration should be placed on the frequency and type of measure most suited. Where they are effectively used, psychometrics can optimise training to improve performance and avoid injury.

Autonomic heart rate regulation

Measurement of the autonomic nervous system (ANS) variation is another promising indicator for identifying training-induced fatigue. Such markers measure the ANS response to training stress during and after exercise, indicating the body's ability to tolerate an exercise stimulus (186). These include measures of (I) heart rate variability (HRV), which provide metrics such as the root-mean-square of successive normal R-R intervals (RMSSD) relating to cardiac vagal regulation, and (II) post-exercise heart rate recovery (HRR) measurement, which evaluates how quickly the heart rate returns to resting rate after

exercise (186). The measures aim to isolate the impact of both acute training bouts on the autonomic system and the adaptive effect of repeated bouts. Even giving insight into an athlete's athletic adaptation capacity or “trainability” (187). This provides a way to assess an athlete's stress state and recovery. However, these measures need context to be interpreted correctly and are best used in conjunction with other indicators. Moreover, the results are variable and can be influenced by factors outside training (188). Therefore, such measures need to be done in a controlled manner to yield reliable results.

Performance Testing

The standard test for evaluating kayaking performance is a time trial. This is the real-world result of the training which the athlete has undergone. It tests all relevant factors concurrently, including strength, aerobic and oxygen-independent fitness, and technique. If athletes have improved in one or more areas, they should improve their performance. This applies to all disciplines, including flatwater, sea and river kayaking. The improvement in a flat-water time trial is probably attributed to superior fitness, while improvements on the sea or river may be more related to improved skill. The challenge with time trial testing in kayaking is to control for factors that could affect the results. Even small changes in wind, water depth, or water conditions can significantly impact kayaking speed. Therefore, most time trial testing is done on flat water, where these effects can be controlled.

Nevertheless, conducting a time trial under controlled conditions has consistently been affirmed as an effective method for measuring the performance of kayakers (37,42,123,124,163,164). However, testing how well an athlete is prepared for a given race by making them complete a maximum effort test might not be optimal preparation leading into a race. Thus, the duration and frequency of such tests should be carefully considered.

Summary of Measures

In summary, effective monitoring of training load and performance in marathon kayaking involves considering a range of measures tailored to the demands of the sport. These demands encompass enhancing kayaking skills and techniques, often relying on coach intervention and video analysis. Conversely, there are numerous options for monitoring physical conditioning, with various technologies available to track an athlete's internal and external load.

Stroke and Discipline Skill

Video analysis of stroke allows for stroke tracking based on a two or four-phase model. Furthermore, simply tracking improvements in speed or efficiency might indicate improvement in this area. However, these improvements are hard to isolate from improvements in physical conditioning.

Physical Conditioning: Training Intensity, Volume and Frequency

GPS sports watches are commonly used to track kayaking speed, distance, and acceleration. These can all be useful in describing training volume, frequency, and intensity. However, challenges arise due to the variation in indirect effects from water conditions, necessitating additional contextual information for accurate data interpretation. Moreover, such devices have additional sensors to monitor heart rate.

Heart rate variations during exercise correlate with exercise intensity. Tracking heart rate relative to other markers may indicate improvements in efficiency. However, it should be considered in the context of an athlete's overall state, as factors like stress and recovery can influence heart rate. Moreover, heart rate monitors can sometimes measure autonomic nervous system variation via heart rate regulation.

Power meters can offer direct measurement of physical output. However, they are expensive and have yet to be widely adopted. Moreover, stroke rate, counted using additional sensors or accelerometers, might be a good indicator of kayaking intensity but still needs integration with current sports watches.

Physical Conditioning: Training Response Measures

Advanced Tools, such as breath gas analysers, can measure crucial metabolic parameters. These tools offer valuable insights into an individual's metabolic rate and energy expenditure, aiding in fitness and endurance performance evaluation. Additionally, testing kits can analyse blood samples for hormone concentrations and metabolic by-products, shedding light on an athlete's physiological state.

Psychometric measures, collected through self-report questionnaires, assess mood states, stress levels, and recovery. They are sensitive to training changes and cost-effective, making them invaluable for monitoring athletes' responses to training.

Heart rate monitors can sometimes measure autonomic nervous system variation via heart rate regulation. Monitoring changes in the autonomic nervous system, such as heart rate variability (HRV) and post-exercise heart rate recovery, can provide insights into an athlete's stress state and recovery. However, these measures require controlled settings for reliable results.

Performance Measures

The most effective all-factor performance test is a time trial testing all factors like strength, aerobic fitness, technique, and oxygen-independent fitness. However, controlling confounding factors, particularly in open water, can be challenging. Moreover, completing

TT to test performance can be taxing on the athlete. Therefore, the duration and frequency of testing need to be carefully considered.

In conclusion, no single training load method or marker stands alone; their effectiveness lies in their broader context and the synergy between them. Selecting the most appropriate measures involves weighing factors like cost, usability, and the real-world challenges athletes encounter. Moreover, an effective monitoring programme should be systematic and answer specific questions. Furthermore, a well-balanced combination of these monitoring methods, customised to meet the unique demands of various kayaking disciplines and geared to specific questions, can enhance training, improve performance, and minimise the risk of injuries.

Monitoring Practices in Other Sports

Sports With Established Monitoring

Distance Running- High Acute Loads

Distance running and road cycling have garnered much scientific interest. The stakes for succeeding in international competitions within these sports are considerable.

Consequently, substantial resources are allocated to improving performance. Given the importance of performance optimisation, numerous load testing tools are available, each with broad effectiveness tailored to diverse contexts.

Distance running mass participation has steadily increased since the running boom of the 1970s (189). This is likely due to it being an accessible exercise modality and its recognised protective effect against modern societal diseases (190). However, running is an activity with repetitive, moderate-high ground impact forces that can induce elevated stresses and strains within skeletal tissues (151). Therefore, running carries a particular injury risk, and with increased participation comes upticks in running-related injuries. However, with optimal management of the rest-stress balance in training, injury risk can be effectively mitigated (19). Monitoring training assists in this management.

Standard running load measures are generally related to distance, speed, and duration. These include accumulative running distance, duration (total running time), and session frequency (typically per week) as a measure of external load and running pace (looked at relative to race pace) as a measure of intensity (189). These measures are normally taken with the help of GPS wearables, which usually have other sensors to measure heart rate, stride length, and ground contact time, to name a few (63).

As kayaking occurs outdoors and without a fixed course, GPS wearables are a helpful means of tracking distance, speed and duration. GPS is very appropriate for tracking

kayaking as it is more accurate in open areas where kayaking takes place (63). However, measuring intensity in terms of pace is difficult in kayaking as the water conditions have a sizeable but inconsistent effect on kayaking speed. Nevertheless, tracking distance and duration as external load measures might be appropriate. Moreover, pace could also be used to measure intensity, but only if shown within the conditional context and interpreted cautiously.

Road Cycling- Direct Measures and Managing Large Training Volume

Professional road cycling is an extreme endurance sport, with cyclists covering staggering distances at astounding intensities in both training and racing (191). Therefore, training and racing have considerable physiological and psychological loads. This load or dose needs to be managed, and the response to this dose must be measured correctly to ensure the correct balance between stress and rest to optimise performance (192). Mechanical power is a valuable intensity measure in cycling. Sensors that take advantage of the bike setup (the crank is a fixed length, and rotation is about a fixed point) allow for the direct measurement of power (169). This can and should be combined with other measures, such as heart rate or psychometric measures (e.g. RPE), to inform the dose-response relationship with the training load and the outcome of interest (192). Road cycling measures must also deal with the variable physiological demands of different stages in a road cycling race (i.e., flat parcours vs mountain stages or time trials) (193).

Marathon kayaking races on flat water, oceans, and rivers also have varying stages that have different physiological demands. Understanding how cycling deals with this by integrating different load measures to understand the physiological impact of different types of cycling might be applied to kayaking to increase the training load resolution of kayakers who are training and racing for multiple subdisciplines.

Another lesson from cycling may be the integration of power meters, which may have promise in directly measuring kayaking intensity. It has shown some promising results in

slalom and sprint kayaking (170,171). However, as previously described, there are challenges related to the mechanics of paddling vs. cycling. The paddle (where the power would need to be measured) is free-moving, making power measurement more complex and the power loss from the paddle-water interface difficult to determine. However, these challenges could be overcome with time, resulting in cost-effective direct power measurement in kayaking.

Sports With Similar Unique Demands

Pool Swimming- Indirect Measures

Competitive swimming has existed for nearly 150 years, with competitions held since 1849 (194). The races range from 20 seconds to several minutes. Swimming training has traditionally included large training volumes, with swimmers training up to 110km per week (195). The large volumes and the athlete's response must be measured to ensure the best possible adaptation.

Swimming and kayaking have some similarities. Both involve propelling oneself through the water. Furthermore, proficiency in both is strongly linked to correctly using their respective techniques (92). The consequence of this similarity in the scope of monitoring is that both sports have difficulty measuring power output. Therefore, they need alternative ways of monitoring external load.

Wearable technology such as sports watches can give the wearer information about stroke distance, cadence, and lap times. However, the accuracy of these may be too low for highly competitive swimmers (173). In swimming, a survey study of globally used monitoring methods found that the two most widely employed methods were tracking swim distance, weekly or daily, and using a session Rating of Perceived Exertion (sRPE) measure (196). The focus of monitoring trends towards more global measures as opposed to specific direct measures. This might be attributed to the difficulty of measurement. Moreover, as

swimming performance largely depends on the synergetic action of multiple systems, much like paddling, isolated measures may have less practical use (197).

By examining how swimming tackles similar monitoring limitations, Kayaking can learn valuable lessons from swimming. For instance, it might be beneficial for kayaking to adopt a similar overall approach to monitoring training. This could involve using external measures like distance, average speed, and duration to assess training load. Additionally, measures like sRPE could provide insight into the training load response.

Rowing- Tracking Overall Load

Olympic rowing has races of 200-2000 meters, which range from 30 seconds to around 8 minutes. Rowing is relatively unique in being a part-static and dynamic exercise, owing to the stroke movement requiring the arms to hold the position while the legs extend during a rowing stroke (198). Therefore, it requires extreme fitness, being highly conditioned for aerobic and oxygen-independent demands. Furthermore, strength is essential as athletes must consistently develop substantial pulling forces (198). Rowing training, therefore, needs to include both strength and endurance training.

However, previous research has pointed to the potential for interference between strength and endurance when trained concurrently (128). Consequently, high-level rowing training is periodised to limit interference between the divergent adaptations accompanying certain types of strength and endurance training (130). Furthermore, increased training distance is associated with competitive success (199). However, increasing volume without considering athlete responses will likely result in suboptimal training. Therefore, tracking overall training volume in rowing seems necessary while monitoring the athlete's response for signs of non-functional overreaching (200,201). In rowing, there is some reliance on biochemical and psychometric markers (201).

Kayaking shares a similar fate of being an exercise with both dynamic and static components. Albeit not to the extent of rowing. However, the potential of the adaptation interference of strength and endurance should be considered in kayaking, with periodisation in place to maximise the desired adaptations to training (6,130). Kayaking could learn to use similar approaches. This means ensuring that athletes appropriately respond to workloads, considering individual responses, and adjusting training using psychometrics and total load metrics.

Monitoring Technique

Biomechanical Movement Tracking with Accelerometry

Sports, where specific movements must be carried out correctly, tend to use motion tracking methods to ensure the correct technique. Ball sports such as cricket can use inertial sensors to track the tibial accelerations in fast bowlers (202). Wearable devices with embedded kinematic sensors, including triaxial accelerometers, gyroscopes, and magnetometers, are becoming widely used in applications for tracking human movement. The kinematic sensors can be used to estimate orientation but can only estimate changes in position over short periods (203). Integrating such sensors with a kayak paddle could precisely map the cyclic motion of a stroke using currently employed tracking algorithms validated for human movement. This could be used with power sensors and video tracking to help kayakers track their technique through a range of intensities, helping them improve their technique.

In summary, the insight gained from other training load monitoring practices in different sporting disciplines should not be underestimated. Examining well-funded sports with established monitoring protocols can uncover valuable insights into which measures reliably optimise performance and reduce injury risk.

Distance running showcases the worth of GPS-based metrics like distance and speed, which indicate training volume and intensity. Moreover, in extreme endurance sports like road cycling, using sport-specific tools tailored to the intricacies of the sport's mechanics, such as power meters, can prove immensely valuable. Moreover, using various metrics to compile a comprehensive view of training impact is also beneficial.

Other sports must tackle novel challenges. Swimming's use of psychometric measures like RPE demonstrates how practical such measures are when direct measures are inaccurate or elusive. Moreover, the concurrent static-dynamic sport of rowing sheds light on the necessity of considering varying athletic demands and how resultant adaptations interact. Furthermore, the external load is considered a benchmark to reach, but training should be adjusted according to internal measures based on athlete reactions.

Finally, with technique being such a fundamental part of kayaking, including a measure that can track motion, such as kinematic sensors in cricket, might prove valuable in tracking and improving kayaking stroke. However, this will likely only be adapted when such measures become reliable and affordable. Collectively, these insights provide a blueprint for refining the monitoring of marathon kayaking, thereby elevating its performance-monitoring practices.

Monitoring for Marathon Kayaking: Conclusions

Many aspects must be considered when selecting the best training load measures for a sport. The sport's objectives must be understood, and the demands must be isolated and recognised. The most appropriate load measures for the demands then need to be considered within specific parameters. These include the constraints of the sport, both physical and practical, such as where the sport takes place, the cost, aversiveness and effectiveness of a measure, and which measures are most effectual concurrently.

The demands of kayaking can be broadly categorised into two main areas (see Figure 6). The first is skill and technique. Fundamentally, it is the ability to perform the stroke correctly. Furthermore, it incorporates the skill of kayaking on the sea with wind and swell or down the river with rapids and portaging. These practices are improved through engaging in these types of paddling on multiple occasions. Progress can be measured by noting the progression of efficiency in flatwater or time improvement in sea or river skill. However, direct measuring the progression of kayaking technique or skills improvement, distinct from physical conditioning, presents a challenge.

While kayaking techniques can be analysed through methods like video analysis or coach intervention during training sessions, the consistent and ongoing tracking of these skills is only sometimes practised despite its significant role in achieving overall kayaking success. The advent of devices that track the movement of the paddle through space and are paired with power meters might be a more consistent way to track progress digitally, but these methods are not currently available.

The second area involves physical conditioning. Kayaking requires high endurance and substantial strength. To effectively monitor the physical conditioning of kayakers, it's essential to choose appropriate measures that can:

1. **Evaluate Competition Demands:** This involves assessing duration, distance, and pace factors.
2. **Analyse Training Intensity and Volume:** To understand the intensity, volume, frequency, and completion of intended training sessions (training dose measures), metrics like pace and heart rate, which can be monitored with GPS sports watches, prove invaluable. Additionally, as power measures become more affordable, they may become desirable additions.
3. **Evaluate the Kayaker's Training Response:** Psychometrics are a highly suitable option for assessing how the kayaker responds to training due to their validation across various sports, affordability, and ease of interpretation. More advanced tools like biomarkers may be considered for elite athletes with ample resources. Heart Rate Variability (HRV) can also complement other markers when relevant.

Selecting and utilising these measures judiciously will help provide comprehensive insights into kayakers' physical conditioning. It's important to emphasise that no single training load method or marker should stand alone; their effectiveness thrives in the context of how they work together. Crafting the most suitable set of measures should consider cost, aversiveness, and the practical challenges relating to deployment.

Finally, when it comes to performance testing, the gold standard is conducting flat water time trials under the most controlled conditions possible and considering possible confounding factors. These trials provide the most realistic assessment of all factors influencing performance. However, due to their demanding nature, it's essential to consider how often and for how long athletes should undergo these tests within their training regimen.

Monitoring Tools to Consider for Investigation

The scoping and narrative reviews revealed a gap in the literature on continuous monitoring for marathon kayaking. Existing studies have focused on short-term, laboratory-based tests such as biochemical analysis or oxygen uptake. While these measurements are helpful for mechanistic type studies, they have inherent limitations and cannot be used practically in a monitoring programme.

Considering marathon kayaking's predominantly recreational nature and the constraints of limited budgets, it is crucial to identify the most widely applicable monitoring tools. These tools should be inexpensive, non-aversive, reliable, and valid for most paddlers.

Furthermore, to make the testing accessible to many participants, metrics which can be deployed remotely have several benefits. The sample size can be pronouncedly increased, the testing pool becomes more diverse, and the protocol can be more easily repeated in future studies.

Table 4 evaluates monitoring tools based on their non-aversiveness, low cost, and compatibility with on-water kayaking. The evaluation also considers the suitability of the measures for remote deployment. It is important for tools to be optimised for these qualities to make them most applicable for long-term monitoring in kayaking.

Table 4. Training load measures and the associated aversiveness, cost and compatibility with kayaking. Measures are rated according to their benefits and limitations.

	Measure/Tool	Non-aversive	Low cost	Compatibility with on-water kayaking	Suitable for remote testing
External	Wearables GPS Speed	✓✓✓	X	✓✓	✓
	Wearables GPS distance	✓✓✓	X	✓✓	✓
	Power output	✓✓	XX	✓✓✓	X
	Stroke rate	✓✓✓	X	✓✓	X
	KMCS*	✓✓	XXX	✓✓	X
Internal	Oxygen uptake	XX	XXX	✓✓✓	X
	Biomarker measurement	XX	XX	XXX	X
	Wearable Heart rate	✓✓✓	X	✓✓✓	✓
	Psychometric	✓	✓✓✓	✓✓✓	✓

*KMCS= kayak motion capture system

— Roadmap —

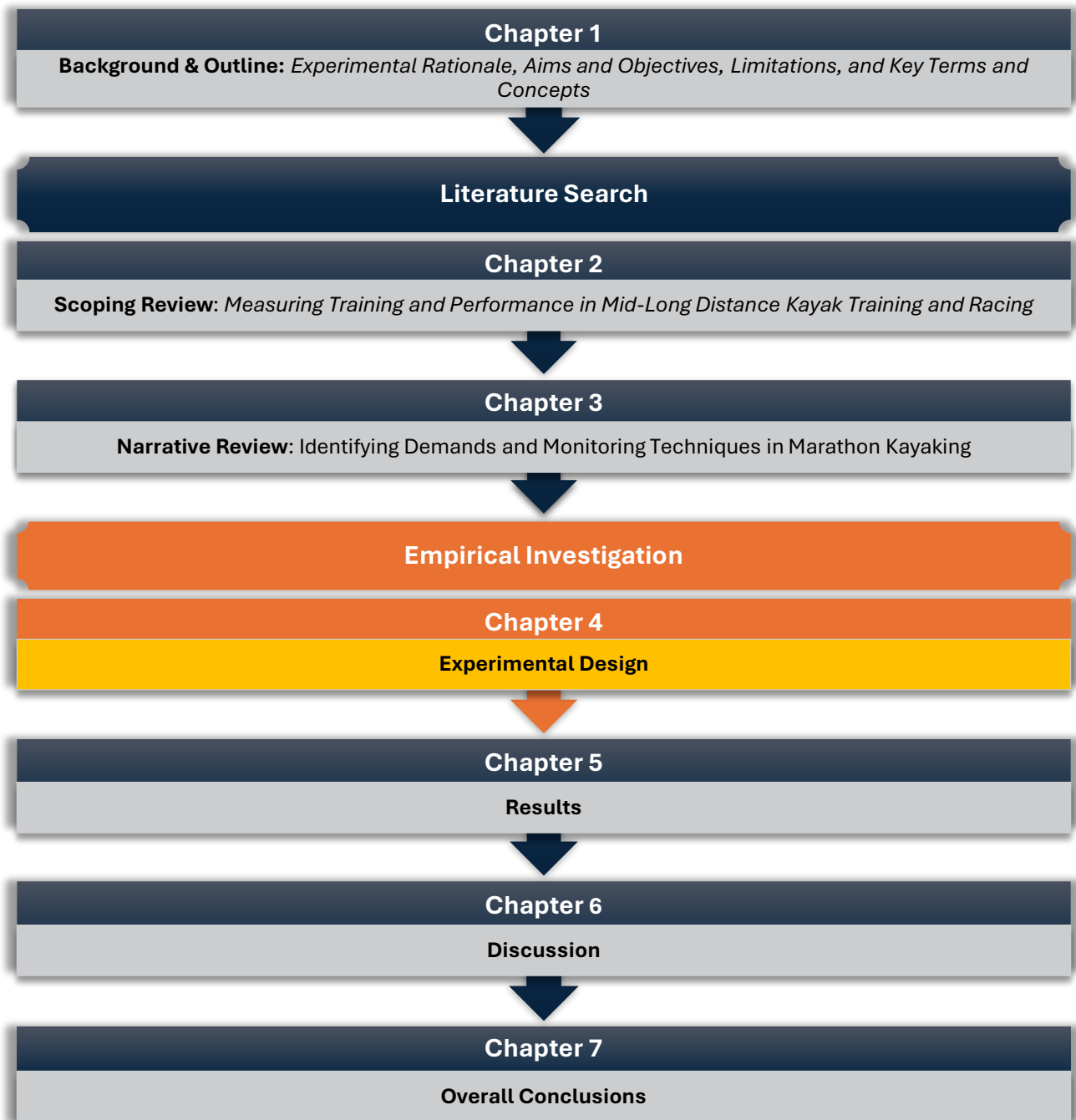


Figure 15. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed

— Chapter 4 —

Empirical Investigation: *Experimental Design*

Purpose of Experiment

Monitoring training loads is critical to optimising athletic performance across different skill levels. Its importance lies in maximising peak performance while safeguarding against overtraining and non-functional overreaching. The literature on monitoring marathon kayaking training is limited, leaving the potential for optimisation.

This experiment investigates training load monitoring in flatwater, ocean, and river marathon kayaking. The study will specifically focus on exploring the relationships between training load metrics and the training responses of marathon kayakers preparing for competition. This research will help identify potential challenges and provide new insights into the sport. This investigation aims to expand on the knowledge gained from the scoping and narrative reviews of training load monitoring in marathon kayaking. The study will focus on designing and implementing an experimental protocol to address any gaps in the field. This protocol will examine the practices of training load monitoring to demonstrate their benefits and limitations.

A nuanced understanding of load monitoring will improve the precision and effectiveness of the tools used for it. This will contribute to refining training programs and optimising performance while minimising injury risk. The objective of this research is to contribute towards the development of effective, context-specific monitoring practices, which will ultimately enhance the training experiences and performance outcomes for marathon kayakers.

Introduction

Exercise training leads to improvement in exercise performance (4,5). This is undoubtedly true for marathon kayaking (5,6). Kayaking, a combined endurance-strength sport, requires training to target aerobic and oxygen-independent capacity (204,205). Monitoring training load is an essential tool to optimise the training, ensuring a balance of physiological stress and recovery, as was detailed in Chapters Two & Three (5–8,206). Accurately measuring both internal and external training loads is essential for informing this balance (9). Moreover, such practices suitable for and tailored to marathon kayaking have yet to be established. Ultimately, this area would undoubtedly benefit from more academic attention.

Chapter Two, an in-depth examination of marathon kayaking monitoring practices, found no set standards or widely used metrics for measuring the core tenets of training load monitoring (158). However, in this investigation, studies used various training load monitoring metrics. For example, a study on energy-saving during kayaking used multiple measures to determine kayaking intensity (36). Similar insights were gained from other examined literature, achieving study objectives using monitoring tools (35,38,45,51,207).

Studies in this area have used measures with a limited scope, focussing on measures suitable for a controlled laboratory setting. However, these measures may have limited relevance to monitoring in marathon kayaking, where insight in certain areas necessitates robust on-water monitoring. Moreover, none of these studies evaluated these measurements in long-term monitoring schemes, as their feasibility in the context of marathon kayaking was not the primary focus. Therefore, there is a compelling need to establish robust monitoring principles tailored specifically for marathon kayaking.

However, overcoming the challenge of establishing best practices in marathon kayaking is impeded by the absence of a clear framework for monitoring the demands. This is

compounded by a need for more techniques to tackle context-specific challenges associated with existing monitoring methods. Additionally, monitoring training can result in improved performance (8,9). This potential is supported further by making sport-specific adjustments to accommodate constraints or contextual factors that may impact training measures (91). These adjustments can improve interpretation and simplify load monitoring for increased convenience and effectiveness.

In Chapter Three, the goal was to identify the specific demands of marathon kayaking precisely. It established two broad areas of importance. Foremost, as with many endurance sports, general physical conditioning was essential(5,31,32). Kayaking has substantial endurance (aerobic) in addition to strength and power (oxygen-independent) demands (123,127). Additionally, kayaking techniques and skills are foundational to performance. These include coordination and balance to remain steady in the kayak and the contribution to the correct kayaking technique (29,95,103). Additionally, discipline-specific skills are needed to race different crafts in different environments and under varying conditions (80,84,110,112). Consequently, the development of both physical conditioning and kayaking techniques is vital for success in any format of marathon kayaking (28). Figure 6 underscores the interconnectedness between these fundamentals

Beyond understanding the unique demands of a sport, it is key to recognise kayaking-specific constraints and characteristics for effective data collection and context-specific interpretation (208). Marathon kayaking is practised across various formats, each with some overlapping and other unique characteristics. Therefore, evaluating the efficacy of a measure in a range of kayaking conditions should be a consideration. Addressing these challenges enables improved measurement and enhanced interpretation of data.

When developing monitoring schemes and practices, it's essential to consider the target population they aim to serve. Creating a highly sophisticated, overly expensive or complex tool is impractical for widespread use. Efforts for marathon kayaking monitoring should

focus on the largest group of marathon kayakers. The 2023 ICF Ocean Racing Championships had a record number of entries (3). A significant increase likely coming from the Tier 3 'Highly trained' category (209). This suggests a substantial population in Tiers 2-4 who could benefit the most from improving training load practices.

The insights gained from the previous investigations in Chapters Two & Three have paved the way for more precise objectives. Notably, no studies have undertaken evaluations for longer-term monitoring of marathon kayaking, warranting a closer examination. An undertaking of these evaluations should account for the sport's unique demands and adapt to its novel contexts. Additionally, the monitoring methods explored should balance accuracy, user-friendliness, and affordability. This ensures reliable and valuable information for athletes and coaches, catering to most marathon kayakers.

Therefore, the primary aims of this study were (I) to explore low-cost, non-invasive methods for monitoring training load and (II) to address existing gaps in understanding training load monitoring in the context of marathon kayaking. A broader objective was to contribute to the development of effective, context-specific monitoring strategies, with the intent of providing actionable insights for researchers and practitioners. These insights may inform future applications of monitoring tools to enhance training practices and ultimately improve performance outcomes in marathon kayaking.

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Aims and Objectives

Aim

To identify the training load measures and metrics applicable to ocean, flatwater, and river marathon kayaking. The evaluation will focus on their effectiveness in informing physical conditioning and overall performance in training.

Key Objectives

Objective 1: Evaluating Kayaking Intensity Measures

- Examine the proficiency of the identified metrics in evaluating kayaking intensity across different paddling water conditions and session contexts.
- Suitability of metrics for in-session, in-training prescription, and retrospectively for describing session intensity.

Objective 2: Assessing Overall Training Load

- Evaluate the effectiveness of multiple metrics in assessing the overall training load, particularly concerning prescribed training and expected competition demands.

Objective 3: Investigating Training Stress Assessment

- Investigate the ability of selected metrics to assess training stress, focusing on understanding the athlete's response to training.
- Assessing the suitability of measures of recovery.

Objective 4: Identifying Performance Measures

- Identify and analyse metrics suitable for assessing performance or improvement in marathon kayaking.

Experimental Approach to the Problem

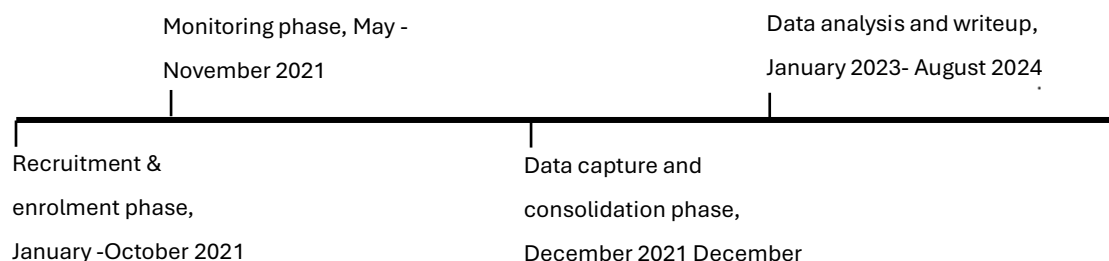
Overview

The study was a longitudinal observational study with repeated measures. The study was conducted remotely and focused on non-aversive, cost-effective measurements. It was performed on a group of variously trained kayakers participating in marathon kayaking ($n=38$). The study included a recruitment phase. Herein, the study was advertised, and the potential participants were screened. Eligible participants then went through an onboarding process, which included clarification of study details and completing informed consent.

The subsequent stage, spanning eight weeks, constituted the monitoring phase where training load monitoring occurred. This included measuring training, recovery, and performance through monitoring devices coupled with physiological and psychometric tests. The amalgamation of these methods provided insights into training load, athlete responses, and performance readiness.

The penultimate stage in the study involved data capture and consolidation. During this phase, participant data were collected and underwent diverse transformations to create a coherent dataset. This phase culminated in the compilation of the final scrutinised dataset. The final phase encompassed data analysis and the documentation of the experiment. This involved conducting specific data analyses and summarising the experimental findings in a written format.

Timeline:



Recruitment

The study used various methods to recruit participants, primarily by promoting the research through social media groups specific to kayaking, such as WhatsApp®. In addition, interested individuals were encouraged to share the advertisement with their networks.

Appendix 2 provides an example of the promotional material. This was sent to all members of Canoeing South Africa (CSA) through the CSA mailing list, ensuring coverage across all official communication channels. Additionally, the investigators actively engaged coaches, athletes, and managers, mainly based in South Africa, seeking their assistance in promoting the study within their networks.

Prospective participants expressing interest were directed to complete an online questionnaire (see Appendix 3). This questionnaire served as a preliminary screening tool, assessing basic eligibility criteria. It determined whether individuals were within the specified age range (18 to 60 years), possessed the requisite kayaking skills, and had access to a GPS monitoring device.

The recruitment period of the study spanned March to October 2021, aligning with various flat-water, river, and ocean marathon kayaking events in the CSA race calendar. A total of 92 participants initially indicated interest within this timeframe.

Participant Enrolment and Study Requirements

Participants were recruited upon meeting the inclusion criteria and agreeing to experimental requirements following an explanation of the experimental procedures, including a discussion of the associated risks and benefits.

These study requirements included:

1. Completing a minimum of three paddling sessions per week during the monitoring period;
2. Participation in one or more of the agreed-upon events (Appendix 4);
3. Use of a pre-approved GPS monitoring device and accompanying heart rate monitor for the duration of the monitoring period; and
4. Be injury-free.

The participants who met the eligibility criteria and agreed to be included in the study were guided to sign a consent form (see Appendix 5). Subsequently, additional information was collected through once-off questionnaires (see Appendix 6, Appendix 7, Appendix 8, Appendix 9 and, Appendix 10). Participants also were provided with more comprehensive details of the study.

The recruited and onboarded participants in the study included male and female kayakers with diverse training backgrounds. Seventy-eight participants were initially onboarded and signed informed consent.

Twelve Individuals were excluded as they failed to meet the study prerequisites (Appendix 1). As a token of appreciation for their interest, they were offered training-related information and any helpful insights upon the conclusion of the study.

Sample Size Determination

The sample size calculation, detailed in Appendix 12, determined that a sample size (n) of 35 participants was required for a significance level (p) of 0.05 and a power of 80% in a single sample (Kayakers) with a continuous outcome (time-trial time result).

This calculation was based on an anticipated difference of 28 seconds in participants' initial and final time-trial performances during the load monitoring period. The difference was informed by anecdotal results from a kayaking squad engaged in regular two-kilometre time trials.

However, the initial recruitment targeted 80 participants to account for potential dropouts, poor adherence, or equipment failures during testing.

Ethical Considerations

The study was performed in accordance with the principles of the Declaration of Helsinki (2013, Fortaleza, Brazil), International Conference on Harmonisation and South African Good Clinical Practice (GCP) guidelines and the laws of South Africa. The University of Cape Town's no-fault insurance policy covered the study. To participate in the study, participants must have passed the health screening test. There was a written and verbal explanation of the study, including its risks or associated risks. These are detailed in the informed consent (Appendix 5). They were informed that participation in the study was voluntary, and they could withdraw from the study at any time without reason. If satisfied with the conditions, they were asked to sign informed consent before starting the study.

The data captured were kept secure and confidential and were only used for scientific purposes. The personal information, such as names and contact information, was only recorded at the beginning of the study and was stored separately from the rest of the participants' information. Participants were assigned a unique identifying code, which they

used to fill out the other forms or questionnaires, as well as any other data they shared with the research team. The identity of the participants was only linked to their information via the participant code. These data were stored on cloud-based accounts and only accessible to the research team. The anonymity of participants was ensured should the data be published.

The project received ethics approval (See Appendix 13) from the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC REF Number 160/2021).

Covid 19 Precautions

This study did not require direct, in-person contact or interaction with participants. Therefore, it was unaffected by COVID-19 restrictions.

Monitoring Phase

This phase included training load monitoring and performance testing to coincide with individual event preparation. Participants were monitored using various non-invasive and cost-effective tools, which were selected based on evidence from scoping and narrative reviews (Chapters Two and Three). These are described in Table 4. All selected monitoring methods were self-administered and required no direct interaction with researchers. This selection was aligned to test a monitoring scheme accessible to individuals to use continuously, without input or interpretations from outside practitioners. Moreover, this made the design non-contact, eliminating the need for physical interaction with researchers. Furthermore, this approach bolstered the study's recruitment potential.

The monitoring period started approximately eight weeks before *the event* (see Kayaking Events), set to align with the beginning of a new training week, typically on Mondays. The participants were informed of this date during the onboarding process. Subsequently, multiple reminders were provided to bolster compliance throughout the monitoring phase.

This phase included the day-to-day monitoring of training sessions. This was done via the short session questionnaire (SSQ) and data from GPS wearables. The SSQ captured essential session-related information, including duration, distance, and location, alongside psychometric measures pertaining to the session and the day. The deliberate brevity of the SSQ aimed to prevent questionnaire fatigue, aligning with the study's commitment to non-aversive measures. The GPS wearable devices captured both GPS and heart rate data, offering precise objective data on training sessions. These measures accumulatively gathered data on overall kayaking load and training session intensity, in addition to short-term measures of stress.

Weekly activities included completing a psychometric wellness questionnaire and an Orthostatic Tolerance Test. The former served as a tool to assess wellness and recovery. At

the same time, the latter evaluated athletes' autonomic function and, by implication, stress levels by examining heart rate responses to orthostatic stress. Together, these measures contributed to the evaluation of the rest-stress balance.

Performance testing was done by means of an individual time trial. This time trial was repeated twice in the monitoring period to assess performance readiness. The procedure is detailed later.

These data were recorded in the lead-up to a kayak race. The completion of the race marked the end of the monitoring phase and the conclusion of the experiment for participants.

Kayaking Events

As a prerequisite for study enrolment, participants were asked to select a marathon kayaking event between March and October 2021. This is referred to further as *the event*. The chosen event needed to cover a minimum distance of 10km. This criterion was implemented as a training incentive, recognising the motivating influence of participating in an event on training consistency.

In cases where participants lacked access to a suitable event in the study timeframe or the event they had chosen was cancelled or delayed, they were directed to undertake a local 10km time trial. This is a common practice at various kayak clubs. This alternative served as their designated event, allowing virtual competition with other participants. The specifics of the selected events and participating individuals can be found in Table 17.

Questionnaires

Multiple questionnaires were used throughout the study. These were all administered electronically through Google Forms, a survey administration software developed by Google. The responses were automatically uploaded to a spreadsheet, which could only be accessed by the creator of the survey or questionnaire. The forms were administered so that only one form, Personal information (Appendix 6), had the participant's name and contact information. When completing this form, the participant was assigned a unique identifying code. This was used when all the other forms or questionnaires were completed. This kept the participants' names and contact information separated from other information to ensure anonymity and confidentiality.

The questionnaires include:

1. A Personal information form (Appendix 6).
2. A General information questionnaire (Appendix 7). This included general questions detailing basic demographic information, medical history, questions devoted to the kayaking skill level, training habits and current form of the participant.
3. A Sleep questionnaire (Appendix 8). This includes the Horne-Ostberg "morningness-eveningness" questionnaire and the Epworth Sleepiness Scale (ESS), which were used to assess the participants' Chronotypes' and levels of daytime sleepiness;
4. The Daily Analysis of Life Demands for Athletes (DALDA) (Appendix 9). The questionnaire assessed the participants' training and life stress levels throughout the study. This was repeated weekly.
5. The American College of Sports Medicine (ACSM) Risk Screening Questionnaire (Appendix 10); and
6. Short session questionnaire (SSQ) (Appendix 14). This included various subjective training intensity (RPE), stress and recovery questions (Quick POMS). It was repeated for every kayaking session. This data was later paired with data from participants' GPS wearables.

When the eligible participants agreed to participate in the study, they completed a set of once-off questionnaires before beginning the monitoring period. These included the above questionnaires listed 1-4. The general information questionnaire provided researchers with insights into participant kayak-related characteristics. The ACSM Risk screening functioned as a supplementary screening tool, ensuring participants were healthy enough for the study. Similarly, the sleep questionnaire, primarily designated as a reference point, was consulted if consistently poor sleep was reported during the monitoring phase of the study.

The DALDA questionnaire (5, listed above) was completed both before the monitoring period began and weekly throughout the monitoring period. In the monitoring period, participants were required to complete the Short Session Questionnaire (SSQ) (6, listed above) following each kayaking session. The participants were encouraged to familiarise themselves with the SSQ before the monitoring period. To promote adherence to this portion of the protocol, there was a system of notifications reminding participants to complete the repeating questionnaires.

GPS Sport Watches

Global Positioning System (GPS)-enabled sports watches, as wearables, utilise the satellite-based radio navigation system to give users geolocation and time information. These devices offer monitoring metrics such as speed, distance, and duration.

Furthermore, these watches commonly incorporate built-in heart rate sensors and accelerometers. However, in this study, participants were required to use chest heart rate straps due to concerns about the accuracy of wrist-based optical sensors, particularly in water (26).

Each participant utilised their personal monitoring device, sharing the data with the research team. Only devices of known reliability (see Appendix 15) were allowed. These

devices were used for all kayaking training sessions during the monitoring period, and the summary information for each session was securely shared with the research team through an anonymous upload protocol. The sessions were all exported together at the end of the monitoring period. This streamlined the process, allowing easier data organisation on the part of the researchers and ease of compliance for the participants.

Protocol for Recording Sessions

Participants secured the monitoring device to the craft or their person. They were asked to confirm that the GPS function and the heart rate sensor were functioning correctly before starting the timer. The device timer was started at the beginning of the session and left on for the duration. At the end of the session, the activity was saved, and the data were uploaded to the relevant vendor portal.

Protocol for Recording Time Trials

For the time trial, the participant followed the same protocol for recording the training sessions. However, the participant needed one additional step. They were required to select the Lap function just before the start of the time trial. This allowed the researcher to determine which time period to observe in the analysis. Alternatively, the participant could save the time trial as a “segment”. This isolated the time trial from the session data automatically. Participants who had difficulty following the protocol could contact investigators for help, including instructions specific to their device.

Time Trials

During the two weeks of the monitoring phase, participants completed a self-selected distance time trial ranging from one to four kilometres. This chosen time trial was then repeated in either week 7 or 8. The recorded results from these time trials were

documented. Furthermore, participants were encouraged to voluntarily record additional time trials if these were already part of their prescribed training routine.

The participants performed their regular warm-up before each attempt. The participants were instructed to wear their GPS monitoring devices during the time trials, which took place on a familiar stretch of water. After the time trial, participants reported weather and water conditions, including wind and tidal specifics where applicable. Additionally, participants reported their Rate of Perceived Exertion (RPE) for each time-trial attempt, with this information being submitted upon completion of the short session questionnaire. An example of how to mitigate condition-related disturbances can be found in Appendix 16.

Outcome variables: Speed, distance, time, heart rate, RPE.

The Rusko Orthostatic Test

Participants underwent a weekly orthostatic/supine heart rate test. This test involved a rest period of approximately 5 minutes, followed by two recording periods of 2 minutes each in the supine and standing-still positions. The detailed protocol can be found in Appendix 17. These tests, conducted under free-breathing conditions, involved continuous heart rate observation throughout the test duration. For consistency, the test was performed at the same time and day of the week after the participant's waking time. The heart rate monitor for training sessions was also used for the orthostatic test. All these data, including all training sessions during the monitoring period, were exported at the end of the study (refer to Appendix 18 for details on bulk data export).

Outcome variables: The difference in standing and supine heart rates will represent the orthostatic tolerance.

Competition

Participants, upon consenting to participate in the study, were tasked with choosing a kayaking event that served as the focus of their training and dictated when the monitoring period would occur—primarily serving to motivate participants' training. When an event was cancelled due to unforeseen circumstances, such as a resurgence of COVID-19, participants were asked to complete a contingency race. Participants determined the location and course for the contingency race based on considerations of local conditions or other regional factors. When participants had to do the contingency race, it took place within approximately one week of the initially scheduled event it was intended to substitute.

Protocol for Acquiring and Sharing the Sports Watch Data

The Sport watches were connected to their respective vendor's cloud-based portals. The researcher then accessed the Flexible and Interoperable Data Transfer (FIT) or GPS Exchange Format (GPX) files. These were the original files direct from the device with unfiltered session data. The participants were required to acquire these files in one of the following manners:

1. The participants could upload the sessions to Strava®, an internet service with networking features for exercise. Where sessions have reflected on Strava, they can be bulk exported. This procedure was explained to participants, including how to create a Strava account and link a device (Appendix 18).
or
2. The participant could share the data directly from their vendor portal. For example, a Garmin® watch user could share the files directly from Garmin Connect. The instructions for this were on the vendor's web pages. When participants were unclear about these procedures, the researcher assisted them in sharing the required data.

When the participants acquired their data files, they shared them with the researchers. They shared in one of the following ways:

1. Participants shared the files via a Google form upload. The form (Appendix 19) directed the participants to upload their data directly to the researcher without disclosing email or other personal information.
2. The participant emailed the researcher copies of the FIT files or a web link to these files. They were also required to include their participant code instead of any other identifiers with this information.

The shared data was received and uploaded to a secure cloud account. The data was never stored with personally identifiable information such as names or contact information.

Data Capture and Consolidation Phase

Many GPS devices format participant data as a Flexible and Interoperable Data Transfer (FIT) file. These data can only be accessed using software from a device vendor like Garmin. Without such software, the data files required multiple transformations to be compatible with spreadsheet software (E.g., Microsoft Excel). Therefore, the researcher used Jupiter Notebook version 6.1.4, a server-client application for editing and running notebook documents via a web browser. These Jupyter Notebook documents can contain and run programming code, such as Python.

A Python script (Appendix 20) was used to convert the FIT files into Comma Separated Values (CSV) formatted files. The relevant information extracted from the original files included timestamps, coordinates, speed, distance, and heart rate information. These files could then be viewed and further processed in Microsoft Excel for Mac, Version 16.66. Once opened in Excel, the CSV files were converted to the .xlsm format to enable further processing. Macroinstructions (macros) were written and executed to extract and summarise the relevant information (Appendix 21). The macros were written in Visual Basic for Applications (VBA), a programming language developed by Microsoft.

Macroinstructions and Data Consolidation

The researchers systematically collected data from all participants following the study protocol. Each participant had confirmed an intent to complete a minimum of 24 sessions over the eight weeks (i.e., three sessions per week). After the transformations, a significant amount of unstructured data was generated. To manage these data, the researchers employed macros, outlined in Appendix 21, to automate functions that processed the data for statistical analysis in a familiar manner.

The macros executed the following functions:

- Separation of data from various sessions into distinct sheets

- Identification of disparities between training sessions and orthostatic tolerance tests
- Interpolation of missing data
- Calculation of session length
- Generation of data averages
- Identification of session maximum and minimum values
- Identification of different heart rate zones
- Validation of values within physiological and reasonable ranges

The final data set for each participant presented a summary of training sessions, including maximum and mean heart rate and speed values, total distance, ratios of values, heart rate zones, and time spent at specific intensities.

The data collected from wearable devices during kayak sessions and orthostatic tolerance tests were processed and summarised. The next step involved combining these data (from the GPS sports watches) with psychometric information (the DALDA and SSQ responses collected via online surveys). This challenge involved integrating the related data captured from different sources at different times and integrating the data for analysis. To ensure accurate consolidation, verifying the accurate integration of all session data for each participant's multiple sessions was necessary. The wearable and psychometric data which could not be reconciled were excluded from the analysis.

After removing any unsuitable data (see *Participant Exclusion for Data Inconsistency*), the remaining data was prepared for statistical analysis. The researcher thoroughly examined the combined data using both manual checks and macro functions. Next, the summarised and processed data were carefully formatted for analysis. The statistical analysis was then conducted using IBM's Statistical Package for the Social Sciences (SPSS) Statistics software (210).

Participant Exclusion for Data Inconsistency

The original dataset underwent a comprehensive validation process involving the comparison of SSQ (Short Session Questionnaire) data and wearable (GPS and HR) data using a macro function. Subsequently, manual checks were conducted to ensure data from different sources were aligned correctly. Further confirmation of agreement was sought by performing a Pearson's correlation between self-reported time and GPS elapsed time—two sets of values derived from Psychometrics and wearables data, respectively, with the expectation of demonstrating consistency.

In cases where discrepancies requiring further examination arose, researchers investigated potential errors in reporting or instances where the GPS timer might not have been promptly stopped. If a substantial change (exceeding 10 minutes) remained unreconciled through various means, and the correlation between the values for a participant fell below 0.8, that participant was excluded from the final analysis. Appendix 11 includes the cases which were excluded from carrying out this protocol.

Data Analysis

Data analysis was completed using IBM's Statistical Package for the Social Sciences (SPSS) Statistics software, specifically version 25 for Mac (210). Continuous variables underwent a Shapiro-Wilk test to assess normal distribution within the sample (W = test statistic, p -value). Depending on the distribution results, data were presented as mean $\pm$ standard deviation (for parametric data) or median $\pm$ interquartile range (for non-parametric data).

Measuring Differences

Changes in variables measured at the beginning and end of the study were analysed using a dependent t -test, written in text as [$t(\text{degrees of freedom}(\text{df})) = t\text{-statistic}; p\text{-value}$]. Alternatively, a Wilcoxon signed-rank test was used for the non-parametric data, reported as [$W = \text{test statistic}, p\text{-value}$].

A Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test was used for analysing the difference among related groups with more than two related samples. Written in text as ($\chi^2(\text{df}) = \text{test statistic}, p\text{-value}$), or ($\chi^2 = \text{test statistic}, \text{df} = \text{df}, p\text{-value}$). Alternatively, where the data were parametric, a repeated measures analysis of variance (ANOVA) was used. Independent samples Kruskal-Wallis tests were used to investigate the potential differences in dependent variables among different data groupings presented as ($H = \text{variable test statistic}, \text{df}, p\text{-value}$).

Correlation analyses were conducted using Pearson's or Spearman's correlation tests, written as ($r = \text{correlation coefficient} [\text{Lower CI} - \text{Upper CI}]$) or ($r_s = \text{correlation coefficient}, p\text{-value}$), respectively. The correlations confidence interval calculation was based on the assumption that $z = \frac{1}{2} \log \left(\frac{1+r}{1-r} \right)$ is approximately normally distributed with variance $\frac{1}{n-3}$, where r is the correlation coefficient and n is the sample size (211).

The repeated measures correlations were calculated using the *rmcorrShiny*, a Shiny application which provides an intuitive graphical interface for computing and plotting such measures (212). The method was suited to tabulating repeated measures correlations for many different individuals, subsequently calculating an overall correlation or repeated measures correlation between specified variables with a reduced chance of statistical error. These were reported as ($r_m(df)$ = correlation coefficient, 95% CI [Lower CI, Upper CI], p-value). A multivariate analysis was used to identify any optimal combination of variables predicting performance.

Significance was accepted at $p < 0.05$. Cohen's Effect size (d) was used to understand the magnitude of differences found, using previous classifications of small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$) (213–215).

Presentation of Data

Considering the heterogeneity of the results, proportional comparisons were considered more appropriate. Therefore, in the results, the heart rate data are primarily presented as a percentage of the individual's maximum heart rate (%HR). Additionally, speed is mainly presented as a percentage of the best-reported TT pace (%TTS).

Training Zones

The macro completed the quantification of training zones during the data consolidation phase. This study employed the 5-Zone Intensity Scale, which sets specific heart rate zones based on the *individual's maximum heart rate* (216,217). Refer to Table 5 for values.

Table 5. The 5-zone intensity scales used in the current study

Intensity zone	Heart rate (% max)
5	$x \geq 92$
4	$87 \leq x < 92$
3	$82 \leq x < 87$
2	$72 \leq x < 82$
1	$55 \leq x < 72$

Individuals' max heart rate

This was determined by data received from the participants. It was assumed that a maximum or near maximum heart rate value would be included within all the data obtained. Where this value was supraphysiological (due to errors in recording), the researchers based the HR zones off values in a more likely physiological range.

Efficiency

Paddling efficiency was a metric derived for this study to understand how much effort is required to achieve a certain velocity. It is expressed as the ratio of speed to heart rate. Higher scores on this scale signified improved efficiency. The calculation in Equation 1 computes a score close to one when optimal efficiency is achieved, indicating a situation where high speed is attained with a lower heart rate. Refer to Table 5 for the classification of efficiency scores.

Equation 1. Efficiency calculation

$$\text{Efficiency} = [\text{speed (km. h}^{-1}) \times 10] / \text{Heart rate (bpm)}$$

Table 6. Efficiency classification based on the efficiency score from the calculation in Equation 1

Classification	Efficiency score
Optimal	≥ 0.95
Good	$0.95 > x \geq 0.85$
Average	$0.85 > x \geq 0.70$
Poor	< 0.70

Eliteness Index

The Eliteness index is a scoring of 2-10 (within-sport comparison), broadly categorising different athletes' competitiveness. The scoring was adapted from *Defining elite athletes: Issues in the study of expert performance in sport psychology* and adapted to describe competitiveness in the included sample best (218). The scoring system works to assess the level of performance of participants in a sport. The definition relied on the athletes' highest level of achievement, their success at that level, and their accumulated experience at that standard. Equation 2 shows the index calculation. Moreover, Table 7 shows the index classifications used in this study.

Equation 2. Eliteness index calculation in current study.

$$\text{Eliteness}' = \left[\left(a + b + \frac{c}{2} \right) \right] \times \left[\frac{220 - d^*}{220} \right]$$

a = Highest competition level, **b** = Success at competition, **c** = Experience at highest competition level and **d** = age. * The age of the participants (**d**) was only included as a factor if the participant exceeded 40 years of age. Note, experience is arguably not as crucial as performance or success in indicating expertise, it is assign only half the value in this equation(47).

The variables are assigned values ranging from 1 to 4 within a scoring system, except for variable '**b**', which can also assume a value of 0. Consequently, the overall score ranges

from a minimum of 2 to a maximum of 10. Please consult Appendix 22 for the variable scoring rubric and corresponding values of **a**, **b** and **c**.

Table 7. Eliteness classifications of the index used in the groupings in this study.

<i>Classification</i>	<i>Efficiency score</i>
<i>Elite</i>	$7.5 \leq$
<i>Semi-elite</i>	$4.0 \leq x < 7.5$
<i>Novice</i>	$4.0 >$

The range used in the study is smaller, and the classification index has fewer categories than that proposed in *Defining elite athletes: Issues in the study of expert performance in sport psychology*. This was mainly driven by the study's small sample size; having more categories would further reduce the sample size, ultimately reducing statistical power.

— Roadmap —

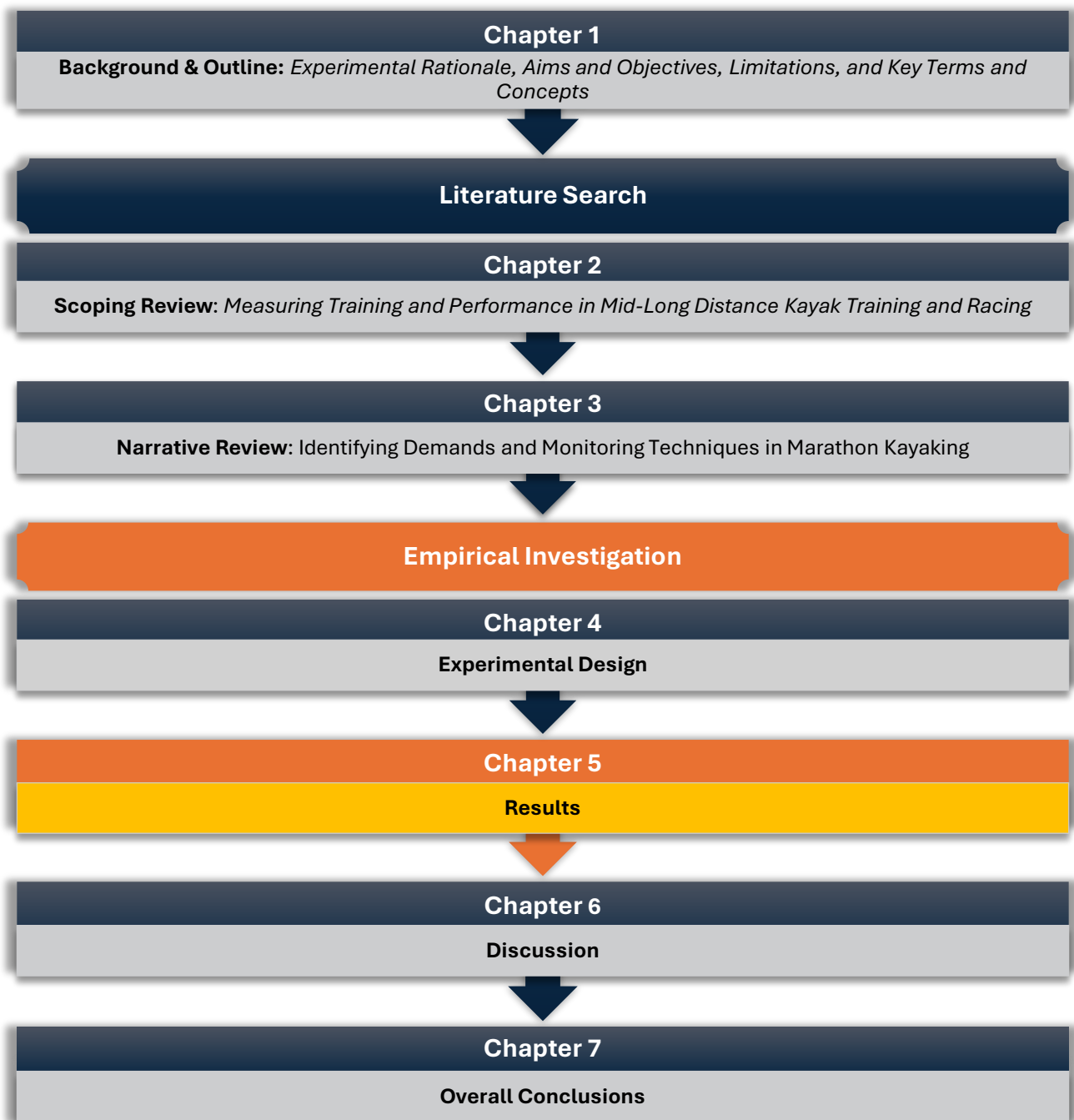


Figure 16. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed

— Chapter 5 —

Empirical Investigation: *Results*

Characteristics of Participants

General Characteristics

Table 8 displays the general characteristics and paddling ability of the participants. According to the coefficient of variation (CV), the sample was heterogeneous based on several metrics. Participants' ages ranged from 20 to 58 years, their height from 163 to 195 cm, their kayaking experience from 1 to 30 years, and their Eliteness index from 1 to 10. The average pace for a TT was 3.7m/s, approximately 80% of the best pace observed for the discipline.

Table 8. General descriptive statistics of the participants (n = 38; females = 11, males = 27)

	Mean ± SD	Min	Max	CV (%)
Age (y)	39 ± 12	20	58	30
Height (cm)	178 ± 8	163	195	5
Weight (kg)	77 ± 12	56	109	15
BMI (kg/m ²)	24 ± 3	19	38	12
Kayaking seasons (y)	9 ± 7	1	30	71
Mean sessions/wk	4 ± 1	2	6	28
Best TT Pace (m/s)	3.7 ± 0.5	3.1	4.9	13
Eliteness index	7 ± 2	2	10	28

SD= standard deviation; Min = minimum; max = maximum; CV(%) = coefficient of variation (as %); TT = time trial; Eliteness index = based on the framework in *Defining elite athletes: Issues in the study of expert performance in sport psychology* by Swann et al. a scoring from 2-10 (within-sport comparison) which broadly categorises the competitiveness of different athletes(218)

Table 9 summarises the athletes' training characteristics for all training sessions over the eight weeks. On average, they trained at 74% of their maximum heart rate and 84% of their best time trial speed. Their mean Foster's Rating of Perceived Exertion (RPE) was 5.6.

On average, approximately 35% of the training time was spent in T2 (72-82% max HR). However, there was a considerable variation among the athletes (4% to 79%). Paddling efficiency, a metric derived in this study and used to understand how much effort is required to achieve a certain velocity, was 0.76 with a range of 0.48 to 0.96 km/h · bpm.

Table 9. Training characteristics during the eight weeks and the TT pace improvement of the participants ($n = 38$; females = 11, males = 27) for a period of ~8 weeks

Characteristic	Mean $\pm$ SD	Min	Max	CV %
TT Pace improvement %	8 $\pm$ 10	-6	28	123
Number of sessions	32 $\pm$ 9	16	51	29
Mean duration of each session (m)	76 $\pm$ 17	47	134	22
Total duration (m)	2438 $\pm$ 759	922	4155	31
%TTS	84 $\pm$ 7	72	96	8
%HR	74 $\pm$ 6	64	85	8
RPE (1-10)	5.6 $\pm$ 1.0	4.2	7.7	17
T2%	35 $\pm$ 20	4	79	58
T2 duration(m)	745 $\pm$ 523	53	2514	70
T5%	10 $\pm$ 9	0	37	94
T5 duration (m)	189 $\pm$ 179	0	647	95
Efficiency (km/h·bpm)	0.76 $\pm$ 0.12	0.48	0.98	16

TT = time trial; %TTS = Mean speed as % of TT pace; %HR = Mean HR as % of HR max T2 = time in zone 2 (74-83% max HR); T5 = time in zone 5 (>94% max HR); Efficiency = [(Speed(km/h)·10)/HR(bpm)]

Sex

The study included both male ($n = 27$) and female ($n = 11$) participants. Overall, minimal mean differences were observed between the two groups across most of the training measures examined. The differences are presented in Table 10. Specifically, there were significant differences in absolute speeds between the male and female participants, with

males achieving faster average ($M = 3.04 \pm 0.31$ m/s)¹ and maximum session speeds than females ($M = 2.66 \pm 0.21$ m/s) ($t(36) = 3.77$; $p < 0.001$)². However, when these metrics were analysed as relative scores (%TTS), there was no statistically significant difference between the male and female participants ($t(36) = 0.06$; $p > 0.05$). Since the differences were not significant when analysed as relative scores and separating the participants into smaller groups would decrease statistical power, the groups were not separated in the further analysis.

Table 10. Differences between males($n=27$) and female ($n=11$) participants in the monitoring study

Factor	Sex	Mean $\pm$ SD	Mean difference	t
%TTS	Male	85 $\pm$ 7	0	0.06
	Female	84 $\pm$ 6		
Speed (m/s)	Male	3.04 $\pm$ 0.31	0.39	3.77*
	Female	2.66 $\pm$ 0.21		
Max speed (m/s)	Male	5.13 $\pm$ 0.80	0.80	3.04*
	Female	4.33 $\pm$ 0.51		
Height(cm)	Male	181 $\pm$ 7	12	5.69*
	Female	169 $\pm$ 4		

%TTS = mean session speed taken as a % of the participants best TT mean speed; * $p < 0.005$

The height of the kayakers was self-reported at the onset of the study, with the groups divided by sex. The men were significantly taller ($t(36) = 5.69$; $p < 0.001$) than the women. In the male group, a significant positive correlation was observed between height and measures of kayaking proficiency, including mean speed ($r = 0.51$ [0.15-0.74])³ and paddling efficiency ($r = 0.44$ [0.12-0.74]). However, no significant correlations were found between height and Eliteness or years of paddling. No significant correlations were

¹ Mean $\pm$ standard deviation

² Dependent t-test in text ($t(df) = t$ -statistic; p -value)

³ Pearson's correlation in text ($r =$ correlation [Upper CI- Lower CI])

identified in the women's group, but the smaller sample size may have impacted this analysis.

Kayaking Proficiency Level

Years of paddling and Eliteness (218) could be used to describe the kayaking proficiency of the participants. Each has been related to various factors associated with training using Pearson's correlations controlling for participants' age (Table 11). The results are similar for some factors: %TTS (moderate negative r) and paddling efficiency (moderate positive r). Eliteness and years of paddling are themselves positively associated ($r = 0.42$ [0.18-0.66]).

Table 11. Pearson's correlation of training factors controlling for the participants' age with (i) Number of years paddling (YOP) and (ii) Eliteness index. Participants ($n = 38$; females = 11, males = 27)

Training factor	YOP	Eliteness
	r [Lower CI - upper CI]	r [Lower CI - upper CI]
%TTS	-0.46 [-0.68--0.18] **	-0.41 [-0.64--0.10] *
Paddling efficiency	0.51 [0.27-0.69] **	0.48 [0.18-0.70] **
HR mean as %max	-0.50 [-0.69--0.24] **	-0.11 [-0.43-0.24]
Mean RPE	-0.12 [-0.38-0.15]	-0.25 [-0.52-0.08]
Z2 % paddling	0.59 [0.37-0.75] ***	0.08 [-0.27-0.41]
Z5 % paddling	-0.43 [-0.64--0.17] *	-0.12 [-0.45-0.23]
sRPE	0.21 [-0.12-0.50]	0.35 [0.03-0.60] *
Eliteness	0.42 [0.18-0.66] *	-

YOP= years of competitive paddling, Eliteness = a scoring from 2-10 (within-sport comparison) which broadly categorises the competitiveness of different athletes (218); r = Pearson's correlation; %TTS = mean session speed taken as a % of the participants best TT mean speed; sRPE= session rating of perceived exertion (Foster's RPE x Time(m)); * $p < 0.05$;

** $p < 0.005$; *** $p < 0.001$

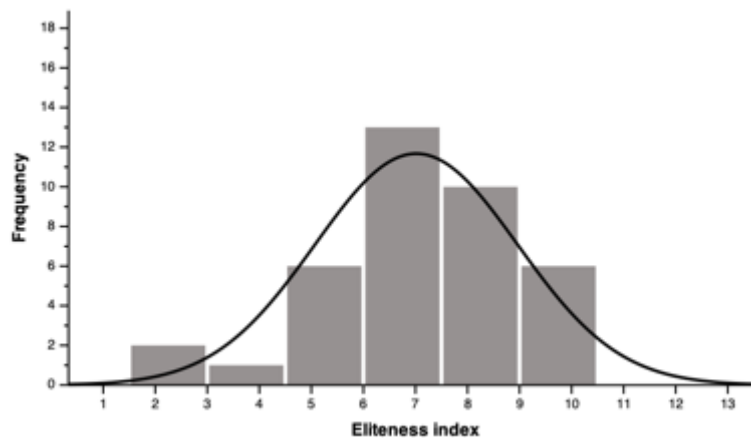


Figure 17. The distribution of the Eliteness assessed for normality using a Shapiro-Wilk test. (W statistic = 0.95, $p = 0.09$)

Training factors only associated with years of paddling include Mean %HR and %Z5 paddling, which have moderate negative correlations, and %Z2 paddling has a strong positive correlation. Collectively, these factors suggest more low-intensity training (Long Slow Distance (LSD) type sessions). A training metric only associated with Eliteness was sRPE, which has a moderate positive correlation. While certain factors (Mean %HR, %Z5, and sRPE) were associated with only one of the proficiency measures, there was no contradiction between them. Instead, only one factor exhibited a statistically significant correlation.

The Eliteness index score was favoured over years of paddling as a measure of paddling proficiency for categorisation in the study. Its derivation allowed for better accounting for the participants' ages. Moreover, the distribution of scores was not significantly different from normal among the participants. (see Figure 17, ($W(38) = 0.95$, $p > 0.05$)⁴ Furthermore, it would facilitate the ease of comparison to studies looking at training in other sports modalities.

⁴ Shapiro-Wilks test statistic in text ($W(df)$ = test statistic, p -value)

Types of Sessions

The participants were required to answer questions about the training session. Based on their responses, the sessions were classified into three primary groups: long slow distance (LSD), interval type (INT) and race type (RACE). These classifications were used to determine the relationship between the different intensity measures for each session. LSD (n=569) sessions were the most common, comprising 48% of the total sessions, followed by INT (n=370) at 31%, and finally by RACE (n=243) at 21% of total sessions.

Contrasting Intensity Measures

Figure 18 shows the distributions of RPE for different training session types. There were more LSD sessions with RPE of 2-5 (peak at 3) than INT or races. The INT sessions included a wide range of RPE values with moderate peaks at RPE scores of 5 and 7. Race sessions, which included any non-stop race type of kayaking, have a distribution clustered around the higher RPE values of 7-9. Proportionally, Figure 18 shows the most common RPE rating (tallest bar) of LSD =2, which included 28% of all LSD sessions. INT =7, which included 23% of all INT sessions. RACE RPE peaks = 7, 8 and 9, accounting for 22%, 21% and 21% of all RPE race scores, respectively. Accumulatively, 56% of all sessions had an RPE score of between 4 and 7.

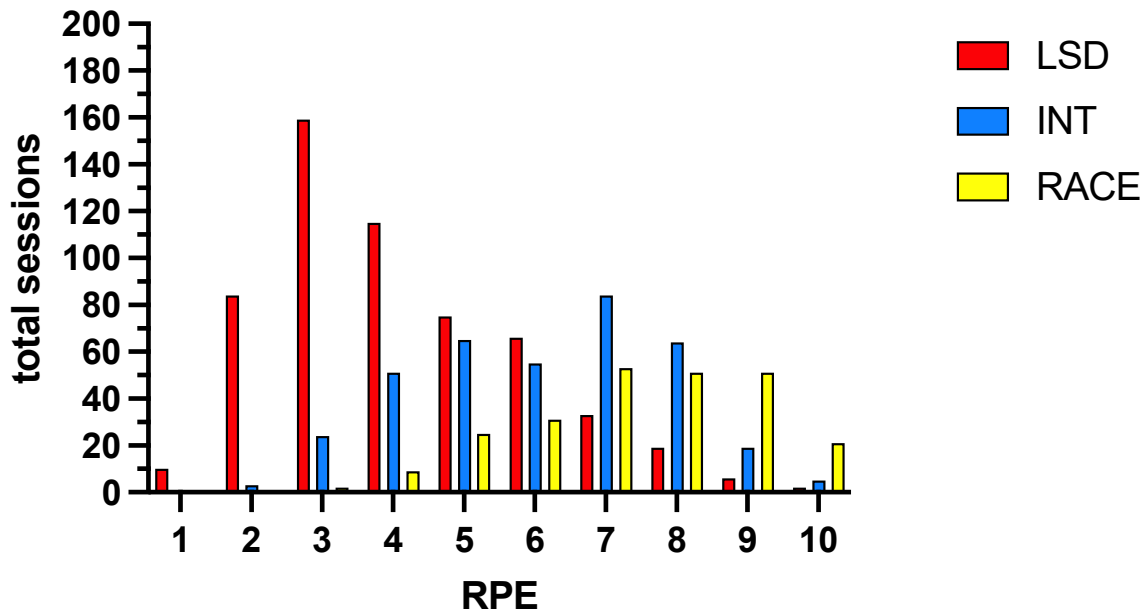


Figure 18. The distribution of the Accumulative count of session RPE ratings across different session types of the participants (n=38) over the 8-week monitoring period. LSD = long slow distance (n =569), INT = interval type training (n =370) and Race = race or race practice (n =243).

Figure 19 shows the median, quartiles, minimum and maximum of RPE, mean HR and mean speed (as proportions of total session) in different training session types in a box and whisker plot. The figure visually demonstrates the sensitivity of the different intensity measures in discerning dissimilar sessions based on these measures.

The RPE values exhibit the highest sensitivity to differences in session types. The Friedman test revealed a significant difference among the groups. It is also evident in the distinct median and IQR ranges for each session type. In contrast, %HR and %TTS differences across sessions are less pronounced ($\chi^2_{\%HR} = 46.2$, $df=2$, $p<0.001$; $\chi^2_{\%TTS} = 41.1$, $df=2$, $p<0.001$)⁵. Additionally, changes across sessions in RPE and %HR align in direction. Conversely, %TTS report higher mean intensity in LSD compared to INT, contrary to what was observed in RPE or %HR. Table 12 illustrates the disparities between and within intensity measures for various sessions.

⁵ Friedman's test in text (χ^2_{variable} = test statistic, $df=df$, p -value)

Table 12. Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test pairwise comparisons of the RPE, %TTS and %HR across the different session types, LSD, INT and RACE for participants (n=38)

	Test statistic	Std. Error	Adj. p
Overall (df) RPE	66.2 (2)	-	<0.001
Overall (df) %TTS	41.1(2)	-	<0.000
Overall (df) %HR	46.2(2)	-	<0.000
<i>Pairwise comparisons RPE</i>			
LSD – INT	1.1	0.23	<0.000
LSD – RACE	-1.8	0.23	<0.000
INT – RACE	-0.7	0.23	<0.007
<i>Pairwise comparisons %TTS</i>			
LSD – INT	-0.4	0.23	0.175
LSD – RACE	-1.4	0.23	<0.000
INT – RACE	-1.0	0.23	<0.000
<i>Pairwise comparisons %HR</i>			
LSD – INT	0.8	0.24	<0.005
LSD – RACE	-1.6	0.24	<0.001
INT – RACE	-0.9	0.24	<0.001

LSD= session with Long Slow Distance characteristics; INT= session with Interval type characteristics; RACE= session with continuous race type characteristics; RPE = rating of perceived exertion; %TTS = speed as percentage of best time trial pace; %HR= heart rate as a percentage of maximum heart rate.

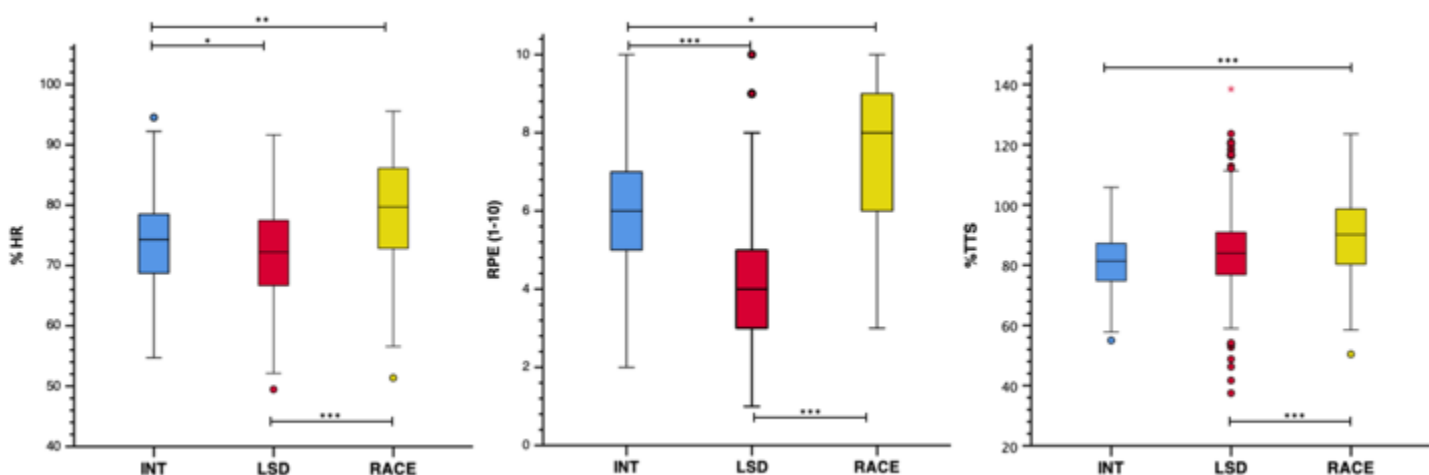


Figure 19. The box and whisker plot of the Rating of perceived exertion (RPE (1-10)), speed as a percentage of best time trial speed (%TTS) and Mean session HR as % of Max HR (%HR) in different training sessions. Sessions are classified into long slow distance (LSD), interval type (INT) and race type (RACE). Bar with “*” indicate significance in Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test between groups, * $p < 0.01$, ** $p < 0.001$, *** $p < 0.0001$.

Consider Figure 19, which displays the relative differences in measured intensity for different session types. According to Figure 19, the intensity of an LSD-type session is characterised by a lower RPE value (4 ± 2 AU), a moderate %TTS (84 ± 12 %), and a low to moderate %HR (72 ± 8 %). Moreover, the INT session is characterised by a moderate to high RPE value (6 ± 2 AU), a lower %TTS (81 ± 8 %), and a low to moderate %HR (74 ± 7 %). Furthermore, the Race session is associated with a higher RPE value (7 ± 2 AU), a higher %TTS (90 ± 12 %), and low to high %HR (79 ± 9 %).

The race-type session seems most distinct, with all measures of intensity agreeing in magnitude and direction. The LSD and INT sessions tend to have mean %HR and %TTS that are similar. However, the session's RPE values can differentiate them more clearly. Note that these are mean differences, and there is much variation even within these session types. Additionally, different kayakers will classify sessions differently when self-reporting. Notwithstanding, RPE is the most attuned to changes in session type, which speaks to its sensitivity as an intensity measure in kayaking.

Changes in Training Composition Over Eight Weeks

The contribution to accumulative weekly sRPE from different session types varied throughout the study. Figure 20 shows how the total weekly load is comprised by session type. It indicates that the contribution to the total training load (TTL) from LSD-type sessions remains consistent throughout the study, and any fluctuations in the TTL are attributed to the non-LSD sessions.

The mean load from each session type is different $\chi^2(2) = 91.9, p < 0.001^6$, with the LSD session being the lowest and the Race-type session being the highest. The sum of the load does not differ significantly ($\chi^2(2) = 2.5, p > 0.05$). However, while the mean load contribution from LSD and interval-type sessions is more constant over the eight weeks INT ($\chi^2(7) = 5.2, p > 0.05$), LSD $\chi^2(7) = 3.3, p > 0.05$, the contribution from Race-type sessions tends to fluctuate over time ($\chi^2(7) = 27.6, p < 0.001$). It implies more race practice is done as the athlete approaches an event until about two weeks before when the athlete begins to taper.

⁶ Friedman's tests statistic ($\chi^2(df)$ = test statistic, p-value)

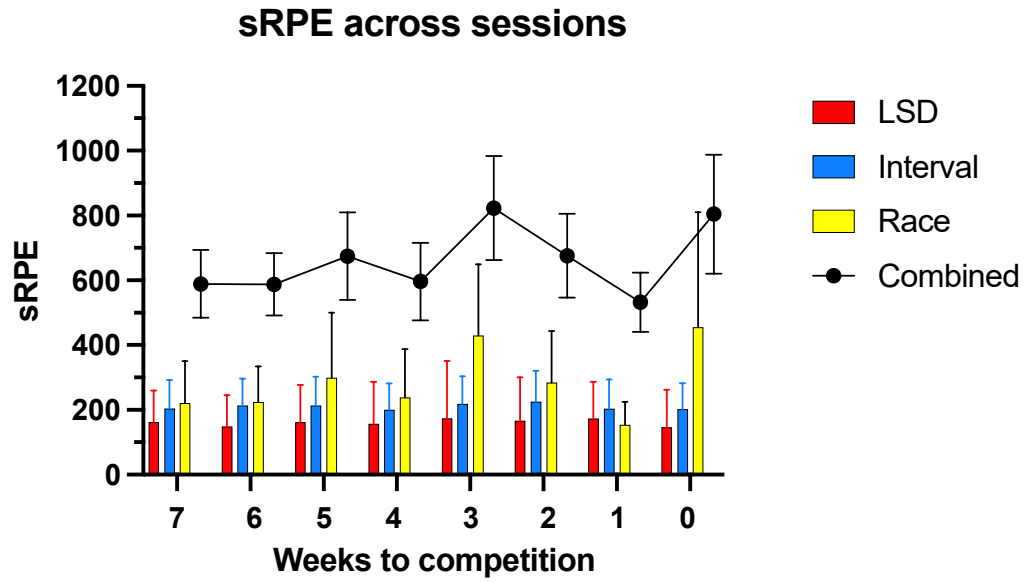


Figure 20. The constitution of the accumulative weekly session rating of perceived exertion (sRPE) by session type, categorised as, LSD, RACE or INT.

Relationships Between Variables

Intensity Measures: GPS Wearables & RPE

Figure 21 demonstrates the relationship between the variables collectively and for each individual's scores. Figure 21 shows the repeated measures correlation between the rating of perceived exertion (RPE) and other measures of intensity, measured by GPS wearables, for all the participants except those without data. Measures of speed show a slight positive correlation with RPE (%TTS vs RPE $r_{rm}(1086)=0.32 [0.27 - 0.37]$)⁷. Heart rate (mean session HR as a % of maximum heart rate) was positively associated with RPE ($r_{rm}(966) = 0.49 [0.44 - 0.53]$). The time in high HR zones was positively correlated with RPE ($r_{rm}(977)= 0.50 [0.45 - 0.54]$). Moreover, there was a slight negative correlation with the proportion of time in lower heart rate zones such as (Z2 $r_{rm}(966) = -0.20 [-0.26 - -0.14]$). In general, the correlations between the intensity measures, the RPE and heart rate measures exhibit a more robust correlation than the RPE measures with speed-derived metrics.

⁷ Rmcorrshiny repeated measures correlation ($r_{rm}(df)$ = correlation coefficient, 95% CI [Lower CI, Upper CI], p-value)

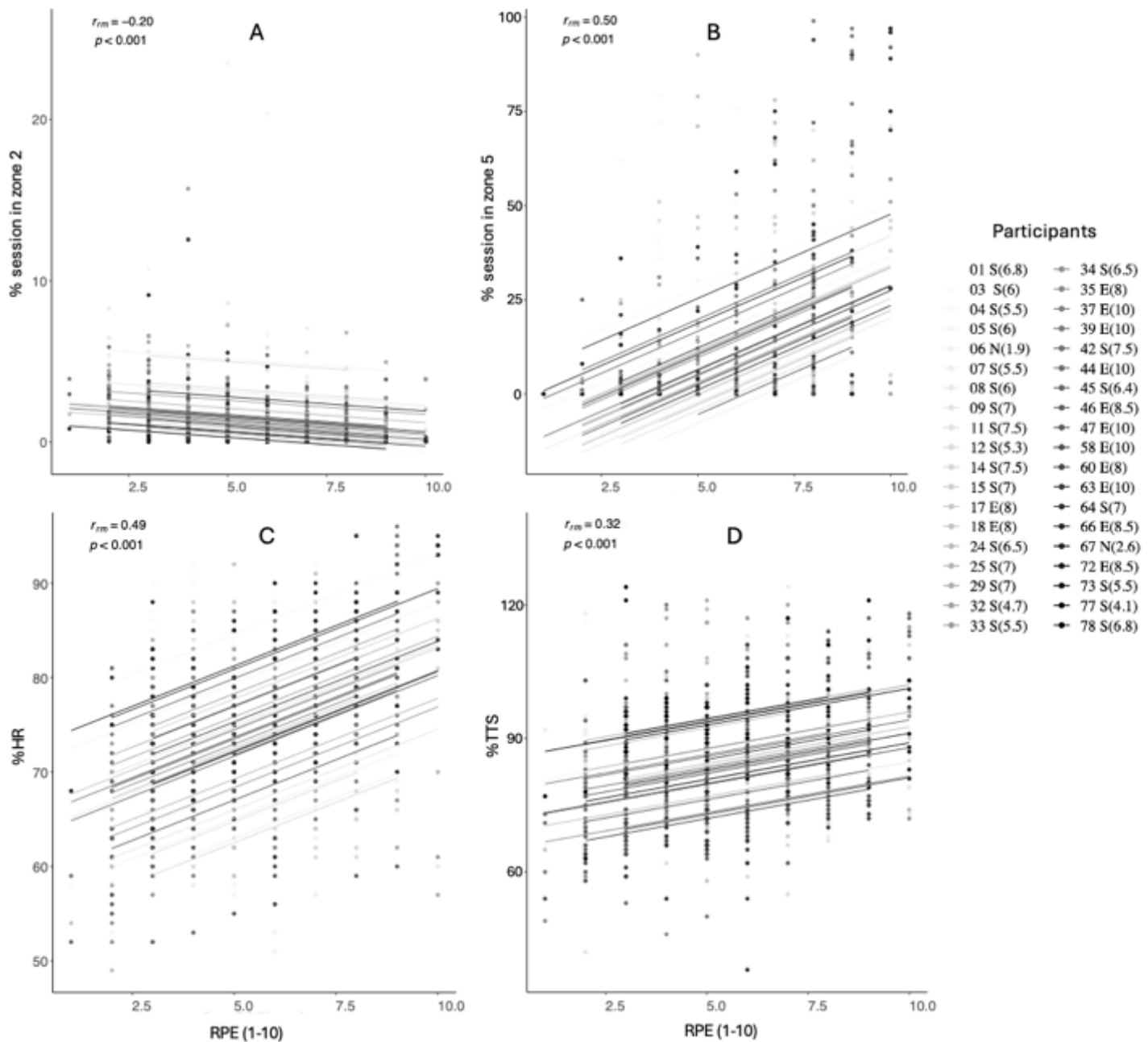


Figure 21. The repeated measures correlation of Rating of perceived exertion (RPE) with intensity measures for all participants training sessions. **(A)** % session in zone 2 ($r_{rm}(977) = -0.20$, 95% CI [-0.26, -0.14]), **(B)** % session in zone 5 ($r_{rm}(977) = 0.50$, 95% CI [0.45, 0.54]), **(C)** %HR ($r_{rm}(966) = 0.49$, 95% CI [0.44, 0.53]) and **(D)** %TTS ($r_{rm}(1086) = 0.32$, 95% CI [0.27, 0.37]). All results, $p < 0.001$; %TTS = mean session speed taken as a % of the participants best TT mean speed; %HR = mean session heart rate taken as a % of the participants Max heart rate. See methods for heart rate zone (Z2 and Z5) and data exclusion criteria.

RPE & HR Zones

A moderately strong positive correlation exists between RPE and %HR (see Figure 21C). These are both measures of intensity. Thus, a linear relationship might be expected between them. This is the case in training sessions in which intensity is consistent throughout. However, the relationship between RPE and HR zones appears more nuanced, as illustrated in Figure 22. Most participants had this more linear relationship, with negative or low negative correlations with the lower zones (T1 & T2) and stronger positive correlations with the higher zones (T4 & T5). Some participants had a trend that was more “U” or “J” shaped. In these cases, the individual's RPE to HR zone associations are higher at the extremes (T1 & T5) and lower in the intermediate zones (T2, T3 & T4). This is characteristic of interval training at high intensity (time in Z5) with a long rest (time in Z1). This underscores the importance of understanding factors in kayaking affecting the data and intensity measures. Figure 22 demonstrates the correlation between RPE and the HR zones.

Some participants show no clear associations between HR and RPE. This included no associations in heart rate zones (T1 & T5). This can likely be attributed to intra-individual variation or an inconsistency between recorded RPE and HR. Alternatively, an error in the heart rate zone classification could be caused by incorrect HR zone cut-offs (see Training Zones)

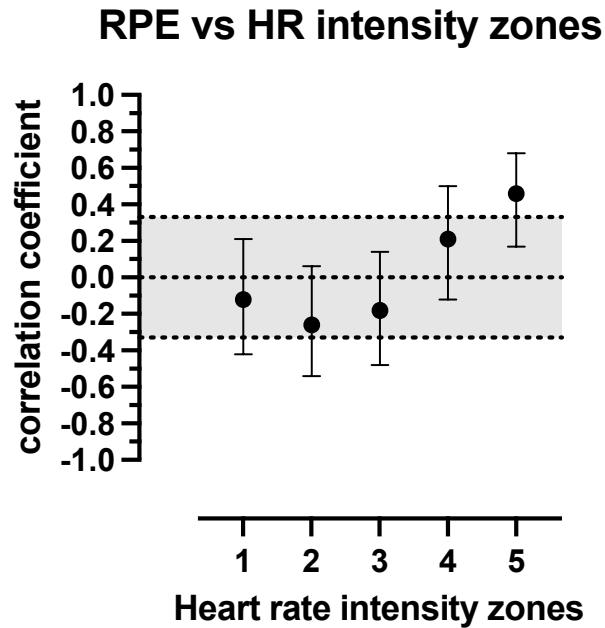


Figure 22. The Pearson's Correlation (r) between heart rate intensity zones 1-5 and RPE of different participants ($n=35$). The data are presented with bars representing a 95% CI for that correlation based on confidence limits for r with limited sample size (202). The shaded area designates a correlation that is not statistically significant based on sample size.

Training Volume: sRPE, tHB & distance

There was a strong correlation between session duration and the other training accumulation measures. This is true for the individual measures, all Eliteness groupings and overall. The overall mean Pearson's correlation between duration and distance was ($r_{rm}(1066) = 0.94$, 95% CI [0.94, 0.95], $p < 0.001$) and between duration and total heart beats was ($r_{rm}(945) = 0.98$, 95% CI [0.98, 0.98], $p < 0.001$).

Naturally, the session duration will tend to correlate with any accumulative measure. Moreover, this study observed accumulative training measures correlated positively with session duration. However, while duration is a pertinent dimension, the drawback of using it exclusively to measure accumulative load is that it does not account for training intensity. Consequently, the session rating of perceived exertion (sRPE) method, which accounts for the perception of effort and exercise duration, was used as the default measure of total training load.

Table 13 demonstrates the individual, as well as the group, mean correlations and confidence intervals between different quantifiers of accumulative training. The sRPE was compared to the distance and total heart beats (tHB). There was, generally, a strong positive correlation between these measures. There were no meaningful differences between the different Eliteness groupings. The Pearson's r between sRPE and distance ($r_{rm(ELITE)}(434) = 0.79$, 95% CI [0.75, 0.82], $p < 0.001$; $r_{rm(SEMI)}(585) = 0.80$, 95% CI [0.76, 0.82], $p < 0.001$; overall $r_{rm}(1054) = 0.80$, 95% CI [0.77, 0.82], $p < 0.001$). Similarly, the Pearson's r between sRPE and tHB ($r_{rm(ELITE)}(366) = 0.83$, 95% CI [0.80, 0.86], $p < 0.001$; $r_{rm(SEMI)}(519) = 0.82$, 95% CI [0.79, 0.85], $p < 0.001$; overall $r_{rm}(933) = 0.82$, 95% CI [0.80, 0.84], $p < 0.001$) was not significantly different.

When there was a weaker association between sRPE and tHB, there tended to be more variation in the session RPE values reported by the participants. These did not correlate with other intensity measures, such as mean heart rate. In most cases, there was at least a moderate statistically significant correlation. For instance, in the outlier case of Participant 39, the reported sessions took place in the ocean where ocean tides, swells and currents considerably influenced session distance. It appears the association of sRPE with distance is dependent on the kayaking conditions. This highlights the drawback of using distance only as a quantifier of training volume in kayaking, especially if the recorded kayaking takes place on the ocean or rivers.

Table 13. Pearson's correlation (r) of total training load (min $\bullet$ RPE (1-10)) with (i) Distance and (ii) Total heart beats for each participant and the average for the eliteness group and an overall mean ($n=38$; $f=11$, $m=27$). The number of data points for participants ranged from 16 to 51. Data expressed as r [lower CI - upper CI]. Where E = elite, S = semi-elite and N = novice referring to eliteness category

Participants	Distance (km)	Total Heart beats
Eliteness(Eliteness index)	r [Lower CI - upper CI]	r [Lower CI - upper CI]
37 E(10)	0.86 [0.76-0.92]	0.9 [0.82-0.94]
39 E(10)*	0.04 [-0.34-0.41]	0.43 [0.05-0.69]
44 E(10)	0.71 [0.53-0.83]	0.82 [0.69-0.89]
47 E(10)	0.80 [0.62-0.90]	-
58 E(10)	0.94 [0.87-0.97]	0.93 [0.86-0.97]
63 E(10)	0.95 [0.9-0.97]	0.93 [0.88-0.96]
46 E(8.5)	0.62 [0.41-0.76]	0.72 [0.53-0.84]
66 E(8.5)	0.74 [0.52-0.86]	0.79 [0.61-0.89]
72 E(8.5)	0.74 [0.5-0.87]	0.79 [0.58-0.89]
17 E(8)	0.67 [0.41-0.82]	0.46 [0.15-0.68]
18 E(8)	0.70 [0.39-0.86]	0.71 [0.4-0.86]
35 E(8)	0.63 [0.35-0.8]	0.64 [0.35-0.80]
60 E(8)	0.89 [0.76-0.95]	0.94 [0.81-0.98]
Elite(9)	(df=434) 0.79 [0.75-0.82] #	(df=366) 0.83 [0.80-0.86] #
11 S(7.5)	0.81 [0.59-0.91]	0.83 [0.64-0.92]
14 S(7.5)	0.76 [0.54-0.88]	0.75 [0.51-0.88]
42 S(7.5)	0.95 [0.86-0.98]	-
09 S(7)	0.73 [0.37-0.89]	0.63 [0.12-0.86]
15 S(7)	0.88 [0.75-0.94]	0.92 [0.83-0.96]
25 S(7)	0.86 [0.73-0.93]	0.76 [0.54-0.87]
29 S(7)	0.46 [0.08-0.76]	0.59 [0.25-0.8]
64 S(7)	0.70 [0.29-0.88]	0.71 [0.26-0.89]
01 S(6.8)	0.76 [0.56-0.87]	0.77 [0.59-0.88]
78 S(6.8)	0.85 [0.68-0.92]	0.88 [0.76-0.94]
24 S(6.5)	0.64 [0.43-0.78]	0.87 [0.76-0.93]
34 S(6.5)	0.70 [0.47-0.84]	0.67 [0.41-0.82]
45 S(6.4)	0.62 [0.38-0.77]	0.71 [0.51-0.83]
05 S(6)	0.92 [0.83-0.96]	0.94 [0.88-0.97]
03 S(6)	0.77 [0.61-0.86]	0.83 [0.70-0.90]
08 S(6)	0.73 [0.53-0.85]	0.62 [0.37-0.78]

<i>Participants</i>	<i>Distance (km)</i>	<i>Total Heart beats</i>
<i>Eliteness(Eliteness index)</i>	<i>r [Lower CI - upper CI]</i>	<i>r [Lower CI - upper CI]</i>
73 S(5.5)	0.35 [0.02-0.61]	0.41 [0.08-0.66]
04 S(5.5)	0.78 [0.53-0.90]	0.83 [0.62-0.92]
33 S(5.5)	0.82 [0.60-0.92]	-
07 S(5.5)	0.75 [0.51-0.88]	0.68 [0.39-0.84]
12 S(5.3)	0.75 [0.05-0.95]	0.77 [0.59-0.95]
32 S(4.7)	0.41 [-0.03-0.70]	0.47 [-0.04-0.70]
77 S(4.1)	0.71 [0.35-0.88]	0.74 [0.40-0.89]
<i>Semi-Elite(6)</i>	(df=585) 0.80 [0.76-0.82] [#]	(df=519) 0.82 [0.79-0.85] [#]
67 N(2.6)	0.99 [0.79-0.97]	0.94 [0.85-0.88]
06 N(1.9)	0.75 [0.43-0.89]	0.90 [0.80-0.95]
<i>Overall (7)</i>	(df=1054) 0.80 [0.77-0.82] [#]	(df = 933) 0.82 [0.80-0.84] [#]

- Data not available; *Participant 39 paddled on the sea with notable conditions/tide swell/water movement; [#] rmcrrshiny repeated measures correlations(212).

Changes in sRPE, Duration, tHB & Distance Over Eight Weeks

Figure 23 shows the weekly average training measured by different training load indicators from the beginning of the study to the participant's competition. Each week's training is presented as a percentage of the overall mean for the entire 8-week duration. The figure demonstrates how these training measures coalesce from week to week. Apart from sRPE and duration (both involving duration), all other quantifiers are independent measures. Notably, there is an increase in overall training during the third-to-last week (week 5) before the competition. Furthermore, a Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test, assessing mean total training load percentage over the eight weeks, indicated non-uniformity in week-to-week loads ($\chi^2 (7) = 15.8$, $p < 0.05$). However, a two-way pairwise comparison of weeks revealed no significant differences between specific weeks when adjusted for multiple comparisons.

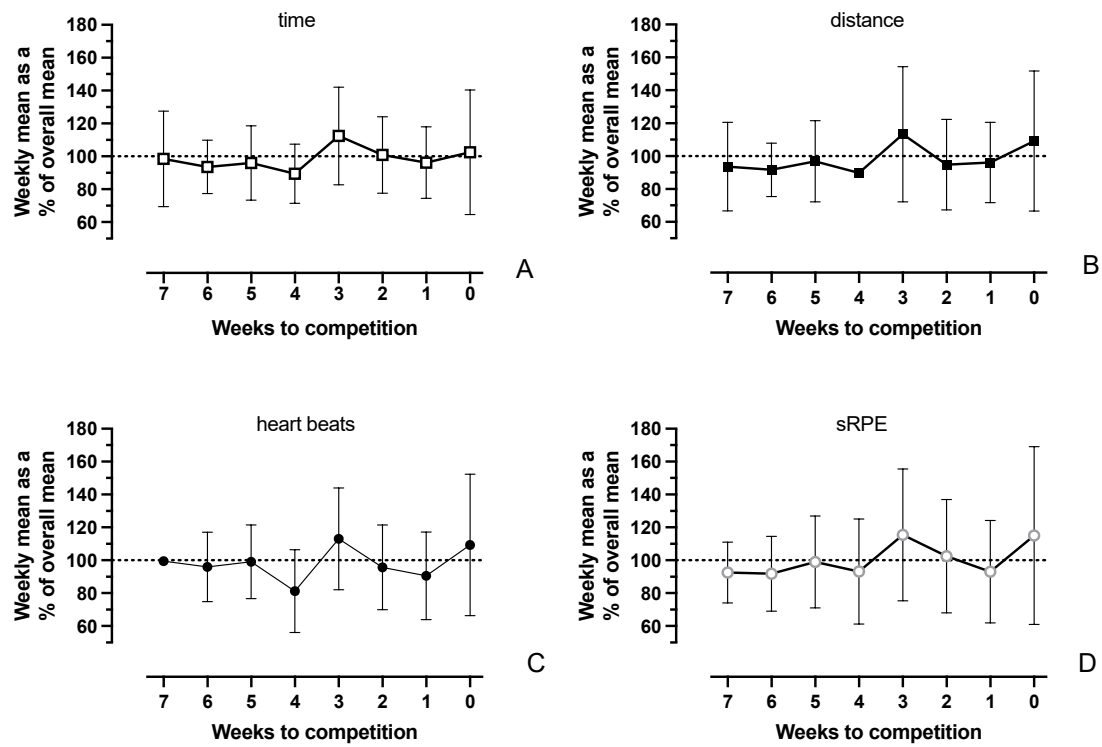


Figure 23. The week on week total training measures of (A) duration, (B) distance, (C) Total heart beats and (D) session rating of perceived exertion (sRPE) presented as weekly means as % of overall means for $n=38$ participants, the week on week mean was significantly different over the 8 weeks for the overall mean ($\chi^2(7) = 15.8, p < 0.05$).

Training Stress Measures

DALDA

Figure 24 demonstrates the DALDA part A (life stress) and part B (symptoms of stress) over the eight weeks of the study. Although there was much variation in the scores between participants, demonstrated by the large standard deviations, there does not appear to be any clear trend or tendency over the eight weeks of the study. This is in contrast to the total training load, which showed non-uniformity in week-to-week loads ($\chi^2 (7) = 15.8, p < 0.05$) (see Figure 23). In addition, Table 14 confirms no significant difference in the mean DALDA scores for part A or part B between weeks.

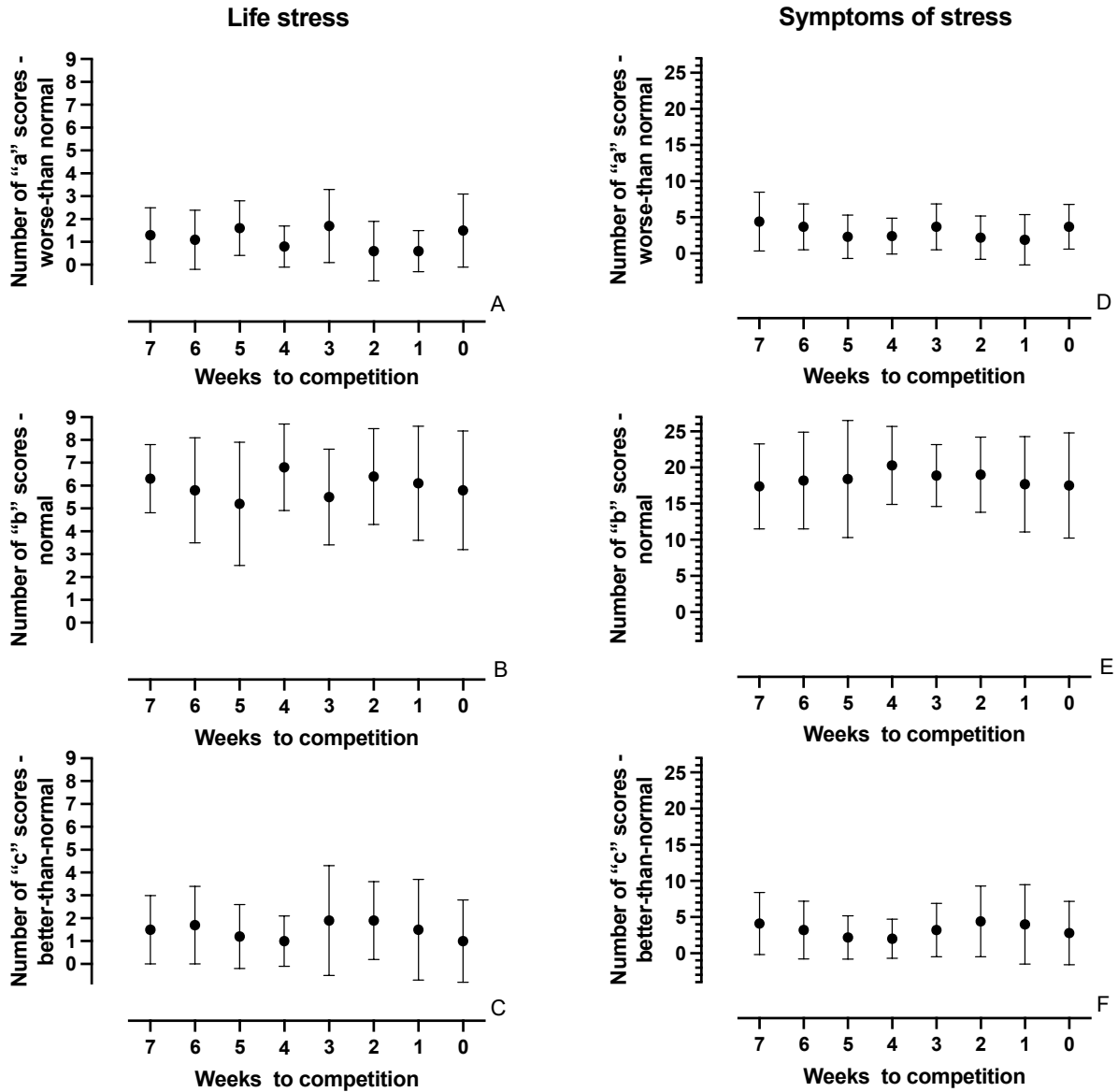


Figure 24. The mean $\pm$ SD of the DALDA scores for part A (Life stress) and part B (Training stress) of $n=38$ participants over the 8-week training study, the x-axis shows the weeks until the participant raced, week zero being the week of competition.

Table 14. The A Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test of the DALDA part A and Part B scores over time.

Score	Friedman's Test statistic (df)	p
<i>DalA'a'</i>	9.0(7)	0.25
<i>DalA'b'</i>	10.3(7)	0.17
<i>DalA'c'</i>	10.3(7)	0.17
<i>DalB'a'</i>	7.2(7)	0.41
<i>DalB'b'</i>	13.3(7)	0.06
<i>DalB'c'</i>	6.5(7)	0.48

DALDA = Daily Analysis of Life Demands for Athletes; *DalA'a'* = DALDA part A score a ("worse than normal"); *DalA'b'* = DALDA part A score b ("normal"); *DalA'c'* = DALDA part A score c ("better than normal"); *DalB'a'* = DALDA part B score a ("worse than normal"); *DalB'b'* = DALDA part B score b ("normal"); *DalB'c'* = DALDA part B score c ("better than normal")

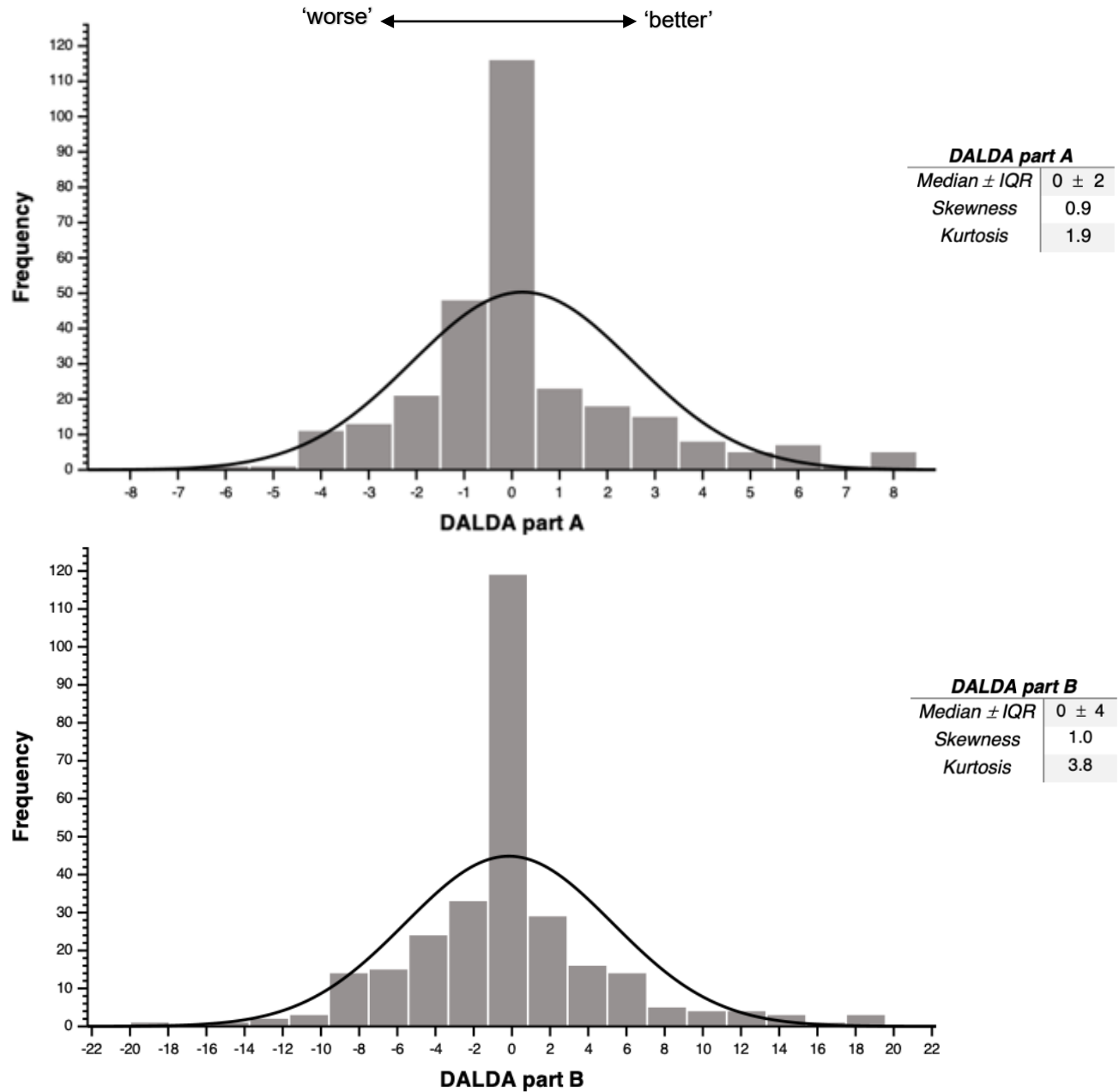


Figure 25. The distributions of the DALDA deviations from normal scores over the 8-week study for participants ($n=38$), a score of zero indicates the participant answered only "normal", a negative score indicates the candidate had more "worse" scores than "better" scores and positive score indicates the participant had more "better" scores than "worse" scores. *DALDA = Daily Analysis of Life Demands for Athletes

Figure 25 shows the distribution of the DALDA score deviations from a normal score. The negative direction shows where scores were “worse than normal”, and the positive direction of the distribution is where scores are “better than normal”. In the variation in week to week (Table 14), the mean scores distribution was consistent for both the DALDA parts A and B. In Figure 25, the distribution for both A and B has a high peak (Kurtosis A=1.7; B=3.6), indicating a high frequency of normal scores, consistent with the previous figure. The distribution is positively skewed (skewness A= 0.9; B=1.0), suggesting that more of the total answers were “worse than normal” than better than normal for both A and B. Therefore, on average, if the participants were deviating from normal, they were more likely to be worse than normal.

POMS

Figure 26 shows how the perception of mood scores changed from week to week. A Related-Samples Friedman's Two-Way Analysis of Variance by Ranks test comparing the POMS scores of the 38 participants indicated there were no significant differences from week to week ($\chi^2(7) = 12.0$, $p > 0.05$).

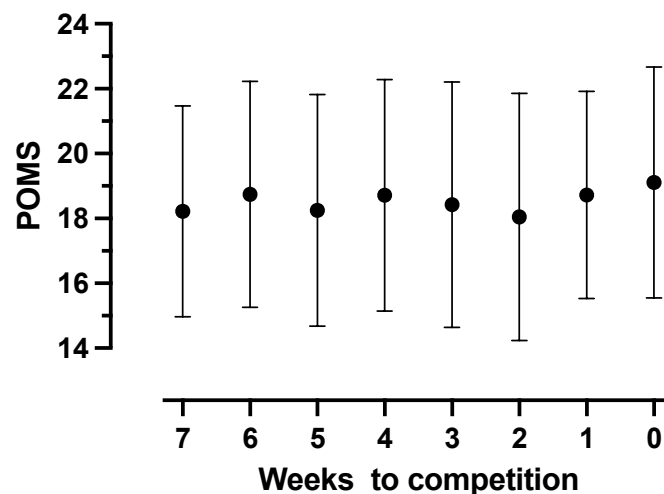


Figure 26. The mean Quick Perception of Mood Score for participants ($n=38$). Measurements were taken through the monitoring period, beginning eight weeks before the competition and ending on the week of the competition.

Table 15 shows the mean $\pm$ SD scores for POMS over the eight weeks of monitoring for each participant. The groups do not show any significant differences in scores or SD of scores. Large disruptions would be seen as changes in the score and or SD of the score.

The psychometric data from the Quick POMS and DALDA showed variation from week to week. However, none of these differences were meaningful or significant. Significant disturbances would have indicated a stress response to training or life stress. No participants in the study self-reported in any manner that might have suggested that they were markedly stressed at any point in the study.

Table 15. The weekly mean $\pm$ SD POMS score for participants (n=38)

Participant	Weeks to competition (Mean $\pm$ SD)							
	7	6	5	4	3	2	1	0
17 E(8)	18 $\pm$ 6	19 $\pm$ 2	17 $\pm$ 5	17 $\pm$ 7	15 $\pm$ 10	21 $\pm$ 4	18 $\pm$ 2	18 $\pm$ 6
66 E(8.5)	19 $\pm$ 3	18 $\pm$ 5	21 $\pm$ 2	19 $\pm$ 2		15 $\pm$ 1	15 $\pm$ 6	22 $\pm$ 3
37 E(10)	14 $\pm$ 4	18 $\pm$ 2	20 $\pm$ 3	17 $\pm$ 1	14 $\pm$ 3	14 $\pm$ 2	18 $\pm$ 2	19 $\pm$ 4
47 E(10)	16 $\pm$ 1	18 $\pm$ 2	18 $\pm$ 2	15 $\pm$ 3	16 $\pm$ 3	14 $\pm$ 4	16 $\pm$ 2	17 $\pm$ 3
46 E(8.5)	17 $\pm$ 3	17 $\pm$ 3	17 $\pm$ 2	19 $\pm$ 2	19 $\pm$ 2	15 $\pm$ 5	21 $\pm$ 2	18 $\pm$ 2
63 E(10)	16 $\pm$ 3	21 $\pm$ 1	18 $\pm$ 3	20 $\pm$ 3	20 $\pm$ 2	19 $\pm$ 3	20 $\pm$ 2	22 $\pm$ 1
18 E(8)	18 $\pm$ 2	14 $\pm$ 1	14 $\pm$ 2	16 $\pm$ 4	14 $\pm$ 3	15 $\pm$ 0	15 $\pm$ 0	16 $\pm$ 4
72 E(8.5)	18 $\pm$ 1	17 $\pm$ 0	18 $\pm$ 5	15 $\pm$ 1	20 $\pm$ 1	20 $\pm$ 2	21 $\pm$ 1	20 $\pm$ 4
58 E(10)	17 $\pm$ 4	21 $\pm$ 1	19 $\pm$ 1	18 $\pm$ 1	17 $\pm$ 3	20 $\pm$ 0	16 $\pm$ 3	17 $\pm$ 3
60 E(8)	18 $\pm$ 2	18 $\pm$ 3	14 $\pm$ 0	-	19 $\pm$ 2	16 $\pm$ 3	21 $\pm$ 0	19 $\pm$ 2
44 E(10)	21 $\pm$ 2	23 $\pm$ 2	-	21 $\pm$ 2	20 $\pm$ 1	19 $\pm$ 2	22 $\pm$ 1	21 $\pm$ 2
39 E(10)	14 $\pm$ 1	16 $\pm$ 2	16 $\pm$ 1	15 $\pm$ 0	16 $\pm$ 2	16 $\pm$ 3	16 $\pm$ 2	17 $\pm$ 1
35 E(8)	22 $\pm$ 2	23 $\pm$ 1	23 $\pm$ 1	24 $\pm$ 1	22 $\pm$ 0	24 $\pm$ 1	22 $\pm$ 1	23 $\pm$ 2
mean E (9)	18 $\pm$ 2	19 $\pm$ 2	18 $\pm$ 2	18 $\pm$ 2	18 $\pm$ 3	17 $\pm$ 2	18 $\pm$ 2	19 $\pm$ 3
14 S(7.5)	20 $\pm$ 5	20 $\pm$ 3	18 $\pm$ 4	14 $\pm$ 5	18 $\pm$ 3	18 $\pm$ 3	20 $\pm$ 3	20 $\pm$ 2
24 S(6.5)	15 $\pm$ 2	12 $\pm$ 9	17 $\pm$ 1	17 $\pm$ 3	16 $\pm$ 2	16 $\pm$ 0	18 $\pm$ 1	16 $\pm$ 3
04 S(5.5)	18 $\pm$ 4	20 $\pm$ 3	18 $\pm$ 5	-	21 $\pm$ 3	20 $\pm$ 2	17 $\pm$ 2	21 $\pm$ 1
11 S(7.5)	18 $\pm$ 3	19 $\pm$ 2	15 $\pm$ 4	15 $\pm$ 2	14 $\pm$ 3	14 $\pm$ 1	14 $\pm$ 2	16 $\pm$ 4
29 S(7)	12 $\pm$ 1	17 $\pm$ 3	19 $\pm$ 1	15 $\pm$ 4	18 $\pm$ 2	17 $\pm$ 3	17 $\pm$ 3	17 $\pm$ 6
15 S(7)	16 $\pm$ 3	17 $\pm$ 2	15 $\pm$ 2	22 $\pm$ 1	21 $\pm$ 2	14 $\pm$ 6	17 $\pm$ 3	20 $\pm$ 3
42 S(7.5)	21 $\pm$ 1	18 $\pm$ 2	17 $\pm$ 5	18 $\pm$ 1	18 $\pm$ 3	18 $\pm$ 3	18 $\pm$ 0	20 $\pm$ 0
03 S(6)	16 $\pm$ 2	16 $\pm$ 3	16 $\pm$ 5	19 $\pm$ 2	19 $\pm$ 3	17 $\pm$ 2	21 $\pm$ 1	21 $\pm$ 1
33 S(5.5)	21 $\pm$ 1	20 $\pm$ 1	24 $\pm$ 0	-	21 $\pm$ 1	19 $\pm$ 4	21 $\pm$ 4	22 $\pm$ 3
34 S(6.5)	18 $\pm$ 2	19 $\pm$ 3	15 $\pm$ 2	15 $\pm$ 1	17 $\pm$ 2	14 $\pm$ 2	18 $\pm$ 3	16 $\pm$ 4
07 S(5.5)	18 $\pm$ 2	14 $\pm$ 1	16 $\pm$ 3	19 $\pm$ 2	15 $\pm$ 4	20 $\pm$ 0	20 $\pm$ 3	-
25 S(7)	17 $\pm$ 3	20 $\pm$ 2	14 $\pm$ 3	14 $\pm$ 1	15 $\pm$ 2	15 $\pm$ 2	17 $\pm$ 2	16 $\pm$ 2
05 S(6)	19 $\pm$ 2	22 $\pm$ 2	22 $\pm$ 1	22 $\pm$ 1	20 $\pm$ 3	21 $\pm$ 1	19 $\pm$ 4	19 $\pm$ 5
45 S(6.4)	16 $\pm$ 0	19 $\pm$ 1	19 $\pm$ 2	17 $\pm$ 2	18 $\pm$ 4	18 $\pm$ 1	17 $\pm$ 2	17 $\pm$ 3
78 S(6.8)	-	21 $\pm$ 1	21 $\pm$ 2	21 $\pm$ 3	-	23 $\pm$ 2	23 $\pm$ 2	21 $\pm$ 2
09 S(7)	22 $\pm$ 4	19 $\pm$ 2	16 $\pm$ 0	15 $\pm$ 0	23 $\pm$ 0	19 $\pm$ 1	20 $\pm$ 4	25 $\pm$ 0
08 S(6)	20 $\pm$ 3	20 $\pm$ 2	23 $\pm$ 1	24 $\pm$ 2	22 $\pm$ 3	23 $\pm$ 2	21 $\pm$ 2	24 $\pm$ 1
64 S(7)	-	13 $\pm$ 1	19 $\pm$ 0	17 $\pm$ 0	-	-	15 $\pm$ 2	16 $\pm$ 2
32 S(4.7)	18 $\pm$ 2	18 $\pm$ 3	20 $\pm$ 0	21 $\pm$ 1	18 $\pm$ 0	17 $\pm$ 0	17 $\pm$ 1	22 $\pm$ 4
73 S(5.5)	17 $\pm$ 2	17 $\pm$ 3	18 $\pm$ 2	18 $\pm$ 1	19 $\pm$ 2	16 $\pm$ 1	18 $\pm$ 1	18 $\pm$ 1
77 S(4.1)	-	21 $\pm$ 1	22 $\pm$ 2	22 $\pm$ 0	16 $\pm$ 1	17 $\pm$ 1	20 $\pm$ 1	18 $\pm$ 2
12 S(5.3)	22 $\pm$ 1	23 $\pm$ 0	24 $\pm$ 1	21 $\pm$ 2	22 $\pm$ 3	23 $\pm$ 1	24 $\pm$ 1	-
01 S(6.8)	22 $\pm$ 2	23 $\pm$ 1	24 $\pm$ 1	24 $\pm$ 1	24 $\pm$ 1	-	25 $\pm$ 0	-
Mean S(6)	18 $\pm$ 2	19 $\pm$ 2	19 $\pm$ 2	18 $\pm$ 2	19 $\pm$ 2	18 $\pm$ 2	19 $\pm$ 2	19 $\pm$ 3
67 N(2.6)	21 $\pm$ 1	18 $\pm$ 4	16 $\pm$ 1	17 $\pm$ 1	-	-	19 $\pm$ 0	18 $\pm$ 3
06 N(1.9)	20 $\pm$ 1	20 $\pm$ 4	18 $\pm$ 3	20 $\pm$ 1	20 $\pm$ 3	21 $\pm$ 1	19 $\pm$ 2	20 $\pm$ 2
Overall (7)	18 $\pm$ 2	19 $\pm$ 2	18 $\pm$ 2	18 $\pm$ 2	18 $\pm$ 2	18 $\pm$ 2	19 $\pm$ 2	19 $\pm$ 3

- data not available | E = Elite; S= semi-elite; N=novice |

The Rusko Orthostatic Test (OTT)

Due to complications relating to the test, the subsequent data capture and participant compliance, the results obtained from the test are not included. See *Orthostatic Tolerance Test* for more details on OTT data. Appendix 23 contains the relevant excluded data.

Performance Measures

Table 16 shows the mean self-reported and % TT pace changes for all participants. The self-reported form appears to agree with the TT pace improvement seen in the study.

Table 16. The mean change in % TT pace and the self-reported form changes over the course of the 8-week study.

Measure	Mean $\pm$ SD
% TT pace improvement	8 $\pm$ 10
% Self-reported form change	12 $\pm$ 25
% paddling efficiency change	12 $\pm$ 25

Figure 27 shows the improvement when the participants were divided into elite, semi-elite and novice. Although many participants improved, the magnitude of the improvement varied. The improvement did not appear to differ between groups ($H_{\text{improvement}} = 0.9$, $df=2$, $p>0.05$)⁸.

⁸ Independent samples Kruskal-Wallis test (H = variable test statistic, df , p -value)

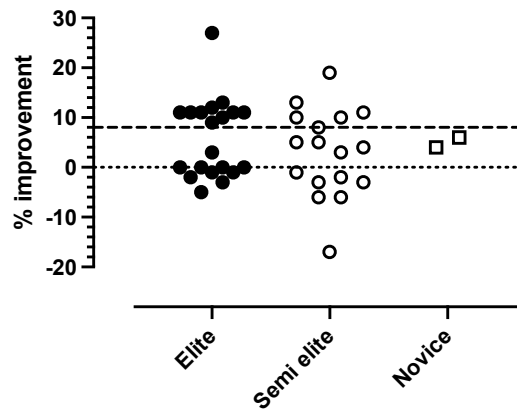


Figure 27. The improvement in time trial performance. The result is shown as a % pace improvement relative to their previous best TT pace. (n=38) The dashed line represents the mean improvement.

Figure 28 shows the repeated measures correlation between % TT improvement and the mean paddling efficiency for participants (n=35). The two factors have a positive correlation $r_{rm}(100) = 0.34$, 95% CI [0.15, 0.50], $p < 0.001$. This suggests that kayakers paddling with better efficiency have a greater capacity to increase their best TT speed. Furthermore, Figure 29A indicates that participants with the most improvement in efficiency also tended to have the most TT improvement over the same period ($r_{rm}(34) = 0.42$, 95% CI [0.10, 0.66], $p = 0.012$). Therefore, improvement in efficiency and not simply maintaining higher efficiency had a more robust association with TT improvement.

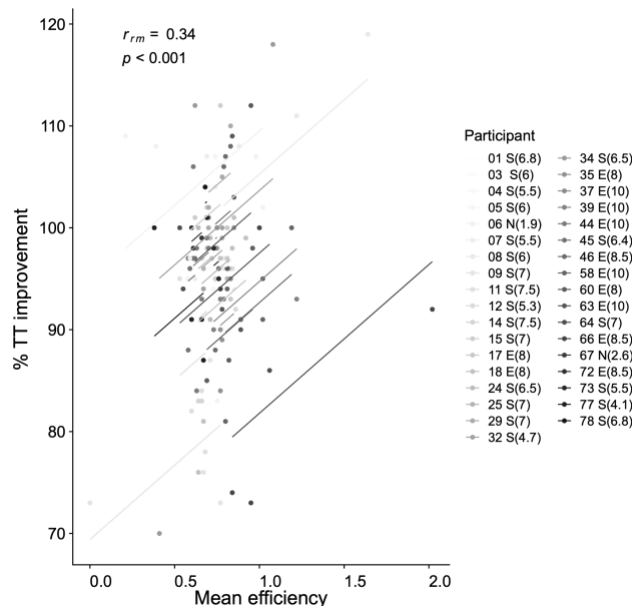


Figure 28. The repeated measures correlation between the mean paddling efficiency and the TT improvement for participants ($n=35$), $r_{rm}(100) = 0.34$, 95% CI [0.15, 0.50], $p < 0.001$. Figure and statistics produced by *rmcorrshiny* (2)

Other training characteristics which showed a statistically significant association with changes in % TT performance are shown in Figure 29. The repeated measures correlation between % TT improvement and mean %TTS ($r_{rm}(34) = -0.36$, 95% CI [-0.62, -0.04], $p = 0.031$) suggests that participants who, on average, paddled more at lower relative speeds improved their TT pace the most throughout the 8-week study (Figure 29B).

Additionally, the positive correlation between % TT improvement and Dalda B ‘worse than normal’ answers ($r_{rm}(34) = 0.38$, 95% CI [0.06, 0.63], $p = 0.022$) (see Figure 29C) suggests that the participants who had more “worse than normal” scores tended to improve more during the monitoring period of the study.

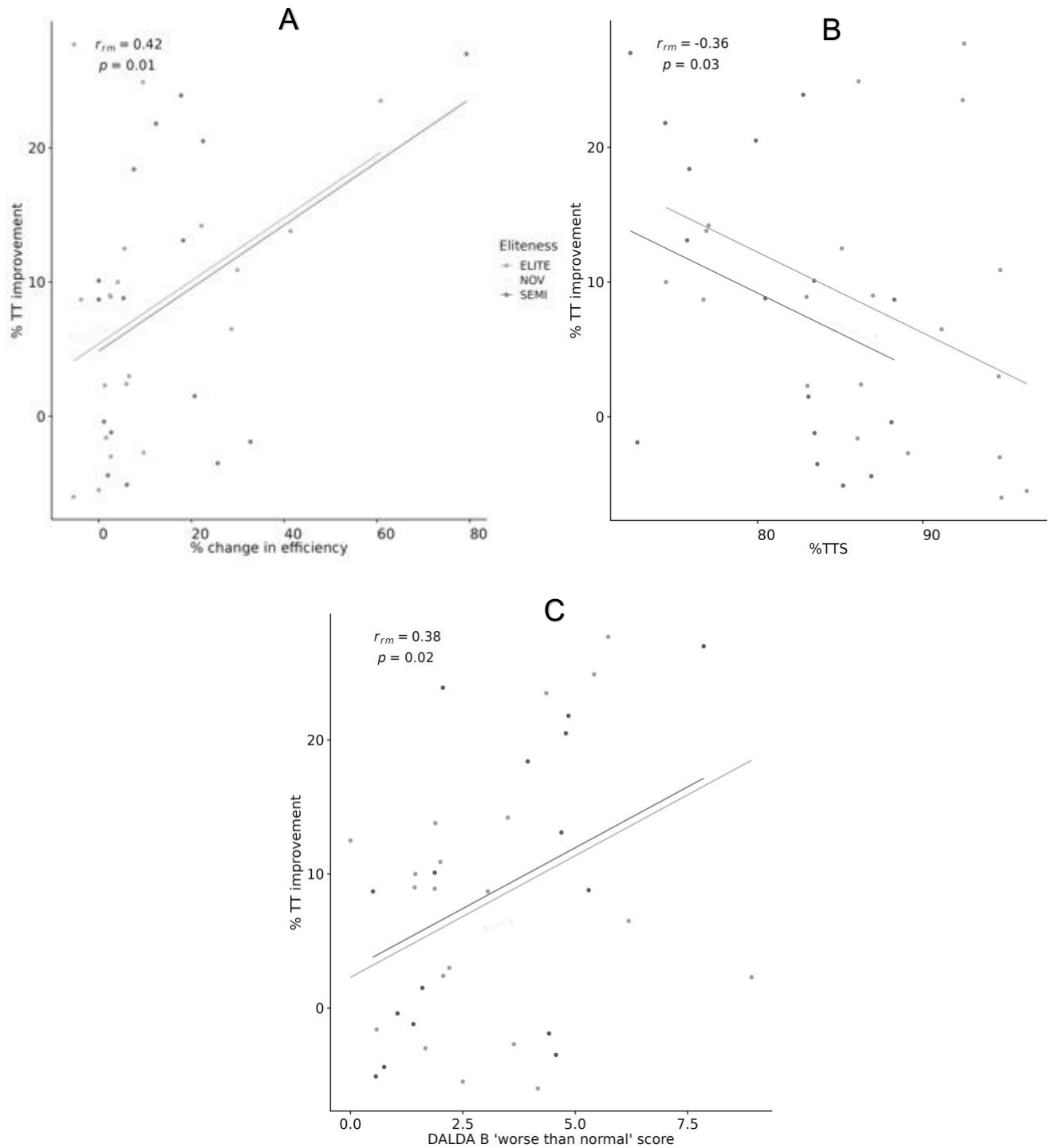


Figure 29. The repeated measures correlations of % time trial (TT) performance improvement with;(A) % change in efficiency($r_{rm}(34) = 0.42$, 95% CI [0.10, 0.66], $p = 0.012$); (B) %TTS ($r_{rm}(34) = -0.36$, 95% CI [-0.62, -0.04], $p = 0.03$); and (C) Mean DALDA 'worse than normal' scores($r_{rm}(34) = 0.38$, 95% CI [0.06, 0.63], $p = 0.022$) Figure and statistics produced by *rmcorrshiny* (2).

— Roadmap —

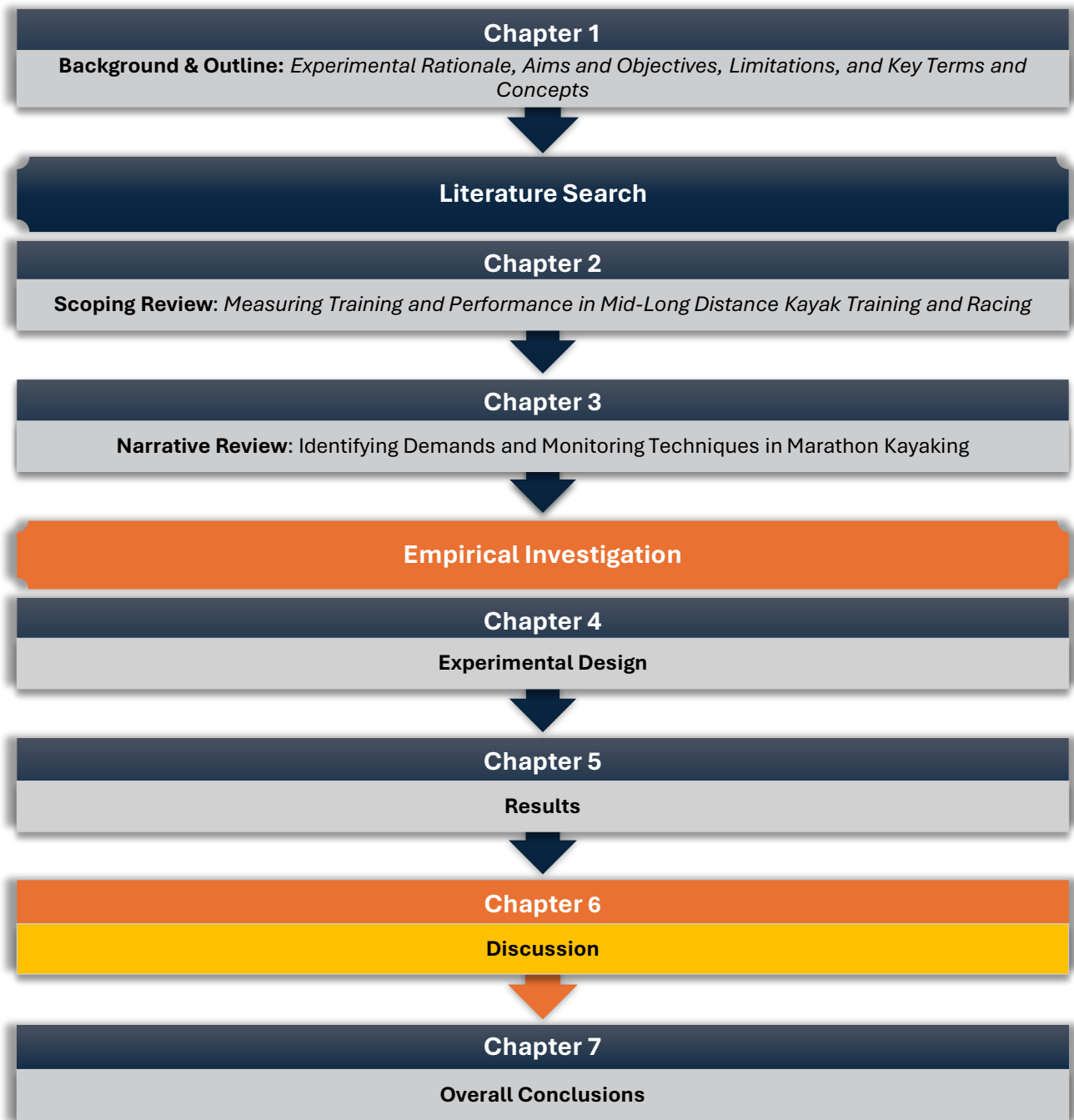


Figure 30. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed

— Chapter 6 —

Empirical Investigation: *Discussion*

Introduction

This study aimed to identify the training load measures and metrics applicable to ocean, flat water, and river marathon kayaking. It was undertaken by selecting metrics from other disciplines that were cost-effective, non-aversive, valid, and reliable and applying them to marathon kayaking. The objective was to determine the tools' efficacy in assessing training load, physical conditioning, and overall performance in marathon kayaking.

The effectiveness of different aspects of training load monitoring was evaluated based on multiple dimensions. Specifically, they were assessed on their proficiency in evaluating the overall training load. This includes the prescribed and completed training, as well as an assessment of metrics for defining and prescribing the intensity of a training session. Furthermore, metrics were assessed for their ability to gauge training stress or the athlete's response to training. Finally, measures were identified that might be suitable for evaluating performance or improvement in kayaking.

Measures Suitable for Intensity (RPE, HR, Speed)

The study measured the rating of perceived exertion (RPE), heart rate (HR), and kayaking speed to track intensity. The Foster's Session RPE (1-10 scale) from each participant was reported for every kayaking session, with 1182 measures across the 38 participants. Additionally, it was reported for time trial and race efforts. Figure 21 shows the repeated measures correlation between RPE and other intensity measures (212). GPS-enabled wearables measured Heart rate and speed continuously in all kayaking sessions. RPE vs %HR and RPE vs %TTS showed moderate and small statistically significant correlations, respectively.

Moreover, the coefficient of determination of the intensity measures ($R^2_{\%HR|RPE}=0.24$; $R^2_{\%TTS|RPE}=0.10$) suggests that while the metrics broadly agree, much variation affects the scores independent of intensity. There are no marathon kayaking studies to which these results can be compared. However, previous sprint kayaking studies have also suggested correlations with HR and RPE-based metrics (180).

Contrasting Intensity Measures

The study participants spent most of their time training at an intensity of 74 ± 6 % of their maximum heart rate, 84 ± 7 % of their best time trial speed, and with a mean Foster's Rating of Perceived Exertion (RPE) of 6 ± 1 AU as shown in Table 9. This offers little insight into the measures' robustness and how well they describe session intensity. Therefore, in trying to evaluate the validity of the metrics, we compared them across the sessions divided into long-slow-distance kayaking (LSD), interval type kayaking (INT) and race or continuous high-intensity kayaking (RACE). Figure 19 demonstrates how intensity measures compare.

Figure 19 demonstrates the agreement between measures and what might be considered the sensitivity of these measures. All intensity measures showed differences in mean

scores for the different training session types. The RPE measures have the biggest difference in mean scores. More minor but statistically significant differences were seen in % maximum HR (%HR) and speed represented as a percentage of time trial pace (%TTS) ^{3/4} see Table 12. Similarly, the pairwise comparisons for LSD, INT, and RACE showed the largest differences in RPE, and the scores differed significantly. Moreover, pairwise comparisons of %TTS and %HR were smaller but showed statistically significant differences between session types. It seems that RPE, %HR and %TTS are sensitive to changes in session types and, therefore, session intensity, with RPE being the most sensitive in differentiating intensity levels.

The relationships between the directions of differences in the measures were also interesting. The magnitude and direction of changes in various intensity measurements for the same session type were inconsistent. An LSD-type session was characterised by a lower RPE value (4 ± 2 AU), a moderate Mean speed % (84 ± 12 %), and low to moderate Mean HR % (72 ± 8 %). These sessions are typically lower intensity; thus, these measures are expected. Similarly, the Race sessions, had as expected, a higher RPE value (7 ± 2 AU), a higher % speed (90 ± 12 %), and low to higher %HR (79 ± 9 %). The INT session was characterised by moderate to high RPE value (6 ± 2 AU), a lower Mean speed % (81 ± 8 %) and low to moderate Mean HR % (74 ± 7 %). It is possible to explain the disagreement between RPE, %TTS, and %HR by considering that interval sessions often involve periods of rest or no movement, which can reduce both the kayaker's heart rate and kayak speed. However, this challenging interval session, even if it has extended rest periods, will likely still have a high RPE score.

RPE

The effects of the water and weather conditions during kayaking on the RPE measures are consistent with what is expected based on the literature. For instance, where shallow water or wind might slow a kayaker down, reducing GPS-measured speed, the RPE would still reflect the same intensity. Additionally, RPE was most consistent with the expected

intensity characteristics of the sessions. Moreover, RPE can be applied easily across disciplines and is used widely across a range of sports (179). It also has further advantages over other intensity measures. Specifically, it is inexpensive, easy to use, both easy to administer and interpret, and requires no specific technology. Moreover, it is relatively unaffected by training status (219). Furthermore, RPE has previously been shown to correlate with other intensity measures (179).

Heart Rate

HR as a measure of intensity was also consistent with what might be anticipated in such a breakdown of the session types. HR during exercise is widely used as a measure of training intensity (168). While an absolute HR value is helpful in training to inform an athlete of their intensity, the relative values, or training-intensity-distribution (TID), are more useful for both a prescription and subsequent analysis (220). The study calculated the time spent in specific intensity zones based on previously determined zone cut-offs (216,217). Figure 22 demonstrates that RPE scores had a small negative correlation with time in zone 2 ($r_{\text{rm}}(977) = -0.20$, 95% CI [-0.26, -0.14]). Moreover, the RPE score had a moderate positive correlation with time in zone 5 ($r_{\text{rm}}(977) = 0.50$, 95% CI [0.45, 0.54]). This suggests that high HR zones are generally associated with higher perceived intensity of kayaking sessions, while lower HR zones are not.

Heart rate monitoring has become relatively easy and non-invasive following the popularisation of Global positioning system (GPS) enabled wearables with HR monitoring capability. The use of these devices is becoming increasingly common in all training fields (63). Heart rate is independent of environmental or water conditions, excluding measurement errors related to water submersion or potential artefacts in measures from vigorous motion (71). However, these measurement errors are mostly confined to wrist-based optical HR sensors.

Generally, speed and HR measurements were taken continuously throughout the session. Therefore, when looking at average measures across the session for different session types, there tends to be only a slight relative difference between INT and LSD in %HR compared to the corresponding RPE scores. This is likely due to rest periods between intervals, which will reduce the mean HR recorded in the INT session, making it appear closer in characteristics to an LSD session. Notwithstanding this measurement issue, it has utility in kayaking intensity measurement, reflecting kayaking intensity where context is understood.

GPS-Derived Speed

Sport watches measure speed, distance, and acceleration, which is useful in many endurance sports (165). Moreover, the devices are most accurate in large open areas, where kayaking mostly occurs (167). Kayaking speed or pace is a valuable measure of progress in kayaking, particularly important in time trials, a decisive kayaking performance measure. GPS-enabled watches allow paddlers to view real-time data to adjust their efforts to maintain a specific pace.

Notwithstanding, on-water kayaking takes place on a fluctuant element. Consequently, numerous factors contribute to speed variation in on-water kayaking. This is especially true in open water or river settings. The session constitution is also important. The observed difference in %TTS of INT and LSD sessions was not significantly different, while the RPE and %HR both showed statistically significant differences between session types (see Figure 19). Without underscoring the metric's value in many kayaking contexts, it is critical to interpret data from these measures within the context of these influencing factors.

Considering this context, flat water kayaking can make the most use of speed measures. Even on flat water (as opposed to a river or ocean), factors emerge which can increase the kayak's net drag forces, influencing speed (111). Observed was an outlying correlation between a participant's distance and sRPE. The participant had paddled primarily on the

sea (see Table 13). Notwithstanding these factors, the measure is used in time trials. These shorter distances lend themselves more to repeatable testing. Some countermeasures can be taken to mitigate some of these issues. For instance, kayaking on a circuit (such as a lap) can help reduce the effects of wind or current. Furthermore, it is even in use as a measure in extreme ocean conditions, such as in “downwind paddles”, referring to paddling downwind with the prevailing wind and swell (110). However, in this instance, an average pace over a km indicates a kayaker’s skill downwind paddling rather than a direct measure of exercise intensity.

Ultimately, helpful intensity measures tick at least one of the boxes, inform athletes of session intensity, allow real-time adjustments, or accurately depict past session intensity (158). An examination of the tested measures shows that RPE as a measure of intensity was the most effective in determining intensity while kayaking. The measures of speed and HR have less sensitivity across different session types. However, while speed and heart rate measures might be less consistent and indicative of specific intensities in all conditions, they are easily applicable methods of completing training at a prescribed intensity. Applying these measures needs to be seen in the context of the paddling condition. Where conditions or training sessions are highly variable, speed measures are likely less appropriate, particularly when only average values are considered. Moreover, using the average HR values as a metric for noncontinuous sessions may misrepresent intensity. HR measures are better used in subsequent analysis in HR intensity zones.

Measures Suitable for Training Volume (sRPE, tHB & Distance)

We selected the Session Rating of Perceived Exertion (sRPE) as a load-tracking method, following evidence of robust correlations with the summated heart rate (HR) zone methods (74). Furthermore, sRPE has gained widespread acceptance as an effective training load monitoring tool in various individual sports, such as cycling, running and karate, in addition to various team sports, such as rugby, football, handball and volleyball (192,221–225). Therefore, it seems reasonable to consider its applicability to kayaking (226).

In this study, metrics of training volume in kayaking, such as distance kayaked and total heartbeats (tHB) per session, were strongly correlated with sRPE (distance r_{rm} (1054) = 0.80, 95% CI [0.77, 0.82], $p < 0.001$; tHB r_{rm} (933) = 0.82, 95% CI [0.80, 0.84], $p < 0.001$)—see Table 13). Consensus among measures, while not a confirmation, is a good sign that measures are sensitive to the same factors.

However, despite the apparent consistency in average correlation scores, it's key to acknowledge variations within and between individual participants. This presents a challenge, as the metrics should consistently quantify the training load that the individuals experience. The variation may point to inconsistency in at least one of the metrics. Understanding a primary source of the variation can help contextualise the measure for better use. For instance, potential errors in heart rate recording, especially in aquatic settings, may contribute to tHB variability (71,91). Additionally, weather and water conditions can introduce significant variations in distance measures. For instance, an elite participant showed a minimal correlation between sRPE and distance due to sessions conducted in an area with extreme tidal currents, resulting in variable distance covered.

It is important to consider the context when interpreting measures of training load. An instance not unique to kayaking might be a session with interval training and extended

rests. In this case, the load will be misrepresented when using tHB measures (91). Nevertheless, methods should be interpreted within the specific kayaking conditions, where weather, water conditions, and excessive water exposure can impact distance measures and introduce inaccuracies in HR measures. Ultimately, each examined load measure proves valuable when contextual factors related to training and kayaking are carefully considered.

Recovery and Stress Response Measures

Athletes often experience stress associated with their training (18). Psychometric questionnaires serve as valuable tools for assessing the stress experienced by athletes (90). Stress was monitored by the daily completion of a condensed version of the Profile of Mood States for Athletes (POMS), known as Quick POMS (181,227). The Quick POMS scores of the 38 participants showed there were no significant differences from week to week ($\chi^2(7) = 12.0, p > 0.05$). See Figure 26. An assessment of the means $\pm$ standard deviation of the scores for the participants week to week also revealed no significant changes. POMS has previously been shown to be a sensitive measure for kayakers (228). Therefore, large changes might have indicated disturbances related to training stress. The results of this study cannot confirm or dismiss the efficacy of Quick POMS.

Participants completed the Daily Analysis of Life Demands for Athletes (DALDA) every week (75). Although these assessments are longer than the Quick POMS, the results have previously provided insights into the athletes' psychological well-being (77). Moreover, the extended length provides deeper insight without sacrificing conciseness compared to other psychometric assessments (77). The large standard deviations demonstrated much variation in the scores between participants. However, there does not appear to be any clear trend over the eight weeks of the study. See Figure 24. Moreover, the DALDA measure did not appear to be associated with any other change.

However, further analysis revealed the distribution of DALDA scores was positively skewed (skewness A= 0.9; B=1.0), indicating that more of the total selected answers were “worse than normal” than “better than normal” for both parts A and B. See Figure 25. Therefore, on average, if the participants were deviating from the “normal” rating, they were more likely to be worse than “normal”. This tendency of a slight tendency with “worse than normal” scores was also associated with improvement in TT for the study. Therefore, it might indicate a reasonable amount of training stress, leading to improved fitness (5). However,

this trend was not supported or refuted by other measures of total training load (i.e., sRPE and tHB) or the quick POMS.

While the psychometric measures did not reveal significant changes throughout the study, suggesting potential insensitivity, a more plausible interpretation is that participants did not experience considerable stress during this period. This is supported by the absence of self-reported indications (separate from POMS and DALDA) from participants, signifying a lack of severe stress throughout the study. Ultimately, it remains that psychometric questionnaires serve as valuable tools for assessing the stress experienced by athletes (90). Moreover, in the context of monitoring load in kayaking and this study, these tools are easy to implement and simple to use and interpret.

Measures Suitable for Performance

Time Trials

Time trials are a well-regarded method for evaluating performance; they are also highly reproducible for maximal performance tests (229,230). Specific protocols for time trials may vary. However, the protocol revolves around athletes completing a specified amount of work and measuring the time to finish (229). The time trial should be specifically implemented to suit the constraints of the sport. This involves working for a sufficient duration to enable realistic and accurate measurements of various endurance factors.

In kayaking, time trials are a suitable performance test. They allow the paddle to be done over shorter distances, making repeatable testing more feasible. Additionally, measures such as kayaking on a circuit minimise the impact of wind or current. Moreover, in kayak racing, the outcome of the race is not reproducible due to many external factors that contribute to the race duration. So unlike a sport such as running, where race time is considered a performance measure, kayaking time trials are better suited to assess performance readiness or endurance factors (231).

The time trials completed in the study were self-administered by participants. They received instructions with a specific procedure (See Methods, Time Trials). There was a group mean $\pm$ SD improvement of 8 ± 10 %. However, this improvement was not consistent among the participants. See Figure 27. Moreover, a negative correlation existed between % TT improvement and %TTS (Figure 29B). The result implies that participants paddling more at lower relative speeds experienced the most improvement in their time-trial (TT) pace during the 8-week study. This could be due to improved physical conditioning (5). Additionally, this could indicate less intense training, resulting in a more tapered state during the later TT. This explains why time trial results tend to be worsen during periods of intensified training (232).

Additionally, there was a positive correlation between % TT improvement and DALDA B's 'worse than normal' answers (Figure 29C). This implies that training, which resulted in more general feelings of fatigue, led to improved time trial performance. Moreover, these relationships were observed independently of the Eliteness groupings.

The variability of the time trial results was large, with a coefficient of variation of the improvement of 123%. This is more variation than might be expected in such a reproducible test (229). In some cases, participants showed decreased performance in their time trials, while no other training measures suggested such a decline. This variability in results speaks to the difficulty of performing a repeatable TT (42,164). While a TT can be effective in kayaking, mitigating external factors is pivotal to reproducibility. Despite these drawbacks, there is currently no tool better to replace a TT. Moreover, the stringent control needed for a formal study is unnecessary for the average paddler, who can assess their progress while being cognisant of these confounding factors.

Kayaking Efficiency

Kayaking involves using a paddle to propel the boat through the water. The boat travelling through the water has a drag force, which resists the boat's motion. This force is overcome with the forward thrust produced by the paddle (111). The drag arising from the interaction of the boat with the water is always present. Therefore, enhancing paddle thrust is the best way to improve boat speed and, ultimately, performance. This can be accomplished through improved physical conditioning, as in any endurance sport, allowing paddlers to execute more stroke cycles and increase paddle thrust (31,32). Moreover, improving the paddling technique could enhance work efficiency and produce greater output for the same input. The measurement of the latter is uncommon.

In this study, an approximate measure of this work efficacy was by contrasting speed (a measure of kayak output) and heart rate (a measure of a kayaker's physical work). This ratio

ranged from most participants was between 0.5 to 1.2 (km/h)/bpm. The higher the figure, the better efficiency the kayaker has based on their recorded speed and HR. The mean $\pm$ SD efficiency was 0.76 ± 0.12 (km/h)/bpm.

This efficiency score correlated with Eliteness scoring and the kayakers' number of years of paddling (controlling for age) (see Table 11) These are both measures of kayaking ability. The coefficient of determination of the measures ($R^2_{R|Eliteness}=0.23$; $R^2_{YOP|Eliteness}=0.26$) indicates that 23 % and 26% of the variation in these measures, a consequential proportion, can be attributed to efficiency.

Moreover, efficiency was associated with improvement in time trial pace, a performance measure. Not only was there a positive correlation between overall efficiency (measured throughout the study) and TT improvement, but the correlation was stronger between improvements in efficiency and improvements in TT performance (see Figure 28 and Figure 29A). The coefficient of determination was $R^2_{R|TT\%} = 0.18$, indicating that 82% of the variation cannot be explained by the efficiency score and could be attributed to factors. However, this still points to the improvement in efficiency being a component of performance readiness. Therefore, better efficiency might reflect a combination of improved technique and fitness.

Kayaking efficiency could be considered an approximate measure of progress linked to both physical conditioning and technical improvement. It might be akin to a test of paddling at a submaximal intensity based on kayak output (such as speed) and noting the HR at a steady state. This measure has challenges; as mentioned, kayaking speed depends on the conditions. Thus, the metric only applies under conditions where confounders can be mitigated or considered and contextualised. Moreover, the measure cannot distinguish improvement of technical skills from physical conditioning. Furthermore, the interpretation of the simple ratio between craft speed and heart rate assumed a linear relationship which may not be the case. Therefore, despite some promise, this measure needs further

scrutiny and empirical validation before it is adopted in any meaningful way. If this is successful, the measure could offer a quick reference, using data that often is already being recorded.

Valuable measures: RPE and sRPE

Rating of Perceived Exertion (RPE) is sometimes overlooked as a serious measure because of its simplicity. Using it can occasionally feel less rigorous than using objective measures. However, RPE has demonstrated considerable utility as a measure of training intensity, offering a sensitive and reliable assessment of an athlete's internal load. It has proven effective in distinguishing between session difficulties, showing greater consistency and less susceptibility to external confounding factors than other metrics. Furthermore, when extended to session RPE (sRPE), it aligns well with established measures of total training load (TTL), such as total distance or total heartbeats, reinforcing its validity. Notably, RPE is also highly practical: it is simple to implement, requires no specialised equipment, and incurs no financial cost. Given these advantages, RPE and sRPE should play a central role in monitoring training load in marathon kayaking to better inform intensity and volume and serve as a benchmark against which other load metrics can be evaluated.

Participant Characteristics

Kayaking Proficiency

The study involved a diverse group of kayakers with varying experience and skill levels. This may have impacted the results, particularly the relationships between variables.

Consequently, it was necessary to assess the kayakers' proficiency, as this could affect the study's relevance to different populations. The athlete classifications included Eliteness and years of competitive paddling (YOP) (218). The mean $\pm$ SD Eliteness score was 7 ± 2 AU, meaning the average Eliteness was the upper end of semi-elite. The YOP mean $\pm$ SD was 9 ± 6 y. The cohort age ($\bar{n} = 39$ y). This was older than typically seen in elite sportspeople (141).

Measures of Eliteness and YOP were positively correlated (see Table 11). Moreover, the correlations between both measures of proficiency and training characteristic mean speed % show clear agreement between the direction and relative strength of correlations (moderately negative).

However, there was a lack of agreement between some of the metrics. For example, increasing training duration in Zone 2 (72-86% max HR) is a potential indication of more advanced training in line with training intensity guidelines seen in other elite endurance sports training (220). This training characteristic significantly correlated with YOP while having no statistically significant relationship with Eliteness. However, in cases where factors were only associated with one of the measures (Table 11), they did not contradict one another. Instead, the alternate proficiency measures were not significantly correlated.

The classification utilised in this study appeared suitable for marathon kayaking, as the indicators generally suggested that higher proficiency scores were associated with more advanced training methods (220). Moreover, this classification can help evaluate the relevance of the findings in this study to future or similar studies.

Limitations and Constraints

The study design used pragmatic measures, which athletes could utilise without outside assistance or intervention. While this made the study more ecologically valid, it made certain procedures more cumbersome as researchers operated remotely. Moreover, there was a reliance on participants' accurate self-reporting and good adherence to the protocols. Furthermore, the research was counting on the accuracy and reliability of the participants' monitoring equipment. Notwithstanding safeguards present and the exclusion of devices not approved by researchers (see Appendix 15). It was difficult to assess how such factors influenced the results.

Unforeseen issues arose from the number of different monitoring devices present. For instance, differences in the data collection frequency of these devices imposed real challenges on data collection and analysis. This restricted the researchers' assessments of certain novel measures, such as the OTT. Such a problem may have been eliminated had the researchers had the resources to hand out specific devices which could have been correctly calibrated for this study.

Orthostatic Tolerance Test

The Orthostatic tolerance test was one of the measures of participants' state of stress-rest balance. Participants underwent a weekly orthostatic/supine heart rate test in conjunction with answering the DALDA questionnaire. In the test, the difference in standing heart rate and supine heart rate represents the orthostatic tolerance. Therefore, the efficacy of the test relied on accurate high-resolution HR data for this short period. This was not the type of data which most devices typically produce. Generally, sports watches record measures over longer durations in "smart modes" with lower frequency and interpolate the data. This, combined with other issues such as indoor interference with the GPS data, made the results from this test unusable.

Conclusions

The results showed the participants' diversity in proficiency. Paddling efficiency separated the more proficient and less proficient paddlers, suggesting that paddling efficiency may be a measure that could be used to assess how an individual is improving their paddling over time.

Session RPE, session total heartbeats and session total distance measured the accumulated training load in kayaking relatively consistently. However, the sRPE method is likely to be the most sensitive, as RPE was the most sensitive measure of training intensity.

Other valuable metrics include heart rate and paddling speed. Examining the speeds relative to a previous best TT pace and previous maximum heart rate might be a helpful way for coaches to set the training intensity. However, understanding these measures in the context of the type of session and the paddling condition is important in both the prescription and the examination of data.

Psychometric measures such as DALDA and quick POMS are valuable tools in understanding how much stress the athlete can tolerate, both from training and daily life. However, the data in this study indicate no significant associations to the total training load. This might suggest that the measure is not overly sensitive. This is unlikely as other studies have shown both measurements are responsive to training stress. A more likely explanation is that the kayakers were not overly stressed during the study. Further examination of these measures is necessary. Furthermore, paddling-specific questionnaires might also need to help specifically examine stresses that kayakers might face.

Time trials are a performance measure which has shown efficacy in kayaking and other endurance sports. However, in this study, the results were variable, which can be attributed

to the conditions under which the time trials were performed. Controlling the impact of any variable water conditions is crucial to achieving consistent results.

In summary, measures suitable for monitoring marathon kayaking exist in the training load monitoring space. However, these measures may need to be interpreted in a marathon kayaking context and utilised in a discipline-specific way. Notwithstanding, these measures can be effective while being non-aversive and affordable.

— Roadmap —

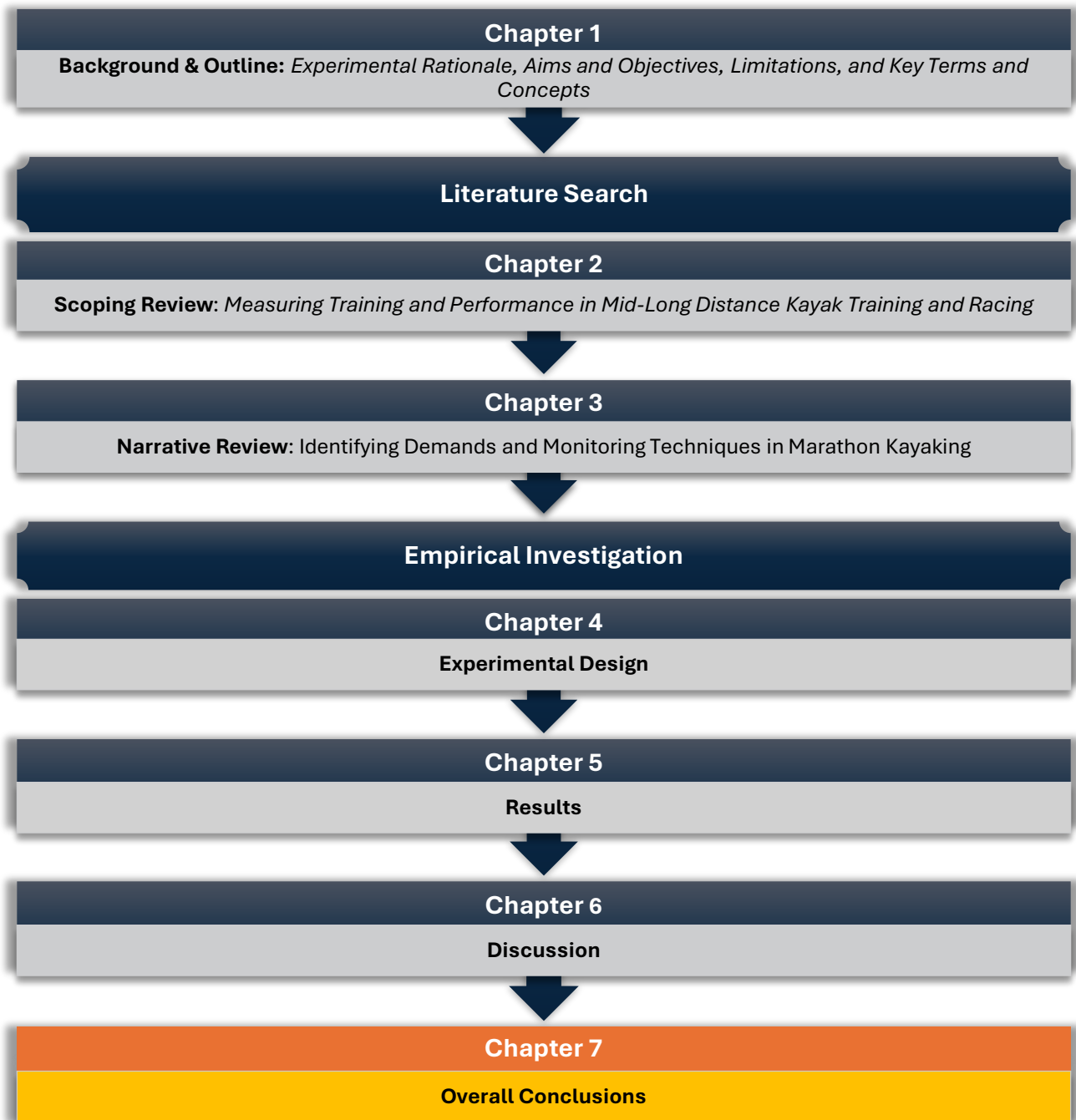


Figure 31. The dissertation roadmap includes the order of events and how each section is related. The highlighted portion indicates the current section of the dissertation being viewed.

— Chapter 7 —

Overall Conclusions

Summary of Procedure and Findings

The project began with a scoping review, which led to a narrative review that delved into areas the initial scoping review had not explored. Information from both reviews was used to design the experimental phase of the dissertation.

The scoping review examined studies of physiological factors such as heart rate (HR), blood lactate, and O₂ uptake as markers of intensity. Additionally, measures of kayaking output, such as GPS measures, power output, and stroke rate, were examined. Most studies were conducted using controlled laboratory testing instead of on-water measurement. Therefore, the assessed metrics were not ecologically valid and impractical for monitoring everyday marathon kayaking loads. This review highlighted the underexplored nature of monitoring training load and responses in kayakers and prompted an additional investigation—a narrative review with a freshly refined set of objectives. At the core of the narrative review was an exploration of the intricacies of marathon kayaking, delving into the physiological and psychological demands arising from training and racing. Furthermore, the investigation highlighted schemes, metrics, and tools from other endurance sports suitable for monitoring demands of training and competition and athlete responses.

The two key components of success in marathon kayaking were identified: skill and technique. This includes performing superior kayak paddling techniques and executing various other marathon kayaking-associated specific skills in challenging conditions. These aspects, which require continuous refinement, are not straightforward to measure. Kayakers' physical conditioning, particularly strength and endurance, was another component contributing to success.

In the training load monitoring literature for endurance sports, effective monitoring of physical conditioning involves identifying methods that can meet monitoring objectives—

specifically, assessing the overall training load, evaluating training intensity, evaluating training response and identifying suitable performance measures. The review considered the constraints of the sport and identified methods or metrics which could satisfy these objectives.

Based on insights from the reviews, the study objective was refocused on comparing metrics for on-water marathon kayaking and their efficacy in addressing effective load monitoring in endurance exercise.

Rating of Perceived Exertion (RPE), percentage of maximum heart rate (%HR) and pace as a percentage of best time trial pace (%TTS) were all identified as candidates for intensity measurement. RPE was the most sensitive metric quantifying on-water intensity, showing the largest contrast in different session types with known differences in intensity. While %HR and %TTS both responded to session intensity changes, they had certain challenges. Water can interfere with HR sensor measurement, particularly if a wrist optical HR sensor is used, compromising accurate measurements of %HR. %TTS, a more direct measure of kayaking output, had a more pronounced susceptibility to environmental factors.

Despite these challenges, when the data are considered with context, such as an athlete's internal state and environmental conditions, and appropriate measurement tools are used, the heart rate and speed metrics can be valuable intensity measures for athletes and coaches. Moreover, these measures are easy to obtain, and many kayaking athletes are accustomed to using these metrics to monitor intensity during sessions.

Session RPE (sRPE), session total heartbeats (tHB) and session total distance appear to be consistent as measurements of the accumulation of training load in kayaking. Consensus among the measures suggests they are sensitive to the same factors. However, it is important to acknowledge that these load metrics are sensitive to the same factors as the

intensity measures from which they are derived. Underscoring the importance of contextual consideration of the distance and HR-derived measures.

Psychometric measures such as Daily Analysis of Life Demands for Athletes (DALDA) and Abridged Perception of Mood Scores (quick POMS) are useful tools for understanding how much stress athletes can tolerate, both from training and daily life. However, the participants did not experience significant training stress in this study. Therefore, the group's psychometric measures did not change. However, it is likely that on an individual basis, these measures are a good reference for athletes.

The most practical performance measure described in the literature was a time trial (TT). This method allows the assessment of all relevant factors of performance in marathon kayaking. Moreover, the test is not exhaustive and can be performed reasonably close to the competition. The study highlighted the need to mitigate the confounding factors always present in on-water kayaking. Additionally, a nuanced understanding of these factors allows for a more appropriate assessment of the data and better informs subsequent training decisions.

Training load monitoring tools offer valuable insights into various aspects of training, including total volume, intensity, response, and performance evaluation. Their deployment should be context-specific, considering the variation in the applicability of various methods across the discipline and in specific conditions. Nevertheless, these tools are well-suited to the constraints of the sport. Their non-aversive nature and cost-effectiveness align with the needs of the most competitive kayakers, making them accessible and user-friendly for practical use and interpretation.

Areas of Novel Interest

Seeking Complexity & Occam's Razor

Seeking metrics that can utilise monitoring technology advancements is a necessary part of improving monitoring capabilities. Moreover, new technologies move incredibly fast, with exciting innovations allowing increasing tantalising possibilities. However, scientific scrutinisation, by its nature, is a slower process. This increases the likelihood that more foundational principles can be overlooked in favour of using the technologies. This manifests as either using the measurement tool in an inappropriate context or overinterpreting data received from unscrutinised metrics. Note that Occam's Razor still applies to the current era of new and novel technologies (233).

The principle of Occam's razor is used in problem-solving and scientific reasoning. It suggests that the simplest explanation, or the one with the fewest assumptions, is usually correct. This assertion is quoted in many books on logic and is attributed to William of Ockham (234). The idea is that when faced with multiple explanations for the same phenomenon, the one that requires the fewest leaps of logic or introduces the fewest new elements is preferred.

Therefore, with the advice of Occam, emphasis on evidence-informed practice, well-grounded fundamentals, should underpin practice. This ensures that the allure of technology does not outweigh better judgment. Load metrics should be constructed with the smallest set of elements or the fewest number of assumptions. Ultimately, pursuing a future of better monitoring should not come at the expense of monitoring today.

While simple measures must not be overlooked and should be used more often, the exploration of novel methods should continue. However, the measures would benefit from more critical examination, especially when the underlying technology is poorly understood. With this in mind, some of the areas of more novel interest that could hold promise for

kayaking monitoring as the technology develops and becomes more accessible are presented.

Novel Session Characterisation via a Machine Learning Algorithm

One of the current limits of using wearable GPS is the ability of users to gain a more nuanced summary of the data. The most common metrics are mean heart rate and speed. These measures are useful in their current form for an exercise performed at a consistent tempo. An example might be a TT or training where participants put forth a consistent effort. In these cases, measures such as the mean are representative. However, there is only sometimes a consistent effort or tempo throughout the exercise session.

Enhancing these measures may involve isolating specific segments, especially in interval-type training, intense activities interspersed with rest periods. This could help isolate the segments, assess the factors within the segment and then accumulate them in a session summary. Theoretically, this could demonstrate heart rate and speed trends and their change over time, potentially creating a kayak-specific training index. Similar indices developed for road running have shown promise in daily monitoring of an individual's training adaptation (235).

The machine learning techniques could help make such a system. These have been implemented to explore the connection between wellness items and training load across different sports (236). In this context, machine learning uses subsets of data, such as speed and HR session data with contextual information about the session, to generate an algorithm that may use novel or different combinations and weightings of these original inputs. The new algorithm will be unique from any derived from first principles (237). The application of such a technology in the context of using wearable data is the ability of such a system to create algorithms to identify session segments (such as intervals or rest periods) or relationships between variables such as heart rate and speed. Moreover, it

could be trained to assign value to these segments. This could provide easy-to-interpret accumulative scores in session summaries.

Moreover, these systems could mitigate the confounding effect of water conditions on session GPS data. By incorporating in-session weather data, the impact of environmental factors can be quantified, allowing for an assessment of how wind, tide, and swell influence a training session. Furthermore, this system could amplify the utility of existing data. Deploying post hoc algorithms enables self-training on an individual's past data, enhancing the algorithm's adaptability. Such systems are currently working to identify and diagnose ophthalmological conditions, such as diabetic retinopathy (238).

Such undertakings will no doubt have their challenges and limitations. These include a sufficient data set to train an algorithm. A competent algorithm needs large datasets with validation keys (237). Additionally, these tools require empirical evaluation by researchers with a depth of understanding across the fields of study. By their nature, these systems are less intuitive than human observers. While this could lead to new insights, it also has the potential for significant outcome errors. A lack of specific understanding of the inner workings of these algorithms, referred to as the “black box” problem, makes these errors harder to solve (239,240). Therefore, an understanding of the data being used to arrive at conclusions should still underpin any investigation.

Camera Motion Capture

A recent paper on a kayak motion capture system detailed a system of tracking a kayaking stroke in water kayaking (54). This is a novel idea of tracking kayaking technique, a vital aspect of kayaking, for which there is no real means of objective monitoring for tracking improvement. These tools could use image recognition software to analyse their stroke and give feedback. These systems could even benefit from using artificial intelligence, which is suited to image pattern recognition (238). The feedback would likely require input from a

practitioner. However, the technology may allow feedback to be more automated. This, integrated with other sensors, could help kayakers identify weaknesses in their performance and areas of training to address.

While this system has some challenges, the current prototype was used only in simulated kayaking as a proof of concept. A key challenge is to account for the environmental factors. For instance, kayaking on the water takes place in open, well-lit areas. However, the light source (the sun) cannot be as well managed as in a laboratory environment. Water sports present additional challenges, particularly for optical sensors like cameras or infrared sensors, as water can interfere with their functionality. Both marker and marker-less motion capture systems face water-related challenges, such as altering reflective properties when markers or reflective objects get wet (241,242). Notwithstanding such challenges, this promising new technology targets skill acquisition, an area of kayak monitoring with few alternatives.

Stroke Force Calculation via Force Transducer and Stroke Rate Counter.

Another useful technology for kayaking which has already gained some traction in sprint kayaking is integrating a force sensor into a kayak paddle (101,243,244). Any forward thrust the kayaker produces is transferred via the paddle (29,245). Therefore, measuring the force on the paddle can directly indicate the thrust the paddler generates. Thus, it is a direct measure of kayaking intensity. Additionally, this approach enables a detailed stroke metric, revealing the points of maximum force and power production during a stroke and providing insights into technique variations. Furthermore, profiling the force exerted on a paddle allows for the assessment of optimal paddle characteristics, including shape, size, angle, and rigidity, tailored to both general kayaking preferences and individual qualities of kayakers.

Nevertheless, currently available technologies are expensive. Additionally, they have yet to be integrated into paddles, meaning the sensors and related equipment are not housed neatly. This makes them more cumbersome to use and limits their applicability to controlled environments for specific testing rather than serving as a practical daily monitoring tool. While the technology provides the most direct measure of effort, it may still overlook other factors critical to measuring intensity in kayaking and how they relate to boat speed.

Notwithstanding, these sensors would be very useful in aiding the arsenal of measuring tools and may be favoured over kayaking speed measures as a more direct measure of kayaking output.

Contributions to the Body of Knowledge

The primary goal of this research was to advance the understanding and application of load monitoring in marathon kayaking, a domain largely unexplored in previous studies. This investigation provides a contemporary and comprehensive analysis of the relevant literature. Providing a holistic view of marathon kayaking, illuminating the key factors relating to training and performance and aiding in identifying relevant monitoring tools. Furthermore, while all tools were considered, the investigation approached monitoring through a lens of practicality, non-aversiveness, and affordability. This practical approach ensured that the proposed and assessed tools were not only theoretically beneficial but feasible for implementation.

Moreover, a focus was on measures which were non-aversive, inexpensive, and accessible to use and interpret. The investigation aimed to advance our understanding of the topic and offer actionable recommendations for many Tier 2-3 ranked participants (209). This group, a significant part of the active racing population, lacks dedicated support. These individuals will not be inclined to adopt aversive or expensive measures for training load monitoring, regardless of efficacy.

Ultimately, this research has provided insight into an underserved domain, addressing gaps in existing knowledge and presenting actionable insights. Furthermore, it has contributed to strategies for improving performance and acted as a stepping stone for future investigation.

Limitations

GPS Sports Watches

One of the limitations of the experiment was the diversity of Global Navigation Satellite Systems (GNSS) such as global positioning system (GPS) watches and the nature of data recording on such devices. The GNSS-enabled watches work by receiving a specific signal from a GNSS satellite, and using the time the signal takes to reach the watch from multiple satellites, and the system can calculate the relative position of the watch (246). The accuracy of these systems can vary, especially if solid objects block the signal (165). However, the system's accuracy is sufficient for distance and speed tracking in a recreational activity. Many devices have a "smart recording mode", which reduces memory usage without sacrificing accuracy by decreasing data recording frequency during relayed satellite communications (247).

However, for this study, the researchers used the devices to measure heart rate in the Orthostatic tolerance test (OTT), a stress-rest balance test. The frequency of data recording on the devices was reduced significantly in these tests due to the smart recording modes. Moreover, these tests were primarily performed indoors, reducing the recording frequency. While the reduction in frequency was not an issue for longer outdoor training sessions, the reduced frequency of data collection was a constraint of the OTT interpretation, as the test needs high-resolution data of at least 1Hz. Ultimately, the data from OTT tests was not high resolution enough to be interpreted.

Data Collection

Data from the GPS wearables were collected from participants' devices. During the proof-of-concept testing phase, the researchers ensured data could be collected and shared from devices (see Appendix 18). Although most participants used the same brand of GPS sports watch- Garmin- the format of data received varied substantially. The researchers

expected the Flexible and Interoperable Data Transfer (FIT) data format. This format is designed specifically for the data originating from sports, fitness and health devices (248). However, this was not the only format of data which was received. This provided an additional challenge as the protocol set up for the data could not be easily modified for such an eventuality. This led to more non-automated tasks for the researchers, which slowed overall progress. Moreover, this led to a reduction in data consistency, which further reduced the ability of the researchers to perform more novel investigations on data.

Some of the data investigations that were attempted are included in Appendix 24. One idea was to produce a system of session classification to ascertain a session impact score based on a more nuanced understanding of GPS and HR data. Ultimately, the diversity of data received would have required additional time and programming skills outside the scope of this research project.

Participant Non-Contact

Participants were not contacted in person during the investigation. The researchers contacted them via email only to follow up on queries and send specific reminders. The project was not intended to interfere with the participant's training. However, there were consequences of the format. Primarily, the participant's adherence to protocols, such as completing questionnaires or performing the prescribed repeating procedures, was worse than anticipated. The lack of in-person sessions with researchers and participants may have reduced their feelings of accountability. Furthermore, feedback was impossible to provide until the end of the monitoring period due to the protocol being designed primarily for the ease of participants and data being received only at the end of the monitoring period. Feedback during the monitoring period may have been a valuable tool for improving protocol adherence.

Self-Reporting

Self-reporting of data can have challenges. The results obtained are subjective and can vary. However, in the case of this study, the self-reported data reported came from validated questionnaires. Moreover, where data were not reported in a validated questionnaire, the researchers did not directly use the reported data. Rather, the data were organised into categorical data based on responses, reducing the chances of a participant directly dictating experimental outcomes. Moreover, the study was designed with real-world application in mind; such methods, when used correctly, have ecological validity.

Recommendations

Measurements and tools used for training load monitoring have inherent differences, leading to differences in aversiveness and effectiveness. Additionally, outside contextual factors can affect a measure. Consideration of the term of use, including the overall duration and frequency. Understanding how these factors impact aversiveness is especially important when deciding which measures best suit a specific regimen.

In the current study, the ease of use of measures was vital for efficacy. Measures employed in the study that were more aversive had far worse compliance and were ultimately less useful in practice despite any theoretical effectiveness.

Based on this research, it's clear that kayaking performance improvement involves training in technique, skill, and physical conditioning of both aerobic and oxygen-independent systems. Furthermore, monitoring training accurately goes a long way towards optimising the training for the best improvement.

Psychometric measures are effective when measuring intensity. Furthermore, RPE is preferred over other methods. Measures with both duration and intensity dimensions are most suitable when assessing overall training. Moreover, sRPE is preferred over other methods due to its sensitivity and consistency in evaluating the total training load. Time trials can be an effective performance gauge. However, careful consideration and mitigation of confounding factors are required to assess performance accurately.

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— Appendices —

Appendix 1

Scoping Review Search Records

Search Overview

	<i>Searches</i>	<i>papers</i>
	<i>PubMed</i>	41
<i>Scopus</i>		100
<i>Cochrane library (for reviews) just main reviews data bases</i>		10
<i>EBSCOhost (MEDLINE;APA PsycArticles;APA PsycInfo;APA PsycTests)</i>		18
<i>Web of Science</i>		56
<i>total</i>		225
<i>Merged, unfiltered, duplicates removed</i>		69
<i>Papers screened</i>		128
<i>papers included</i>		28

Screened Records

Excluded	Reason	Author comment
A new approach to improve cognition, muscle strength, and postural balance in community-dwelling elderly with a 3-D virtual reality Kayak program	Population	population, too old, not looking at monitoring training
A performance analysis of a stand-up paddle board marathon race	Population	SUP not kayak
A review of the impacts of nature based recreation on birds	irrelevant	not on kayakers
ACE and ACTN3 genes polymorphisms among female Hungarian athletes in the aspect of sport disciplines	wrong focus	study looking at genes, not training response
Aerobic-anaerobic transition intensity measured via EMG signals in athletes with different physical activity patterns	Focus not on kayaking	study on lower muscle and effects measured on cycling ergometer
Age-related changes in anaerobic power in the former highly trained oarsmen and kayakers	Wrong focus	study focused on age related changes in oarsmen in aerobic power.
Anthropometric, physiological, and performance characteristics of elite canoe polo players	population	canoe polo players
Antioxidant status, oxidative stress, and damage in elite trained kayakers and canoeists and sedentary controls	Wrong focus	looks at oxidative stress in both kayakers and non kayakers, not training related changes.

Excluded	Reason	Author comment
Application of the double paddle oscillator for quantifying environmental	irrelevant	wrong topic
Autonomous modulations and self-confidence of high performance athletes	population	slalom canoeists
Back pain prevalence in adolescent athletes	Population and focus	population too broad, and focus on health, not training
Body composition and bone mineral density in competitive athletes in different sports	focus of topic	related to health rather than training
Bone mineral content (BMC) and bone mineral density (BMD) in postmenopausal women formerly practising kayaking and fencing	Population and focus	health related and not only kayakers
Canoe polo Athletes' Anthropometric, Physical, Nutritional, and Functional Characteristics and Performance in a Rowing Task: Cross-Sectional Study	Population and focus	canoe polo players looking at rowing modality
Cardiorespiratory Fitness and Training in Quadriplegics and Paraplegics	Population and focus	paraplegics and not training measures
Changes in Skeletal and Cardiac Muscle Enzymes during the Scottish Coast to Coast Triathlon	Focus not on kayaking	primary focus on cycling and running, kayaking not well reported
Comparative analysis of cardiorespiratory fitness, bio-motor abilities, and body composition indicators among sprint kayakers of different age groups and expertise levels.	population	sprint kayakers and sprint distances measured
Comparison of High- vs. Low-Responders Following a 6-Month XC Ski-Specific Training Period: A Multidisciplinary Approach	population	cross country skiers

Excluded	Reason	Author comment
Comparison of physical capacities between nonselected and selected elite male competitive surfers for the National Junior Team.	population	surfers
Comparison of two different modes of active recovery on muscles performance after fatiguing exercise in mountain canoeist and football players	population	mountain canoes and footballers
Delaying mobility disability in people with parkinson disease using a sensorimotor agility exercise program	Population and focus	Parkinson's and health related focus
Detailed heart rate variability analysis in athletes	population	ambiguous, maybe not kayakers
Developing a Strength and Conditioning Technical Framework: An Example From a Canoe Slalom National Performance Program	Population	slalom canoeists
Development of a comprehensive performance-testing protocol for competitive surfers.	Population and focus	surfing study
Differences in lung function, bronchial hyperresponsiveness and respiratory health between elite athletes competing in different sports	focus	focus on health outcome, not performance or training
Does flow experience lead to risk? How and for whom	focus	Outcome of risk taking not training or performance
Effect of a Hamstring Flexibility Program Performed Concurrently During an Elite Canoeist Competition Season	Population	canoeists
Effect of acupoint iontophoresis on heart and lung functions in topnotch athletes	focus	looking at cardiac function, and health

Excluded	Reason	Author comment
		outcomes, not training or performance
Effect of endurance exercise on cardiac marker and exercise-induced immune response	population	cyclists
Effect of Long-Duration Adventure Races on Cardiac Damage Biomarker Release and Muscular Function in Young Athletes	Focus and population	Unclear to differentiate kayaking from other modalities, additionally focus on myocardial damage, not performance.
Effect of Low-load Resistance Training vs. High-intensity Interval Training on Local Muscle Endurance (LLSIT)	population	not clear if kayakers measured
Effect of paddle grip on segmental fluid distribution in elite slalom paddlers(	population	slalom canoeists
Effect of Paddling Cadence on Time to Exhaustion and Kinetics at the Intensity Associated With in Elite White-Water Kayakers	population	whitewater kayakers
Effect of treatment with nasal iga on the incidence of infectious disease in world-class canoeists	Focus and population	Looking at immune markers in canoeists
Effectiveness of 1% diclofenac gel in the treatment of wrist extensor tenosynovitis in long distance kayakers	focus	looking at pain reduction not training or performance
Effects of Creatine Supplementation on Muscle Strength and Optimal Individual Post-Activation Potentiation Time of the Upper Body in Canoeists	population	canoeists, not kayakers
Effects of high-intensity intermittent priming on physiology and cycling performance	population	cyclists

Excluded	Reason	Author comment
Effects of high-intensity interval training on canoeing performance	population	canoeists
Efficiency examination of a 6-month trunk prevention program among recruitment kayak-canoe athletes: A randomized control trial	focus	measures not related to kayak performance or training
Energy cost of running in similarly trained men and women	population	runners
Exergaming for Individuals with Spinal Cord Injury: A Pilot Study	population	not on kayakers. Or kayak training
 Fueguian crania and the circum-Pacific rim variation	topic	not relevant
Gender Differences in Adventure Tourists Who Practice Kayaking in Extremadura	topic	not related to kayak training, but tourism
Gender Differences in Physical Performance Characteristics of Elite Surfers.	population	surfers
Gross Efficiency and Energy Expenditure in Kayak Ergometer Exercise	Population	sprint kayakers looking at sprint factors
Ground Kayak Paddling Exercise Improves Postural Balance, Muscle Performance, and Cognitive Function in Older Adults with Mild Cognitive Impairment: A Randomized Controlled Trial	Population and focus	looking at balance improvement in cognitively impaired adults
Heart Rate Variability analysis of chronotropic response to exercise in rickshaw-pullers	population	HRV in rickshaw pullers
Haematological and iron-related parameters of male endurance and strength trained athletes	population	canoe sprinters
High Gain Compact UWB Antenna for Ground Penetrating Radar Detection and Soil Inspection	topic	caught by filers

Excluded	Reason	Author comment
High-Intensity Kayak Performance After Adaptation to Intermittent Hypoxia	Population and focus	sprint kayakers doing sprint training
How elite endurance athletes experience and manage exercise-induced pain: Implications for mental performance consultants	focus	on tools of pain management
Hydrodynamic characteristics of sea kayak traditional paddles	focus	looking at equipment characteristics
Hypoxanthine as a Predictor of Performance in Highly Trained Athletes	population	not kayaking
Hypoxic Training in Obese Patients (HYPOBESE)	population	looking at walking in obese patents
Identification and reliability of pacing strategies in outrigger canoeing ergometry.	population	outriggers
Impact of endurance exercise on the heart of cyclists: A systematic review and meta-analysis	population	cyclists
Incidence and causes of tenosynovitis of the wrist extensors in long distance paddle canoeists.	topic	no performance or training outcome
Influence of emotional intelligence on sport performance in elite canoeist	focus	focus on Emotional intelligence
Injuries and illnesses sustained during the Eco-Challenge ultra-endurance competition	Focus and population	not specifically kayakers and more on injury outcome
Intra-rater reliability, inter-rater reliability and minimal detectable change of the posterior shoulder endurance test in elite athletes	population	slalom canoeists
Investigating the Cellular and Metabolic Responses of World-Class Canoeists Training: A Sportomics Approach	population	canoeists

Excluded	Reason	Author comment
Laboratory-and field-based assessment of maximal aerobic power of elite stand-up paddle-board athletes	population	SUP not kayak
Left ventricular mass index and sports: the influence of different sports activities and arterial blood pressure.	focus	dealing with LVM in sport
Left ventricular morphology and function in endurance-trained female athletes	Focus and population	focus on morphology, inn
Maximal Strength Training Improves Surfboard Sprint and Endurance Paddling Performance in Competitive and Recreational Surfers	population	surfers
Monitoring physical performance and training load in young surf athletes	population	surfers
Mood states and performance in elite canoe polo players: The mediating role of stress	population	canoe polo players
Multi-Day Prolonged Low- to Moderate-Intensity Endurance Exercise Mimics Training Improvements in Metabolic and Oxidative Profiles Without Concurrent Chromosomal Changes in Healthy Adults	focus	health outcome
Network analysis of associations between anthropometry, physical fitness, and sport-specific performance in young canoe sprint athletes: The role of age and sex	population	sprint canoeists
Nutrition for adventure racing	Focus and population	nutrition in adventure racing

Excluded	Reason	Author comment
Occupational fitness standards for beach lifeguards. Phase 1: the physiological demands of beach lifeguarding	Focus and population	lifeguards
Optimization of load distribution of initial training sportsmen	Population	rowers
Peak aerobic power and paddling efficiency in recreational and competitive junior male surfers	Population	surfers
Performance Analysis of Surfing: A Review.	Population	surfers
Phase 1 Cardiac Rehabilitation With and Without Lower Limb Paddling Effects in Post CABG Patients	not relevant, different topic	
Physiologic Left Ventricular Cavity Dilatation in Elite Athletes	focus	LVCV in athletes, not specifically kayakers
Physiological and physical characteristics of elite dragon boat paddlers.	population	dragon boats
Physiological aspects of surfboard riding performance.	population	surfing study
Physiological effects of variations in spontaneously chosen crank rate during sub-maximal and supra-maximal upper body exercises	focus of topic	crank rate in gym, not kayaking
Plasma vitamins, amino acids, and renal function in postexercise hyperhomocysteinemia	focus	on plasma vit levels
Prediction of 200-m Sprint Kayaking Performance	focus	sprint kayakers and sprint distances measured

Excluded	Reason	Author comment
Prevalence of shoulder pain in Swedish flatwater kayakers and its relation to range of motion and scapula stability of the shoulder joint	focus	shoulder injuries in kayaking
Reduced efficiency, but increased fat oxidation, in mitochondria from human skeletal muscle after 24-h ultraendurance exercise	Focus	ultra endurance in Swedish athletes
Relative Body Weight and Standardised Brightness-Mode Ultrasound Measurement of Subcutaneous Fat in Athletes: An International Multicentre Reliability Study	topic	not relevant
Respiratory parameters in elite athletes - does sport have an influence	Focus and population	looking at breathing in multiple sports
Resting Metabolic Rate in Elite Rowers and Canoeists: Difference between Indirect Calorimetry and Prediction	Focus and population	big on kayaking and not on training
Retrospective Analysis of Training Intensity Distribution Based on Race Pace Versus Physiological Benchmarks in Highly Trained Sprint Kayakers	population	sprint kayakers
Right ventricular adaptation is associated with the Glu298Asp variant of the NOS3 gene in elite athlete	focus	genetic associations
Selected biomechanical aspects of the asymmetrical loading of the human postural system when riding the C1 speed canoe and their influence on the development of muscular imbalances	population	canoeists

Excluded	Reason	Author comment
Significance of the Velocity at $\dot{V}O_{2\max}$ and Time to Exhaustion at this Velocity	population	runners
Some predispositions for top performers in speed canoeing and their changes during the whole year training program	population	canoeists
Structural Achilles tendon properties in athletes subjected to different exercise modes and in Achilles tendon rupture patients	focus	ach tendon rupture
The Effect of a Novel Dual-Task Exercise Program for Balance, Mobility and Cognition in Community Dwelling Older Adults	population	older adults, looking at balance
The Effect of Different Cadence on Paddling Gross Efficiency and Economy in Stand-Up Paddle Boarding.	population	SUP not kayak
The effect of endurance, resistance and combination training on some inflammatory mediators in obese women	Population and focus	obese women inflam
The effect of HIIT vs. SIT on muscle oxygenation in trained sprint kayakers	Population	sprint kayakers doing sprint training
The Effect of Training in the Preparatory and Competitive Periods on Trunk Rotational Power in Canoeists, Ice-Hockey Players, and Tennis Players	Population and focus	canoeists
The effect of whole-body cryostimulation on lysosomal enzyme activity in kayakers during training	focus	looking at health outcomes
The energy cost of swimming and its determinants	population	Swimming
[The evaluation of the state of saturation of the organism with antioxidant vitamins C and E and	Population and focus	Vitamen and anti ox in athletes

Excluded	Reason	Author comment
their influence on the physical efficiency of young sportsmen].		
The importance of ST elevation in V2-4 ECG leads in athletes	focus	Heart remodeling
The relationship between joint range of motion, muscular strength, and race time for sub-elite flat water kayakers	focus	ROM in kayakers
Time-motion analysis, heart rate, and physiological characteristics of international canoe polo athletes	population	canoe polo players
Time-of-day effects on fatigue during a sustained anaerobic test in well-trained cyclists.	population	cyclists
Using a kayak paddle power-meter in the sport of whitewater slalom	population	whitewater kayakers
Validation of a Photoplethysmographic Heart Rate Monitor: Polar OH1	focus	not on kayakers
Vascular complications in high-performance athletes	focus	health outcomes
Ventilatory Muscle Endurance Training in Normal Subjects and Patients with Cystic Fibrosis	Focus and population	cystic fibrosis patents and looking at other sports
Ventilatory Threshold in Various Groups of Highly Trained Athletes	Focus and population	canoeists
Weight changes and serum sodium concentrations after an ultradistance multisport triathlon	Focus and population	hyponatremia in long distance race, not only kayak
2,3-diphosphoglycerate during exercise	population	canoeists

Excluded	Reason	Author comment
An Assessment of the Early Symptoms of Energy Deficiency as a Female Athlete Triad Risk among the Polish National Kayaking Team Using LEAF-Q.	Focus	female athlete triad symp
Dehydration rates and rehydration efficacy of water and sports drink during one hour of moderate intensity exercise in well-trained flatwater kayakers.	focus	rehydration
Effects of short-term detraining on measures of obesity and glucose tolerance in elite athletes	focus	weight gain in detraining
Effects of training on the ventilatory response to hypoxia	focus	ventelatory responses to hypoxia in athletes ves non athletes
High-Resolution Dynamics of Hemodilution After Exercise-Related Hemoconcentration	focus	haemoconcentration in trained and untrained subjects in response to training
Exercise-related hemoconcentration and hemodilution in hydrated and dehydrated athletes: An observational study of the Hungarian canoeists	focus	effects of hydration levels on haemoconcentration
Energetic cost estimation and contribution of different metabolic pathways in speed kayaking	Population and focus	primary focus on sprint kayaking
Identifying the physical and anthropometric qualities explanatory of paddling adolescents 2017 Sinclair et al.	population	surf lifesavers
Method-Induced Differences of Energy Contributions in Women's Kayaking 2018	population	sprint kayaking

Excluded	Reason	Author comment
Examination of Factors Affecting Surfski Paddler Speed	focus	not on training measures, but kayak speed
Enhanced review		
Aerobic and anaerobic metabolism in health and disease: The role of training	other	metabolism, measure of improvement from training, can't find paper
Dynamic simulation of flat-water kayaking using a coupled biomechanical-smoothed particle hydrodynamics model	other	might be relevant for monitoring
Evaluation of factors affecting sports performance among junior athletes in kayaking	other	Can't get access
Heart rate variability in athletes: relationship with central and peripheral performance	other	seems to have canoeists, not clear if they are kayak-canoeists, but also contains cc skiers
Increased platelet oxidative metabolism, blood oxidative stress and neopterin levels after ultra-endurance exercise	other	not only kayaking, but endurance measure
Psychological monitoring and modulation of training load of world-class canoeists	other	ambig if canoe/kayak
Short-term overtraining: effects on performance, circulatory responses, and heart rate variability	other	ambig if canoe/kayak

Search Database History

PUBMED

Search number	Query Sort By	Search Details Filters	Results	Time
24	(#22)	(((((("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR (("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms])) NOT "rafting"[Title]) NOT ("outrigger"[All Fields] OR "outriggers"[All Fields])) NOT "wagging"[All Fields] AND ("education"[MeSH Subheading] OR	17	8:29:07

Search number	Query Sort By Filters	Search Details	Results	Time
23	(#22) (monit oring)	"education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) (((((("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR (("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms])) NOT "rafting"[Title]) NOT ("outrigger"[All Fields] OR "outriggers"[All Fields])) NOT "wagging"[All Fields])	4	8:28:10

Search number	Query Sort By Filters	Search Details	Results	Time
		AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])		
22	(#21) NOT (waggi ng)	((("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR	36	8:26:54

Search number	Query Sort By Filters	Search Details	Results	Time
		"monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms])) NOT "rafting"[Title]) NOT ("outrigger"[All Fields] OR "outriggers"[All Fields])) NOT "wagging"[All Fields]		
21	((#20)) NOT (outrig ger)	((("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH	37	8:19:42

Search number	Query Sort By Filters	Search Details	Results	Time
		Terms))) NOT "rafting"[Title]) NOT ("outrigger"[All Fields] OR "outriggers"[All Fields])		
20	(#19) NOT (rafting [Title])	((("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR (("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms])) NOT "rafting"[Title]	42	8:18:33
19	(#18) AND (#9)	("kayaking"[Title] OR "canoeing"[Title]) AND ("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval	43	8:17:56

Search number	Query Sort By Filters	Search Details	Results	Time
		training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR (("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms])		
18	(kayaking[Title]) OR (canoeing[Title])	"kayaking"[Title] OR "canoeing"[Title]	85	8:09:49
17	(#9) AND (#16)	("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR (("education"[MeSH Subheading] OR	144	8:02:06

Search number	Query Sort By Filters	Search Details	Results	Time
		"education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms]) AND ("surfski"[Title/Abstract] OR "kayaking"[Title/Abstract] OR "canoeing"[Title/Abstract])		
16	(#14) OR (#13) OR (#12)	"surfski"[Title/Abstract] OR "kayaking"[Title/Abstract] OR "canoeing"[Title/Abstract]	325	7:59:59
15	paddli ng[Title /Abstra ct]	"paddling"[Title/Abstract]	392	7:58:27

<i>Search number</i>	<i>Query Sort By Filters</i>	<i>Search Details</i>	<i>Results</i>	<i>Time</i>
14	surfski[Title/Abstract]	"surfski"[Title/Abstract]	5	7:58:09
13	kayaki[Title/Abstract]	"kayaking"[Title/Abstract]	217	7:57:45
12	canoeing[Title/Abstract]	"canoeing"[Title/Abstract]	140	7:57:35
11	(#9) AND (#10)	("ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR ("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields])	10,418	7:56:07

Search number	Query Sort By Filters	Search Details	Results	Time
		OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms] AND ("kayaker"[All Fields] OR "kayakers"[All Fields] OR "kayaks"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "kayak"[All Fields] OR "kayaking"[All Fields] OR ("canoe"[All Fields] OR "canoes"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "canoeing"[All Fields]))		
10	(#1) OR (#2)	"kayaker"[All Fields] OR "kayakers"[All Fields] OR "kayaks"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "kayak"[All Fields] OR "kayaking"[All Fields] OR ("canoe"[All Fields] OR "canoes"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "canoeing"[All Fields]))	31,879	7:55:31
9	(#8) OR (#7) OR (#6) OR (#5) OR	"ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields] OR ("high intensity interval training"[MeSH Terms] OR "high intensity interval training"[MeSH Terms]) OR "endurance training"[MeSH Terms] OR ("education"[MeSH Subheading] OR	8,255,777	7:55:07

Search number	Query Sort By Filters	Search Details	Results	Time
	(#4)OR (#3)	"education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])) OR "4"[All Fields] OR "exercise tolerance"[MeSH Terms]		
8	ergo metr y	"ergometry"[MeSH Terms] OR "ergometry"[All Fields] OR "ergometries"[All Fields]	69,802	7:53:20
7	(High Intensity Interval Training[M eSH Terms]) OR (Sprint Interval Training[M	"high intensity interval training"[MeSH Terms]"	1,647	7:52:17

<i>Search number</i>	<i>Query Sort By Filters</i>	<i>Search Details</i>	<i>Results</i>	<i>Time</i>
	eSH Terms))			
6	Training, Endurance [MeSH Terms]	"endurance training"[MeSH Terms]	451	7:50:06
5	trainin g load monito ring	("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "load"[All Fields] AND ("monitor s"[All Fields] OR "monitorable"[All Fields] OR "monitored"[All Fields] OR "monitoring"[All Fields] OR "monitoring s"[All Fields] OR "monitoring, physiologic"[MeSH Terms] OR ("monitoring"[All Fields] AND "physiologic"[All Fields]) OR "physiologic monitoring"[All Fields] OR "monitor"[All Fields] OR "monitorings"[All Fields] OR "monitorization"[All Fields] OR "monitorize"[All Fields] OR "monitorized"[All Fields] OR "monitors"[All Fields])	2,390	7:48:25
4	Trainin g Load	("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields]) AND "Load"[All Fields]	19,343	7:46:24

<i>Search number</i>	<i>Query</i>	<i>Search Details</i>	<i>Results</i>	<i>Time</i>
	<i>Sort By</i>			
	<i>Filters</i>			
3	Tolerance, Exercise[MeSH Terms]	"exercise tolerance"[MeSH Terms]	14,092	7:45:37
2	canoeing	"canoe"[All Fields] OR "canoes"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "canoeing"[All Fields]	31,609	7:44:38
1	Kayaking	"kayaker"[All Fields] OR "kayakers"[All Fields] OR "kayaks"[All Fields] OR "water sports"[MeSH Terms] OR ("water"[All Fields] AND "sports"[All Fields]) OR "water sports"[All Fields] OR "kayak"[All Fields] OR "kayaking"[All Fields]	31,541	7:44:24

Scopus refine results values

Your query : ((((((TITLE-ABS-KEY(endurance training)) OR (TITLE-ABS-KEY(Ergometry))) OR (((TITLE-ABS-KEY(Training load monitoring) OR TITLE-ABS-KEY(Training load))) OR ((TITLE-ABS-KEY(high AND intensity AND interval AND training) OR TITLE-ABS-KEY(sprint AND interval AND training))))) AND ((TITLE(Kayaking) OR TITLE(Canoeing)))) AND NOT (TITLE-ABS-KEY(Outrigger)) AND (LIMIT-TO (LANGUAGE,"English")))

<i>NUMBER of RESULTS</i>	23
<i>DOCUMENT TYPE</i> [No of titles]	Article [19] ,Conference Paper [2] ,Review [2]
<i>DOCUMENT YEAR</i> [No of titles]	2021 [3], 2020 [1], 2017 [1], 2014 [1], 2012 [1], 2011 [1], 2010 [1], 2008 [1], 2007 [2], 2003 [2], 2002 [1], 2000 [2], 1998 [3], 1991 [1], 1989 [1], 1975 [1]

<i>AUTHOR NAME</i>	Van Someren, K.A. [3], Baker, S.J. [2], Palmer, G.S. [2], Aziz, A.R. [1],
<i>[No of titles]</i>	Ben Abderrahaman, A. [1], Binnie, M.J. [1], Borges, T.O. [1], Brunetto, A.F. [1], Bustillo-Fernandez, E. [1], Castagna, C. [1], Cermak, J. [1], Chan, K.H. [1], Chilibeck, P.D. [1], Czeczuk, A. [1], De-Oliveira, F.R. [1], Doyle, M. [1], Fernandez-Garcia, B. [1], Forbes, S.C. [1], Garbutt, G. [1], García-Pallars, J. [1], Hardy, L. [1], Hauge, C. [1], Heinen, F. [1], Herbez, R. [1], Hirai, D.M. [1], Hogan, C. [1], Holmberg, H.C. [1], Howatson, G. [1], Hsu, S.C. [1], Izquierdo, M. [1], King, N. [1], Klitgaard, K.K. [1], Kunz, P. [1], Kuta, I. [1], Le Douairon Lahaye, S. [1], Lee, M.M. [1], Lester, L. [1], Lum, D. [1], Malczewska, J. [1], Matzka, M. [1], Michael, J.S. [1], Minter, G. [1], Mitchell, A. [1], Nakamura, F.Y. [1], Okano, A.H. [1], Oliveira, A.S. [1], Oliver, J.E.R. [1], Parizkova, J. [1], Peeling, P. [1], Phillips, G.R.W. [1], Pérez-Landaluce, J. [1], Raczyńska, B. [1], Raczyński, G. [1], Robinson, B. [1], Rodríguez-Alonso, M. [1], Rooney, K. [1], Rynkiewicz, M. [1], Rynkiewicz, T. [1], Sitkowski, D. [1], Smith, R. [1], Sperlich, B. [1], Swaine, I.L. [1], Szczepańska, B. [1], Terrados, N. [1], Yang, M.T. [1], Zinner, C. [1], Zouhal, H. [1], Zurek, P. [1]

Search number	Query	Sort By	Filters	Search Details	Results	Time
7	(((training) OR (performance)) AND ((load OR measure OR metric OR quantification OR management))) AND ((marathon) OR (ultra) OR (endurance) OR ("long distance")) AND ((Kayak[Title/Abstract]) OR (kayaking[Title/Abstract]) OR (canoe[Title/Abstract]) OR (canoeing[Title/Abstract]) OR (surfski[Title/Abstract]) OR (paddling[Title/Abstract]))			("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields] OR ("perform"[All Fields] OR "performable"[All Fields] OR "performance"[All Fields] OR "performance s"[All Fields] OR "performances"[All Fields] OR "performative"[All Fields] OR "performatively"[All Fields] OR "performatives"[All Fields] OR "performativities"[All Fields] OR "performativity"[All Fields] OR "performed"[All Fields] OR "performer"[All Fields] OR "performer s"[All Fields] OR "performers"[All Fields] OR "performing"[All Fields] OR "performs"[All Fields])) AND ("load"[All Fields] OR ("measurability"[All Fields] OR "measurable"[All Fields] OR "measurably"[All Fields] OR "measure s"[All Fields] OR "measureable"[All Fields] OR "measured"[All Fields] OR "measurement"[All Fields] OR "measurement s"[All Fields] OR "measurements"[All Fields] OR "measurer"[All Fields] OR "measurers"[All Fields] OR "measuring"[All Fields] OR "measurings"[All Fields] OR "measurment"[All Fields] OR "measurments"[All Fields] OR "weights and measures"[MeSH Terms] OR ("weights"[All Fields] AND "measures"[All Fields]) OR "weights and measures"[All Fields] OR "measure"[All Fields] OR "measures"[All Fields]) OR ((("benchmarking"[MeSH Terms] OR "benchmarking"[All Fields] OR "metrics"[All Fields] OR "metric s"[All Fields] OR "metronidazole"[MeSH Terms] OR "metronidazole"[All Fields] OR "metric"[All Fields]) AND "Or"[All Fields] AND	43	03:10:00

Search number	Query	Sort By	Filters	Search Details	Results	Time
				(("quantification"[All Fields] OR "quantifications"[All Fields])) OR ("manage"[All Fields] OR "managed"[All Fields] OR "management s"[All Fields] OR "managements"[All Fields] OR "manager"[All Fields] OR "manager s"[All Fields] OR "managers"[All Fields] OR "manages"[All Fields] OR "managing"[All Fields] OR "managment"[All Fields] OR "organization and administration"[MeSH Terms] OR ("organization"[All Fields] AND "administration"[All Fields]) OR "organization and administration"[All Fields] OR "management"[All Fields] OR "disease management"[MeSH Terms] OR ("disease"[All Fields] AND "management"[All Fields]) OR "disease management"[All Fields])) AND ("marathon running"[MeSH Terms] OR ("marathon"[All Fields] AND "running"[All Fields]) OR "marathon running"[All Fields] OR "marathon"[All Fields] OR "marathons"[All Fields] OR "marathoner"[All Fields] OR "marathoners"[All Fields] OR "ultra"[All Fields] OR ("endurance"[All Fields] OR "endurances"[All Fields]) OR "long distance"[All Fields]) AND ("Kayak"[Title/Abstract] OR "kayaking"[Title/Abstract] OR "canoe"[Title/Abstract] OR "canoeing"[Title/Abstract] OR "surfski"[Title/Abstract] OR "paddling"[Title/Abstract])		
6	((((training) OR (performance)) AND ((load OR measure OR metric Or quantification OR management)))) AND ((marathon) OR (ultra) OR (endurance) OR ("long distance"))			("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields] OR ("perform"[All Fields] OR "performable"[All Fields] OR "performance"[All Fields] OR "performance s"[All Fields] OR	28,124	03:09:15

Search number	Query	Sort By	Filters	Search Details	Results	Time
				"performances"[All Fields] OR "performative"[All Fields] OR "performatively"[All Fields] OR "performatives"[All Fields] OR "performativities"[All Fields] OR "performativity"[All Fields] OR "performed"[All Fields] OR "performer"[All Fields] OR "performer s"[All Fields] OR "performers"[All Fields] OR "performing"[All Fields] OR "performs"[All Fields])) AND ("load"[All Fields] OR ("measurability"[All Fields] OR "measurable"[All Fields] OR "measurably"[All Fields] OR "measure s"[All Fields] OR "measureable"[All Fields] OR "measured"[All Fields] OR "measurement"[All Fields] OR "measurement s"[All Fields] OR "measurements"[All Fields] OR "measurer"[All Fields] OR "measurers"[All Fields] OR "measuring"[All Fields] OR "measurings"[All Fields] OR "measurment"[All Fields] OR "measurments"[All Fields] OR "weights and measures"[MeSH Terms] OR ("weights"[All Fields] AND "measures"[All Fields]) OR "weights and measures"[All Fields] OR "measure"[All Fields] OR "measures"[All Fields]) OR (("benchmarking"[MeSH Terms] OR "benchmarking"[All Fields] OR "metrics"[All Fields] OR "metric s"[All Fields] OR "metronidazole"[MeSH Terms] OR "metronidazole"[All Fields] OR "metric"[All Fields]) AND "Or"[All Fields] AND ("quantification"[All Fields] OR "quantifications"[All Fields])) OR ("manage"[All Fields] OR "managed"[All Fields] OR "management s"[All Fields] OR "managements"[All Fields] OR "manager"[All Fields] OR "manager s"[All Fields] OR "managers"[All Fields] OR "manages"[All Fields] OR "managing"[All Fields] OR "managment"[All Fields] OR "organization and		

Search number	Query	Sort By	Filters	Search Details	Results	Time
				administration"[MeSH Terms] OR ("organization"[All Fields] AND "administration"[All Fields]) OR "organization and administration"[All Fields] OR "management"[All Fields] OR "disease management"[MeSH Terms] OR ("disease"[All Fields] AND "management"[All Fields]) OR "disease management"[All Fields])) AND ("marathon running"[MeSH Terms] OR ("marathon"[All Fields] AND "running"[All Fields]) OR "marathon running"[All Fields] OR "marathon"[All Fields] OR "marathons"[All Fields] OR "marathoner"[All Fields] OR "marathoners"[All Fields] OR "ultra"[All Fields] OR ("endurance"[All Fields] OR "endurances"[All Fields]) OR "long distance"[All Fields])		
5	((training) OR (performance)) AND ((load OR measure OR metric Or quantification OR management))			("education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields] OR ("perform"[All Fields] OR "performable"[All Fields] OR "performance"[All Fields] OR "performance s"[All Fields] OR "performances"[All Fields] OR "performative"[All Fields] OR "performatively"[All Fields] OR "performatives"[All Fields] OR "performativities"[All Fields] OR "performativity"[All Fields] OR "performed"[All Fields] OR "performer"[All Fields] OR "performer s"[All Fields] OR "performers"[All Fields] OR "performing"[All Fields] OR "performs"[All Fields])) AND ("load"[All Fields] OR ("measurability"[All Fields] OR "measurable"[All Fields] OR "measurably"[All Fields] OR "measure s"[All Fields] OR "measureable"[All Fields] OR "measured"[All	2,271,280	03:08:48

Search number	Query	Sort By	Filters	Search Details	Results	Time
				Fields] OR "measurement"[All Fields] OR "measurement s"[All Fields] OR "measurements"[All Fields] OR "measurer"[All Fields] OR "measurers"[All Fields] OR "measuring"[All Fields] OR "measurings"[All Fields] OR "measurment"[All Fields] OR "measurments"[All Fields] OR "weights and measures"[MeSH Terms] OR ("weights"[All Fields] AND "measures"[All Fields]) OR "weights and measures"[All Fields] OR "measure"[All Fields] OR "measures"[All Fields]) OR ((("benchmarking"[MeSH Terms] OR "benchmarking"[All Fields] OR "metrics"[All Fields] OR "metric s"[All Fields] OR "metronidazole"[MeSH Terms] OR "metronidazole"[All Fields] OR "metric"[All Fields]) AND "Or"[All Fields] AND ("quantification"[All Fields] OR "quantifications"[All Fields])) OR ("manage"[All Fields] OR "managed"[All Fields] OR "management s"[All Fields] OR "managements"[All Fields] OR "manager"[All Fields] OR "manager s"[All Fields] OR "managers"[All Fields] OR "manages"[All Fields] OR "managing"[All Fields] OR "managment"[All Fields] OR "organization and administration"[MeSH Terms] OR ("organization"[All Fields] AND "administration"[All Fields]) OR "organization and administration"[All Fields] OR "management"[All Fields] OR "disease management"[MeSH Terms] OR ("disease"[All Fields] AND "management"[All Fields]) OR "disease management"[All Fields]))		
4	(load OR measure OR metric Or quantification OR management)			"load"[All Fields] OR ("measurability"[All Fields] OR "measurable"[All Fields] OR "measurably"[All Fields] OR "measure s"[All Fields] OR "measureable"[All Fields] OR "measured"[All Fields] OR "measurement"[All Fields] OR "measurement s"[All Fields] OR	7,924,465	03:08:31

Search number	Query	Sort By	Filters	Search Details	Results	Time
				"measurements"[All Fields] OR "measurer"[All Fields] OR "measurers"[All Fields] OR "measuring"[All Fields] OR "measurements"[All Fields] OR "measurment"[All Fields] OR "measurments"[All Fields] OR "weights and measures"[MeSH Terms] OR ("weights"[All Fields] AND "measures"[All Fields]) OR "weights and measures"[All Fields] OR "measure"[All Fields] OR "measures"[All Fields] OR ((("benchmarking"[MeSH Terms] OR "benchmarking"[All Fields] OR "metrics"[All Fields] OR "metric s"[All Fields] OR "metronidazole"[MeSH Terms] OR "metronidazole"[All Fields] OR "metric"[All Fields]) AND "Or"[All Fields] AND ("quantification"[All Fields] OR "quantifications"[All Fields])) OR ("manage"[All Fields] OR "managed"[All Fields] OR "management s"[All Fields] OR "managements"[All Fields] OR "manager"[All Fields] OR "manager s"[All Fields] OR "managers"[All Fields] OR "manages"[All Fields] OR "managing"[All Fields] OR "managment"[All Fields] OR "organization and administration"[MeSH Terms] OR ("organization"[All Fields] AND "administration"[All Fields]) OR "organization and administration"[All Fields] OR "management"[All Fields] OR "disease management"[MeSH Terms] OR ("disease"[All Fields] AND "management"[All Fields]) OR "disease management"[All Fields])		
3	(training) OR (performance)			"education"[MeSH Subheading] OR "education"[All Fields] OR "training"[All Fields] OR "education"[MeSH Terms] OR "train"[All Fields] OR "train s"[All Fields] OR "trained"[All Fields] OR "training s"[All Fields] OR "trainings"[All Fields] OR "trains"[All Fields] OR "perform"[All Fields] OR "performable"[All Fields] OR "performance"[All Fields] OR	6,452,734	03:08:14

Search number	Query	Sort By	Filters	Search Details	Results	Time
				"performance s"[All Fields] OR "performances"[All Fields] OR "performative"[All Fields] OR "performatively"[All Fields] OR "performatives"[All Fields] OR "performativities"[All Fields] OR "performativity"[All Fields] OR "performed"[All Fields] OR "performer"[All Fields] OR "performer s"[All Fields] OR "performers"[All Fields] OR "performing"[All Fields] OR "performs"[All Fields]		
2	(marathon) OR (ultra) OR (endurance) OR ("long distance")			"marathon running"[MeSH Terms] OR ("marathon"[All Fields] AND "running"[All Fields]) OR "marathon running"[All Fields] OR "marathon"[All Fields] OR "marathons"[All Fields] OR "marathoner"[All Fields] OR "marathoners"[All Fields] OR "ultra"[All Fields] OR ("endurance"[All Fields] OR "endurances"[All Fields]) OR "long distance"[All Fields]	153,777	03:07:55
1	(Kayak[Title/Abstract]) OR (kayaking[Title/Abstract]) OR (canoe[Title/Abstract]) OR (canoeing[Title/Abstract]) OR (surfski[Title/Abstract]) OR (paddling[Title/Abstract])			"Kayak"[Title/Abstract] OR "kayaking"[Title/Abstract] OR "canoe"[Title/Abstract] OR "canoeing"[Title/Abstract] OR "surfski"[Title/Abstract] OR "paddling"[Title/Abstract]	1,094	03:06:42

WEB of science search

Fri Oct 06 2023

Web of Science Search Strategy (v0.1)

Database: Web of Science Core Collection

Entitlements:

- WOS.SCI: 1962 to 2023

- WOS.AHCI: 1975 to 2023

- WOS.ESCI: 2018 to 2023

- WOS.SSCI: 1962 to 2023

Searches:

1: kayak* (All Fields) OR canoe* (All Fields) OR surfski (All Fields) OR paddle (All

Fields) Date Run: Fri Oct 06 2023 07:39:59 GMT+0200 (South Africa Standard

Time) Results: 11963

2: marathon (All Fields) AND "long distance" (All Fields) Date Run: Fri Oct 06 2023

07:41:50 GMT+0200 (South Africa Standard Time) Results: 502

3: marathon (All Fields) OR "long distance" (All Fields) OR ultra (All Fields) OR endurance (All

Fields) Date Run: Fri Oct 06 2023 07:42:29 GMT+0200 (South Africa Standard

Time) Results: 374616

4: training (All Fields) OR performance (All Fields) Date Run: Fri Oct 06 2023 07:43:03

GMT+0200 (South Africa Standard Time) Results: 1577387

5: load (All Fields) OR measure (All Fields) AND metric (All Fields) AND management (All

Fields) AND quantification (All Fields) Date Run: Fri Oct 06 2023 07:43:47 GMT+0200

(South Africa Standard Time)

Results: 1341145

Date Run: Fri Oct 06 2023 07:44:10 GMT+0200 (South Africa Standard

Date Run: Fri Oct 06 2023 07:44:22 GMT+0200 (South Africa Standard

6: #5 AND #4

Time)

7: #6 AND #3

Time)

8: #7 AND #1

Results: 49799

Results: 3034

Time)

Results: 11

Date Run: Fri Oct 06 2023 07:44:28 GMT+0200 (South Africa Standard

Cochrane libraries search

Search Name: kayaking scoping search1 Cochrane

Last Saved: 05/10/2023 19:12:00

Comment: (((Kayak[Title/Abstract]) OR (kayaking[Title/Abstract]) OR (canoe[Title/Abstract]) OR (canoeing[Title/Abstract]) OR (surfski[Title/Abstract]) OR (paddling[Title/Abstract])) AND ((marathon) OR (ultra) OR (endurance) OR ("long distance")) AND (((training) OR (performance))) AND (load OR measure OR metric Or quantification OR management)))

ID Search

#1 (kayak):ti,ab,kw OR (canoe):ti,ab,kw OR (surfski):ti,ab,kw OR (paddling):ti,ab,kw
(Word variations have been searched)

#2 (load) OR (measure) OR (metric) OR (quantification) OR (management) (Word variations have been searched)

#3 (training) OR (performance) (Word variations have been searched)

#4 (marathon) OR (Ultra) OR (endurance) OR ("long-distance") (Word variations have been searched)

#5 #3 AND #2

#6 #4 AND #5

#7 #1 AND #6

Search Name:

Date Run: 05/10/2023 19:01:49

Comment:

ID	Search	Hits
#1	(kayak):ti,ab,kw OR (canoe):ti,ab,kw OR (surfski):ti,ab,kw OR (paddling):ti,ab,kw (Word variations have been searched)	301
#2	(load) OR (measure) OR (metric) OR (quantification) OR (management) (Word variations have been searched)	720793
#3	(training) OR (performance) (Word variations have been searched)	483658
#4	(marathon) OR (Ultra) OR (endurance) OR ("long-distance") (Word variations have been searched)	21775
#5	#3 AND #2	236756
#6	#4 AND #5	8510
#7	#1 AND #6	10

EBSCOhost

#	Query	Limiters/Expanders	Last Run Via	Results
S10	S3 AND S4 AND S7	Expanders - Applyequivalent subjects Search modes -Boolean/Phrase	Interface - EBSCOhostResearch Databases Search Screen - AdvancedSearch Database - Africa- WideInformation;MEDLINE;APAPsycArticles; APA PsycInfo;APAPsycTests	16
S9	S3 AND S8	Expanders - Applyequivalent subjects Search modes -Boolean/Phrase	Interface - EBSCOhostResearch Databases Search Screen - AdvancedSearch Database	16

			- Africa- WideInformation;MEDLINE;APAPsycArticles; APA PsycInfo;APAPsycTests	
S8	S4 AND S7	Expanders - Applyequivalent subjects Search modes -Boolean/Phrase	Interface - EBSCOhostResearch Databases Search Screen - AdvancedSearch Database - Africa- WideInformation;MEDLINE;APAPsycArticles; APA PsycInfo;APAPsycTests	15,462
S7	S5 AND S6	Expanders - Applyequivalent subjects Search modes -Boolean/Phrase	Interface - EBSCOhostResearch Databases Search Screen - AdvancedSearch Database - Africa- WideInformation;MEDLINE;APAPsycArticles; APA PsycInfo;APAPsycTests	807,237
S6	load OR measure ORmetric OR manageme nt	Expanders - Applyequivalent subjects	Interface - EBSCOhostResearch Databases	5,537,996

Appendix 2

Promotional Material



WANT SOME INSIGHTS INTO YOUR TRAINING?



Are you interested in understanding how you are reacting to your training?

Would you like to know how well your training is suited to you?



What is on offer for you?

I would like to help flatwater, ocean and river kayakers **improve your training** by helping you effectively measure it. Specifically:

- Personalized training response feedback on your own training.
- Systematic monitoring of your competitive state.
- Retrospective Information on which population training characteristics are associated with performance.

What's the catch?

There are NO costs involved for you. All that is required of you is to sign up for my study. **(Drop me an email at nttnic004@myuct.ac.za)** Within the study you will join an 8-week monitoring program. Within this program your training load will be quantified and assessed. This is done by looking at a combination of Sport watch data and psychometric assessments.

Who can participate?

In order to be included, you should meet some requirements:

1. You must be 18 yrs. or older
2. You need to be completing a minimum of 3 kayaking session per week (for the 8-week monitoring period)
3. You need to have a GPS sport watch (Such as a Garmin, polar, etc) which you can use for the duration of the program.

If you are unsure about your eligibility but are interested in the program, feel free to contact. (details below)



If you are interested or want more information or
have any questions drop a mail.
nttnic004@myuct.ac.za



Appendix 3

Contact Form

Contact information

This form will contain your personal information

* Indicates required question

1. Name and surname *

2. Email *

3. Phone number *

Eligibility

4. Are you between the ages of 18 and 60 years? *

Mark only one oval.

☐ Yes

☐ No

5. Have you completed a minimum of one competitive paddling season? *

Mark only one oval.

☐ Yes

☐ No

6. Do you have the use of an approved* Global Positioning System (GPS) enabled monitoring device, with an accompanying heart rate strap? *

Mark only one oval.

☐ Yes

☐ No

7. Are you completing a minimum of 3 paddling sessions a week, or will be in study's 8-week monitoring period? *

Mark only one oval.

☐ Yes

☐ No

This content is neither created nor endorsed by Google.

Google Forms

Appendix 4

Event List

Table 17. List of events in which the participants of the study completed.

Event Name	Number of participants
<i>Pete Marlin Surfski Race</i>	13
<i>Home Time Trial</i>	10
<i>Fish River Marathon</i>	3
<i>Push and Pull</i>	2
<i>Breede River Marathon</i>	2
<i>Dubai DW Opening</i>	2
<i>Chattajack 31</i>	1
<i>Nite Race</i>	1
<i>Berg River Marathon</i>	1
<i>German Canoe marathon Championships Rheine</i>	1
<i>Baltic Sea Festival</i>	1
<i>Round Lamma Race Hong Kong 22km</i>	1

Appendix 5

Informed Consent

The Efficacy of Training Load Measures in Flatwater and Ocean Kayaking

PARTICIPANT INFORMATION SHEET AND INFORMED CONSENT FORM

Dear Volunteer,

Thank you for volunteering to be a part of this study. It will be performed by researchers at the Exercise Science and Sports Medicine division within the Department of Human Biology at the University of Cape Town.

Why are we doing this study?

Load monitoring can be used to advise training and recovery to improve performance. It is a good way of ensuring athletes are best prepared for their competitions. However, in order to be effective, the methods or markers used to measure the load must be able to monitor a sports training demands reliably. In flatwater and ocean kayaking, the nuances of the demands are not yet fully understood. Therefore, to monitor the training demands of this sport effectively, the usefulness of different measuring practices needs to be further explored.

What are the aims of this study?

This study aims to evaluate the value of practical, cost-effective, load monitoring markers or methods in marathon and ocean kayak exercise training. In the study we will attempt to assess which of these monitoring methods is good at evaluating the competition readiness of kayakers. These findings could be used to aid the monitoring of kayakers and other similar activities in the future.

Who can take part in this study?

- ☐ If you are over 18 years of age;
- ☐ If you have completed a minimum of one competitive paddling season;
- ☐ If you are taking part in one or more of the specified competitions;
- ☐ If you are completing a minimum of 3 paddling sessions a week, or will be at the time of the study;

- ☐ If you have the use of an approved (Global Positioning System) GPS enabled monitoring device; and
- ☐ Are injury free or will be at the time of the study.

What will happen if I decide to take part in this study?

The study will be explained to you, including the risks and benefits associated with taking part in this study. You will be free to share any comments or ask any questions relating to the study. Should you be satisfied and agree to participate in this study, you will be directed to do the following: Firstly, you will be directed to sign a consent form; then you will be asked to complete a questionnaire detailing demographic information, training history, sleep habits and general wellness. This should take approximately 20 minutes to complete. When you have completed the questionnaires, you will be familiarised with the short session questionnaire. Additionally, you will also be shown how to share the GPS device data from your specific device.

Following this initial consultation, and approximately eight weeks out from the agreed upon competition, you will enter the “monitoring period”. Within this eight-week period you will need to fill out a short-session questionnaire following each paddling session. Additionally, you will also be directed to share your GPS device data for the training sessions in this period. These data will be used only in this study and will not be shared or used in other studies without your explicit consent.

What are the associated risks of this study?

There are no associated risks for this study. The study is observational, therefore should not influence your training or pose any additional risk to participants.

Covid 19 precautions?

This study does not require any direct, in-person contact or interaction with participants. Therefore, with no negative impact the study and as a Covid 19 precaution, all contact, communication and data capture will be done in a virtual manner. Therefore, completing this study will not increase your ordinary risk of exposure to SARS CoV-2.

What are the benefits of this study?

There are no direct benefits from this study. However, you will receive personalised feedback regarding your training in addition to the results from the study.

What if something goes wrong?

The University of Cape Town has insurance to cover for any research-related injury or harm resulting from your participation in the study. The insurer will pay all reasonable medical expenses in accordance with the South African Good Clinical Practice Guidelines (DoH 2006). You will not be required to prove fault on the part of the University.

The University will not be liable for any loss, injuries and/or harm that you may sustain where the loss is caused by:

- ☐ The use of unauthorized medicine or substances during the study.
- ☐ Any injury that results from you not following the protocol requirements or the instructions.
- ☐ Any injury that arises from inadequate action or lack of action to deal adequately with a side effect
- ☐ An injury that results from negligence on your part.

By agreeing to participate in this study, you do not give up your right to claim compensation for injury where you can prove negligence, in separate litigation. In particular, your right to pursue such a claim in a South African court in terms of South African law must be ensured. Note, however, that you will usually be requested to accept that payment made by the University under the SA GCP guideline 4.11 is in full settlement of the claim relating to the medical expenses. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study doctor immediately of any side effects and/or injuries during the trial, whether they are research-related or other related complications.

UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while you were taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected. Copies of these guidelines are available on request.

What happens when you finish the study?

Following your participation in the study, the study results will be analysed, and used in research. Should you choose, you will be contacted by the researcher at a later date with feedback regarding your training.

What if I have any questions about the study?

Should you have any ethical concerns about the study, please contact:

Human Research Ethics Committee:

Faculty of Health Sciences - Research Ethics Committee

Floor E53- Room 46, Old Main Building, Groote Schuur Hospital, Observatory, 7925

Tel: (021) 406 6338

Fax: (021) 406 6441

Email: nosi.tywabi@uct.ac.za

Should you have any questions related to the study itself, please feel free to contact any of the investigators:

Nicholas Notten, B.Sc.(med)(Hons)

+27 83 9999 560

nttnic004@myuct.ac.za

Prof. Mike Lambert, PhD

(021) 650 4558

mike.lambert@uct.ac.za

CONSENT

I, the undersigned, have been fully informed about the University of Cape Town's study entitled **"The efficacy of training load measures in flatwater and ocean kayaking"** to be conducted by researchers from the Division of Exercise Science and Sports Medicine within the Department of Human Biology.

- I agree to complete the questionnaires detailing demographic information, training history, sleep habits and general wellness.
- I agree to share the GPS monitoring device data for the specified training period, and that it may be used for the purposes of scientific research.
- I agree to complete the short session questionnaire for the duration of the monitoring period, and that this data can be used for the purposes of Scientific research.

I have been fully informed about the risks inherent in participation in this trial. I have had the opportunity to ask questions about the study and had them answered to my satisfaction. I understand that all the information collected during the study will be treated confidentially, will only be used for scientific research purposes and that my name and personal particulars will not be released under any circumstances.

I have been informed that I will be free to withdraw from the study at any time if I so wish without explanation. I will be free to ask any questions about the procedures and results of the study. I understand that I will receive, where applicable, feedback pertaining to the general results of the study once the study has been completed.

I agree to participate in the study.

Participant:

_____	_____	_____
Full name	Signature	Date

Investigator:

_____	_____	_____
Full name	Signature	Date

Witness:

_____	_____	_____
Full name	Signature	

Appendix 6

Personal Information Form

1/18/2021

Contact information

Contact information

This form will contain your personal information

*** Required**

1. Name and surname *

2. Email *

3. Phone number

4. Participant code *

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Appendix 7

General Information Questionnaire

General Information:

* Indicates required question

1. Participant code: *

2. DOB *

Example: January 7, 2019

3. Sex *

Mark only one oval.

- ☐ Male
☐ Female

4. Height (cm) *

5. Weight (kg) *

Paddling information

General paddling questions, to confirm your eligibility. Please answer all the questions.

6. How many seasons have you been paddling competitively? *

*season ~ years

7. Within the 3 months leading up to an event, approximately how many paddling sessions a week do you complete? *

Mark only one oval.

- ☐ 1 or less
☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ 7 or more

8. Do you have access to a GPS sport watch for each training session? *

Mark only one oval.

- ☐ Yes
☐ No

9. Do you have access to a heart rate monitoring device (such as external chest strap) for each training session? *

Mark only one oval.

- ☐ Yes
☐ No

10. If yes, which monitoring GPS monitoring device do you use? *

Mark only one oval.

- ☐ Garmin
- ☐ Polar
- ☐ Tomtom
- ☐ Suunto
- ☐ I dont have one
- ☐ Other: _____

11. In which of these competitions are you entered or intending to enter? *

You may select multiple events on this list, or if your event is not listed you may write it in at the bottom. If you choose multiple events, you need to decide which will be in the monitoring period (i.e. your most "important" race).

Check all that apply.

- ☐ Pete Marlin Surfski race
- ☐ Berg River Marathon
- ☐ Breede River Marathon
- ☐ Fish River Canoe Marathon
- ☐ Scottburgh to Brighton - surfski
- ☐ Olifants River Marathon
- ☐ Push And Pull paddle
- ☐ Other: _____

12. In the case that the event(s) in which you have chosen to compete is cancelled, or you are unable to attend would you be willing to do a "virtual" surrogate event such as a 10km time trial?

NB: Your answer here is NOT a commitment, simply a gauge of willingness/interest.

Mark only one oval.

- ☐ Yes
- ☐ No

13. What would you consider is your best paddling result? Please name only the race.
please state the race (e.g. Cape Point Challenge)

14. What would you consider is your best paddling result? Please name only the year.
Please state the year of your previous choice (e.g. 2015)

15. What would you consider is your best paddling result? Please name only the
position.
please state the Position (e.g. 15)

16. Do you have any injuries or illness currently which are preventing you or could
prevent from training for the competition(s).

Mark only one oval.

☐ Yes

☐ No

Training questions

17. What is your current paddling form/fitness

Mark only one oval.

1 2 3 4 5

Not ☐ ☐ ☐ ☐ ☐ Race ready!

18. Are your sessions (when preparing for an event) structured*? Do you follow a program and/or have a coach. Please respond below.

*Do your sessions differ in type from day to day, such as intervals one day and steady/constant paddle the next.

Mark only one oval per row.

	Yes	No
Program	☐	☐
Coach	☐	☐
Structured* (ie, interval, steady, tt)	☐	☐

19. Do you currently make use of any training load monitoring to inform your own training?

Mark only one oval.

- ☐ Combination of coach and device
- ☐ Coaches advice
- ☐ Device/app advice (eg Strava suffer score or Garmin recovery advisor)
- ☐ None, or nothing that significantly influences my training

20. Do you complete a regular individual or other time trial?
for example a weekly session with timed 2k, or a 10km time trail.

Mark only one oval.

- ☐ Yes
- ☐ I Don't complete any time trial.

21. (i) If you do a set distance regular time trial, what distance do you do? Answer in kilometers.
e.g. 2 or 1.84

22. For your set distance regular time trial (i), what is your personal best result? Answer in Minutes:seconds form.
e.g. 6 minutes and 56 seconds will be written as 6:56

If you do more than one set distance time trial complete below.

23. (ii) If you do a set distance regular time trial, what distance do you do? Answer in kilometers.

24. For your set distance regular time trial (ii), what is your personal best result? Answer in Minutes:seconds form.

25. Any additional comments addressing any of the above questions?

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<https://docs.google.com/forms/d/1BVAWgWe7jyqjYtRI-mXPtnSHfb2QjZokEZgKGOXSdA0/edit>

6/7

9/19/24, 9:15 PM

General Information:

Google Forms

<https://docs.google.com/forms/d/1BVAVgWe7jyqjYtRI-mXPtnSHfb2QjZokEZgKGOXSDA0/edit>

7/7

Appendix 8

Sleep Questionnaires

Sleep Questionnaires

Horne-Ostberg "morningness-eveningness" questionnaire and the Epworth sleepiness scale.

1. Participant code

Horne-Ostberg "morningness-eveningness" questionnaire

Adapted from "Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, 4, 97–110."

2. 1. If you were entirely free to plan your day, and could wake up any time (that best suits your natural rhythm) what time would that be?

Mark only one oval.

- ☐ 06:29 or earlier
☐ 06:30 - 07:44
☐ 07:45 - 09:44
☐ 09:45 - 10:59
☐ 11:00 or later

3. 2. If you were entirely free to plan your day, and could go to sleep any time (that best suits your natural rhythm) what time would that be?

Mark only one oval.

- ☐ Before 21:00
☐ 21:00 - 22:10
☐ 22:11 - 00:29
☐ 00:30- 01:44
☐ 01:45 or Later

4. 3. When you wake up on a 'normal' day, how dependent are you on an alarm clock?

Mark only one oval.

- 1 2 3 4
Not ☐ ☐ ☐ ☐ Very dependent

5. 4. On a regular day, how easy do you find it to "get up" in the mornings?

Mark only one oval.

- 1 2 3 4
Not ☐ ☐ ☐ ☐ Very easy

6. 5. How alert do you feel in the morning in the first half-hour after you have woken up?

Mark only one oval.

- 1 2 3 4
Not ☐ ☐ ☐ ☐ Very alert

7. 6. How is your appetite in the morning in the first half-hour after you have woken up?

Mark only one oval.

	1	2	3	4	
very	☐	☐	☐	☐	very good

8. 7. How tired do you feel in the first half-hour after you have woken up in the mornings?

Mark only one oval.

	1	2	3	4	
very	☐	☐	☐	☐	very refreshed

9. 8. If you have commitments the next day, what time do you go to bed compared to your normal bed time?

Mark only one oval.

- ☐ Seldom or never later
- ☐ less than 1 hour later
- ☐ 1-2 hours later
- ☐ more than 2 hours later

10. 9. You decide engage in some physical activity on a regular basis, your friend suggests a time of 07:00-08:00. How do you think you would perform, considering only your "best sleep rhythm"?

Mark only one oval.

1 2 3 4
Wou ☐ ☐ ☐ ☐ I would find it very difficult

11. 10. At which time in the evening do you begin to feel tired as a result of needing to sleep?

Mark only one oval.

- ☐ Before 21:00
☐ 21:00 - 22:10
☐ 22:11 - 00:50
☐ 00:51- 02:00
☐ 02:01 or Later

12. 11. If you have to perform a mentally exhausting task (eg. a test) for 2 hours and you are entirely free to plan this day, which times would you be best, considering you natural sleep rhythm?

Mark only one oval.

- ☐ 08:00- 10:00
☐ 11:00 - 13:00
☐ 15:00 - 17:00
☐ 19:00- 21:00

13. 12. If you went to bed at 23:00 how tired would you be?

Mark only one oval.

	1	2	3	4	5	
not :	☐	☐	☐	☐	☐	very tired

14. 13. If you go to sleep several hours later than normal, but there is NO need to wake up at a particular time in the morning, would you...when compared to your regular wake up time?

Mark only one oval.

- ☐ Wake up my usual time, and NOT fall back asleep
- ☐ Wake up my usual time and dose thereafter
- ☐ Wake up my usual time, but fall back asleep after
- ☐ Not wake up until later than usual

15. 14. If you had to be awake for a shift from 4-6am what would you do with regard to sleep?

Mark only one oval.

- ☐ Not go to bed until AFTER the shift was over
- ☐ Nap before the shift, and sleep after
- ☐ Sleep before the shift and nap after
- ☐ Would only sleep before the shift.

16. 15. If you have to perform a Physically exhausting task (eg. a race) for 2 hours and you are entirely free to plan this day, which times would you be best, considering you natural sleep rhythm?

Mark only one oval.

- ☐ 08:00- 10:00
☐ 11:00 - 13:00
☐ 15:00 - 17:00
☐ 19:00- 21:00

17. 16. You decide engage in some physical activity on a regular basis, your friend suggests a time of 22:00-23:00. How do you think you would perform, considering only your "best sleep rhythm"?

Mark only one oval.

1 2 3 4

Wou ☐ ☐ ☐ ☐ I would find it very difficult

18. 17. Suppose you could choose your own work hours, you work consecutive hours (including breaks), which 5 hour period would you be most productive, considering your best sleep rhythm? Select the range where the start of your 5 consecutive hours would fall.

Mark only one oval.

- ☐ 16:45 - 02:44
☐ 02:45 - 07:44
☐ 07:45 - 09:44
☐ 09:45 - 13:29
☐ 13:30 - 16:44

19. 18. At what time of day do you feel you are at your peak?

Mark only one oval.

- ☐ 22:45 - 04:44
☐ 04:45 - 07:29
☐ 07:30 - 08:29
☐ 08:30 - 16:44
☐ 16:45 - 22: 44

20. 19. If you think about people as morning or evening types? Where you you consider yourself on that spectrum?

Mark only one oval.

- 1 2 3 4 5 6
 Definite "Evening type" ☐ ☐ ☐ ☐ ☐ ☐ Definite "Morning type"

Epworth Sleepiness Scale (ESS)

Adapted from "<https://epworthsleepinessscale.com/about-the-ess/>"

How likely are you to dose off or fall asleep in the following scenarios? Please select the appropriate response for each hypothetical situation.

This refers to your usual way of life in recent times. Even if you haven't done some of these things recently, try work out how they might affect you.

21. While sitting and reading?

Mark only one oval.

- ☐ Would never dose
- ☐ Slight chance of dosing
- ☐ Moderate chance of dosing
- ☐ High chance of dosing

22. While watching TV?

Mark only one oval.

- ☐ Would never dose
- ☐ Slight chance of dosing
- ☐ Moderate chance of dosing
- ☐ High chance of dosing

23. While sitting, inactive in a public space (eg theatre or meeting)?

Mark only one oval.

- ☐ Would never dose
- ☐ Slight chance of dosing
- ☐ Moderate chance of dosing
- ☐ High chance of dosing

24. As a passenger in a car for an hour without a break?

Mark only one oval.

- ☐ Would never dose
☐ Slight chance of dosing
☐ Moderate chance of dosing
☐ High chance of dosing

25. While lying down to rest in the afternoon when circumstances permit?

Mark only one oval.

- ☐ Would never dose
☐ Slight chance of dosing
☐ Moderate chance of dosing
☐ High chance of dosing

26. While sitting and talking to someone?

Mark only one oval.

- ☐ Would never dose
☐ Slight chance of dosing
☐ Moderate chance of dosing
☐ High chance of dosing

Appendix 9

Daily Analysis of Life Demands for Athletes & Orthostatic Tolerance Test.

Daily Analysis of Life Demands for Athletes [DALDA] & Orthostatic tolerance test.

Adapted from <https://fullsus.co.za/dalda-questionnaire/>

Sources of life stress, from "Rushall, Brent S. (1990). A tool for measuring stress tolerance in elite athletes. Journal of Applied Sport Psychology, 2(1), 51–66.

doi:10.1080/10413209008406420 "

* Indicates required question

PLEASE GO GET YOUR SPORT WATCH AND HR MONITOR AND PUT THEM ON BEFORE PROCEEDING WITH THIS FORM.

PLEASE ensure you have not had coffee/caffeine products in the last 30 minutes

1. Participant code *

Part A Life stressors

In the following questions please rate the current experience you are having in each of the areas, where:

1 = worse than normal, i.e., this area of your life is worse/more stressful than normal;

2 = normal, i.e., this area of my life is fairly normal, or what i am used to;

3 = Better than normal, ie this area of your life is better than normal, or you are better in it.

2. Diet?

Consider whether you are eating regularly and in adequate amounts. Are you missing meals? Do you like your meals?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

3. Home-life ?

Have you had any arguments with your parents, brothers, or sisters? Are you being asked to do too much around the house? How is your relationship with your wife/ husband? Have there been any unusual happenings at home concerning your family?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

4. School/College/Work?

Consider the amount of work that you are doing there. Are you required to do more or less at home or in your own time? How are your grades or evaluations? Think of how you are interacting with administrators, teachers, or bosses.

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

5. Friends?

Have you lost or gained any friends? Have there been any arguments or problems with your friends? Are they complimenting you more or less? Do you spend more or less time with them?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

6. Training and Exercise?

How much and how often are you training? Are the levels of effort that are required easy or hard? Are you able to recover adequately between efforts? Are you enjoying your sport?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

7. Climate ?

Is it too hot, cold, wet, or dry?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

8. Sleep?

Are you getting enough sleep? Are you getting too much? Can you sleep when you want to?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

9. Recreation?

Consider the activities that you do outside of your sport. Are they taking up too much time?
Do they compete with your application to your sport?

Mark only one oval.

1 2 3
Wor ☐ ☐ ☐ Better than normal

10. Health?

Do you have any infections, a cold, or other temporary health problems?

Mark only one oval.

1 2 3
Wor ☐ ☐ ☐ Better than normal

DALDA - part B

In the following questions please rate the current experience you are having in each of the areas relating to your paddling training, where:

1 = worse than normal, i.e., this area is worse/more stressful than normal;

2 = normal, i.e., this aspect is fairly normal, or what i am used to;

3 = Better than normal, ie this area is better than normal, or you are better in it.

11. Muscle Pains:

Do you have sore joints and/or pains in your muscles

Mark only one oval.

1 2 3
Wor ☐ ☐ ☐ Better than normal

12. Techniques:

How do your techniques seem/feel to you? Have your technical skills changed?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

13. Tiredness:

Your general stage of tiredness is...

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

14. Need for a Rest:

Do you feel that you need a rest between training sessions?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

15. Supplementary Work:

How strong do you feel when you do supplementary training (e.g. Weights, Resistance Work, Stretching)?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

16. Boredom:

How boring is training?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

17. Recover Time:

Do the recovery times between each training effort need to be longer?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

18. Irritability:

Are you irritable? Do things get on your nerves?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

19. Weight:

How is your weight?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

20. Throat:

Have you noticed your throat being sore or irritated?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

21. Internal:

How do you feel internally? Have you had constipation, upset stomachs, etc.?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

22. Unexplained Aches:

Do you have any unexplained aches or pains?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

23. Technique Power:

How do you rate the level of power you develop in your techniques?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

24. Enough Sleep:

Are you getting enough sleep?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

25. Between sessions recover:

Are you tired before you start your second training sessions of the day?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

26. General Weakness:

Do you feel weak all over?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

27. Interest:

Do you feel that you are maintaining your interests in your sport?

Mark only one oval.

1 2 3

Wor ☐ ☐ ☐ Better than normal

28. Arguments:

Are you having squabbles and arguments with people?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

29. Skin Rashes:

Do you have any unexplained skin rashes or irritations?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

30. Congestion:

Are you experiencing congestion in the nose and/or sinuses?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

31. Training Effort:

Do you feel that you can give your best effort at training?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

32. Temper:

Do you lose your temper?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

33. Swellings:

Do you have any lymph gland swellings under your arms, below your ears in your groin, etc.?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

34. Likability:

Do people seem to like you?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

35. Running Nose:

Do you have a running nose?

Mark only one oval.

1 2 3

Wor ☐ : ☐ : ☐ Better than normal

Orthostatic tolerance test

This is a test of your orthostatic (or standing) tolerance, it can be interpreted to give an indication of your current level of stress.

Before you continue with this test you must have been seated for a minimum of 5 minutes, if not, please wait until 5 minutes has passed before continuing. This step is extremely important for the test to give a worthwhile result.

Please conduct the test as follows.

In the **seated** position (after sitting 5 mins):

1. **Turn on** the sport watch and ensure it is **ready to record**. If you have multiple sports modes, select the mode on your sport watch you normally use for paddling.
2. Ensure your watch is **detecting your heart rate**
3. **Start the watch** and let the timer run for **2 minutes** while **seated, at rest** not moving.
4. **At 2 minutes stand up abruptly** and hit the **LAP function** on your watch.

In the **standing** position:

5. Let the timer **run for 2 minutes standing still**, after standing abruptly.
6. After the 2 minutes, **select STOP** and **save the activity** on your sport watch.

36. Have you completed the test?

Mark only one oval.

- ☐ Yes
- ☐ No

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Appendix 10

ACSM Risk Screening Questionnaire

ACSM Risk screening

Adapted from "Balady et al. (1998). AHA/ACSM Joint Statement: Recommendations for Cardiovascular Screening, Staffing, and Emergency Policies at Health/Fitness Facilities. *Medicine & Science in Sports & Exercise*, 30(6). (Also in: ACSM's Guidelines for Exercise Testing and Prescription, 7th Edition, 2005."

*** Required**

History, Symptoms and other health issues

If you marked "yes" on any of the statements in this section, consult your physician or other appropriate healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

1. Have you ever had any of the following? *

Please indicate yes or no.

Mark only one oval per row.

	Yes	No
A heart attack	☐	☐
Heart surgery	☐	☐
Cardiac catheterization	☐	☐
Coronary angioplasty (PTCA)	☐	☐
Heart valve disease	☐	☐
Heart Failure	☐	☐
Heart transplantation	☐	☐
Congenital heart disease	☐	☐
Pacemaker/rhythm disturbance	☐	☐
Implantable cardiac defibrillator	☐	☐

2. Have you experienced any of the following symptoms? *

Mark only one oval per row.

	Yes	No
Chest discomfort with exertion	☐	☐
Unreasonable breathlessness	☐	☐
Dizziness, fainting, blackouts	☐	☐
You take heart medication	☐	☐

3. Do you have any of these conditions? *

Mark only one oval per row.

	Yes	No
Diabetes	☐	☐
Asthma or Lung disease	☐	☐
Burning/cramping in legs on short walks	☐	☐
musculoskeletal problems limiting activity	☐	☐
Concerns about the safety of exercise	☐	☐
Take prescription medication(s).	☐	☐
(females only) Are you pregnant?	☐	☐

ACSM Risk screening

Cardiovascular risk factors - If you marked "yes" on two or more of the statements in this section, you should consult your physician or other appropriate healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified exercise staff to guide your exercise program.

4. Please indicate yes or no if the following apply to you. *

Mark only one oval per row.

	Yes	No
Are you a man over 45 yrs	☐	☐
Are you a women over 55yrs	☐	☐
Postmenopausal/had a hysterectomy	☐	☐
Are you a smoker/quite < 6 months ago	☐	☐
Have BP > 140/90	☐	☐
Don't know your BP	☐	☐
Take BP medication	☐	☐
Blood cholesterol level is >200 mg/dL	☐	☐
Don't know Blood cholesterol	☐	☐
Have a close blood relative who had a heart attack younger than 55 (male) or younger than 65 (female)	☐	☐
You are physically inactive	☐	☐
You are more than 10kg overweight	☐	☐

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Appendix 11

Participant Enhanced Reviews & Exclusions

The participants in Table 18 were excluded because they failed to meet the inclusion criteria outlined in Appendix 3. These participants never received participant identity codes.

Table 18. Participants who were ineligible for the study after they failed the initial screening.

<i>Excluded Participant</i>	<i>Reason</i>
<i>Ex01</i>	Age 61, outside inclusion range
<i>Ex02</i>	Age 64, outside inclusion range
<i>Ex03</i>	Age 69, outside inclusion range
<i>Ex04</i>	Age 65, outside inclusion range
<i>Ex05</i>	Age 61, outside inclusion range
<i>Ex06</i>	Age 61 outside inclusion range
<i>Ex07</i>	Age 17, outside inclusion range
<i>Ex08</i>	Age 64, outside inclusion range
<i>Ex09</i>	Age 69, outside inclusion range
<i>Ex10</i>	Age 61, outside inclusion range
<i>Ex11</i>	Age 65, outside inclusion range
<i>Ex12</i>	Age 15, outside inclusion range

The participants who passed the initial screening were given a participant code, which was a unique identifying number. They were then supposed to start the onboarding process. However, some participants became ineligible after failing to provide the necessary information. Table 19 contains the participants who were excluded with reasons or opted to withdraw. This led to their exclusion from the study. The reasons for these exclusions were:

- **No informed consent returned:** when participants failed to return a signed informed consent form

- **No data received:** where participants following the initial contact form did not complete other information necessary to be a part of the study
- **No monitoring device:** Participants did not have a suitable monitoring device for the duration of the study as defined by Appendix 15

Some of the participants who initially agreed to take part in the study during the recruitment phase were later excluded because they did not meet the requirements outlined at the beginning. Table 19 lists these participants. The reasons are listed and expanded below:

- **Data Incomplete:** The participants did not complete the necessary SSQ or DALDA questionnaires and were excluded.
- **Withdrawn:** Participants could withdraw from the study at any time without explanation. These participants withdrew at various points throughout the study, either formally or by simply not continuing with the study's requirements.

The final group of participants was excluded after the researchers completed a special review of all the remaining participant's data. The participants whose data was included had to meet specific requirements. The primary concern with the excluded participants was that data from the GPS sports watch did not match the data from SSQ responses where this data should have overlapped and should be identical. Another concern was that supraphysiological heart rate data, which was likely the result of measurement error

The special review conditions are as follows: (I) The GPS sports watch duration should have correlations with the SSQ duration exceeding 0.85; (II) The average heart rate of a session should be greater than 50% of the individual's maximum heart rate; and (III) Heart rate or GPS speed values which were supraphysiological for kayaking

Table 19. Participants excluded from the study, with reasons, following the initial recruitment phase.

<i>Participant</i>	<i>Primary reason for exclusion</i>	<i>Participant</i>	<i>Primary reason for exclusion</i>
2	No data received	50	No data received
10	Withdrawn	51	No informed consent returned
13	Withdrawn	52	Withdrawn
16	Withdrawn	53	Withdrawn
19	Withdrawn	54	Withdrawn
21	Withdrawn	55	Withdrawn
22	Withdrawn	57	Withdrawn
23	Withdrawn	59	Withdrawn
26	Withdrawn	61	No Monitoring device
27	Data Incomplete	62	No Monitoring device
28	Withdrawn	65	Withdrawn
30	Withdrawn	68	No informed consent returned
31	Withdrawn	70	Withdrawn
36	Data Incomplete	71	Withdrawn
40	Withdrawn	74	Withdrawn
43	Data Incomplete	76	No informed consent returned
48	Withdrawn	79	Withdrawn
49	Data Incomplete		

Table 20 contains the participants with outcomes of interest following the special review. Where the data was considered unreliable, all the heart rate data for that participant was removed. The participant then did not appear in the results, which was dependent on heart rate data.

- **Data invalid:** The participant's SSQ or DALDA data did not agree with GPS sport watch data by violating conditions (I) or (II) of the *Special Review*.
- **Data inconsistency resolved:** Participants' supraphysiological data (Special Review, III) and other data from the same sensors were deleted, and unaffected data were kept.

Table 20. Results of the special review for participants with flagged data anomalies

<i>Participant</i>	<i>Result of Special Review</i>	<i>Reason</i>
20	Excluded, Data invalid	GPS data corrupted/incomplete
38	Excluded, Data invalid	GPS data corrupted/incomplete
41	Excluded, Data invalid	GPS data corrupted/incomplete
69	Excluded, Data invalid	SSQ data corrupted/incomplete
56	Excluded, Data invalid	SSQ data Incomplete
33	Included	Data inconsistency resolved
42	Included	Data inconsistency resolved
47	Included	Data inconsistency resolved

Appendix 12

Sample Size Calculation

The sample size calculation was done to achieve an alpha level of 0.05 and a power of 80% from a single sample (kayakers) with a continuous outcome (time-trial time). The anecdotal results from a local squad of paddlers completing regular two-kilometre time trials were used (249).

When completing the calculation, it was established that to detect a difference of 28 seconds between the first- and the last-time trial attempts (i.e., μ_1 and μ_2) with a standard deviation of 60 seconds between random samples this equates to an effect size of 0.47, a sample of at least 36 kayakers would be needed. The calculations are shown below.

Formula to calculate effect size (ES):

$$ES = \frac{|\mu_1 - \mu_0|}{\sigma}$$

Calculation:

$$ES = \frac{468s - 440s}{60s} = 0.47$$

Formula to calculate sample size (n):

$$n = \left(\frac{Z_{1-\alpha/2} + Z_{1-\beta}}{ES} \right)^2$$

Calculation:

$$n = \left(\frac{1.96 + 0.84}{0.47} \right)^2 = 36$$

Appendix 13

Ethics Approval Confirmation

HREC REF Number 160/2021



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room G50- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

24 March 2021

HREC REF: 160/2021

Prof M Lambert

Exercise and Sports Science Medicine
Newlands
Email: mike.lambert@uct.ac.za
Student: nittnic004@myuct.ac.za

Dear Prof Lambert

PROJECT TITLE: THE EFFICACY OF TRAINING LOAD MEASURES IN FLATWATER, OCEAN AND RIVER MARATHON KAYAKING- MASTERS CANDIDATE-MR NICHOLAS NOTTEN

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study, subject to: -

1. In Annexure 12, stating upfront that this is a study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020 & 06 July 2020.

Approval is granted for one year until the 30 March 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Mr Nicholas Notten will also be involved in this study.

Please quote the HREC REF 160/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

HREC/REF 160/2021sa

Yours sincerely



PROFESSOR M BLOCKMAN

CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.

Institutional Review Board (IRB) number: IRB00001938

NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

HREC/REF 160/2021sa

Appendix 14

Short Session Questionnaire

Short Session Questionnaire

Subjective training load

* Indicates required question

1. Participant code *

E.g. CON003

2. What activity did you do? *

Mark only one oval.

- ☐ Paddle Skip to question 9
- ☐ Other cardio Skip to question 19
- ☐ Strength/ Resistance Skip to question 23
- ☐ No activity

You can skip to the next section if you have already completed this form today (just scroll to bottom and select "next").

3. Did you feel energetic today?

Mark only one oval.

- 1 2 3 4 5
- Very ☐ ☐ ☐ ☐ ☐ Extremely energetic

4. How recovered did you feel from previous session(s)?

Mark only one oval.

	1	2	3	4	5	
Not	☐	☐	☐	☐	☐	Fully

5. Muscle soreness/stiffness?

Mark only one oval.

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	No soreness

6. How well did you sleep last night?

Mark only one oval.

	1	2	3	4	5	
Poo	☐	☐	☐	☐	☐	Excellent

7. How good is your appetite today?

Mark only one oval.

	1	2	3	4	5	
Poo	☐	☐	☐	☐	☐	Very good

8. Comments (not compulsory)

If you are feeling sick please make a note that here. Just write "Sick" any other comments about your day.

Paddling

Tell me more about this paddle...

9. Session Type: *

Chose the most appropriate option for your session. If not applicable leave blank.

Mark only one oval.

- ☐ Easy cruise
- ☐ Steady/constant effort
- ☐ Intervals
- ☐ Time Trial or Race
- ☐ Sprints with long rest
- ☐ Other: _____

10. What was the total time of your session from start to finish? *

The total time in minutes. e.g. 1:20 session must be written as 80

11. How hard did you go? *

Rest	Really Easy	Easy	Moderate	Sort of Hard	Hard		Really Hard		Really, Really Hard	Just like my hardest race
0	1	2	3	4	5	6	7	8	9	10

Mark only one oval.

1 2 3 4 5 6 7 8 9 10

Real ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Just like my hardest race

12. What time of day did the session start? *

Example: 8:30 AM

13. What did you paddle? *

Mark only one oval.

- ☐ Spec ski
- ☐ LD ski
- ☐ LD Ski SS2
- ☐ River K1
- ☐ River K2
- ☐ Marathon K1
- ☐ Marathon K2
- ☐ Sprint K1
- ☐ Sprint K2

14. Where did you paddle? *

Mark only one oval.

- ☐ Flatwater
☐ Sea
☐ River

15. How much do you think environmental conditions affected this session? (i.e. wind, * tides, weed, etc.)

Mark only one oval.

- 1 2 3 4 5
Not ☐ ☐ ☐ ☐ ☐ Very much

16. (You may leave this blank) if applicable, check the factor(s) which significantly affected your session.

Check all that apply.

- ☐ Wind
☐ Kelp/weed or other obstacles
☐ Low water level
☐ Tides/currents
☐ Cold temperatures
☐ Hot temperatures
☐ Light levels (i.e. too dark to see)
☐ Other: _____

17. Has the the session recorded on your GPS sport watch? *

Mark only one oval.

- ☐ Yes
☐ No

18. Did you complete a Time trail for recording or a race? *

Mark only one oval.

- ☐ Yes *Skip to question 27*
☐ No

Cardio

Tell me more about this session...

19. Session Type: *

If not applicable leave for your activity blank

Mark only one oval.

- ☐ Easy
☐ Steady/constant effort
☐ Intervals
☐ Time Trial
☐ Race

20. How long was the session? *

The total time in minutes. e.g. 1:20 session must be written as 80

21. How hard did you go? *

Rest	Really Easy	Easy	Moderate	Sort of Hard	Hard		Really Hard		Really, Really Hard	Just like my hardest race
0	1	2	3	4	5	6	7	8	9	10

Mark only one oval.

1 2 3 4 5 6 7 8 9 10

Real ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Just like my hardest race

22. What time of day did the session start? *

Example: 8:30 AM

Resistance

Tell me more about this session...

23. Session Type (gym): *

What best describes the majority of your session

Mark only one oval.

- ☐ Body weight or plyometric session.
- ☐ Weight lifting gym
- ☐ Other: _____

24. How long was the session? *

The total time in minutes. e.g. 1:20 session must be written as 80

25. How hard did you go? *

Rest	Really Easy	Easy	Moderate	Sort of Hard	Hard		Really Hard		Really, Really Hard	Just like my hardest race
0	1	2	3	4	5	6	7	8	9	10

Mark only one oval.

1 2 3 4 5 6 7 8 9 10

Real ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Just like my hardest race

26. What time of day did the session start? *

Example: 8:30 AM

Time Trial /race

27. Did you complete a race or a TT? *

Mark only one oval.

☐ Race

☐ TT

28. How far was the race or TT (in Kilometers) *

29. What was your time? *

Please write in the form minutes:seconds eg 7:32

30. How hard did you go? *

Rest	Really Easy	Easy	Moderate	Sort of Hard	Hard		Really Hard		Really, Really Hard	Just like my hardest race
0	1	2	3	4	5	6	7	8	9	10

Mark only one oval.

1 2 3 4 5 6 7 8 9 10

Real ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Just like my hardest race

31. Rate your form (i.e. How good was this attempt for you?)

Mark only one oval.

1 2 3 4 5

Very ☐ ☐ ☐ ☐ ☐ Excellent

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Appendix 15

Sports Watches

Approved devices are the GPS sport watches from the following vendors:

Garmin, Polar, TomTom, Suunto, Fitbit, Sigma, Crane, Decathlon, Epson, Runtastic, ARival, Timex and adidas.

The watch a participant uses from these vendors will need to be primarily a GPS sports watch, as opposed to simply a smartwatch or activity tracker as defined in category D2 in the abstract of Table 2 from *Accuracy and Adoption of Wearable Technology Used by Active Citizens: A Marathon Event Field Study* (Figure 32) (1).

Table 2. Device categories, vendors, models, and apps used by runners. Only vendors, devices, and apps with ≥ 5 occurrences collected with Q₁ are listed. Values in curved brackets represent the number of mentions for the respective category, vendor, device, or app.

Category	Vendors	Devices
D ₁ : Mobile phone and app (181)	Apple (80), Samsung (65), Sony (11)	iPhone 6 (22), iPhone 5s (19), iPhone 5 (12), iPhone (11), Galaxy S5 (11), Galaxy S4 (10), iPhone 6s (9), Galaxy S4 mini (8), Galaxy S3 (7), Samsung: other (7) Apps: Runtastic (126), Runkeeper (10), Nike+ Running (9), Endomondo (7), Sports Tracker (6), Strava (6)
D ₂ : GPS sport watch (437)	Garmin (193), Polar (165), TomTom (38), Suunto (18)	M400 (60), Garmin: other (41), V800 (31), Polar: other (31), Forerunner 305 (22), Forerunner 310XT (19), TomTom: other (16), Forerunner 920XT (13), Forerunner 610 (12), Runner Cardio (11), RS300X (10), Ambit 3 Peak (10), Fenix 3 (10), Forerunner 210 HR (9), RC3 (9), RS800CX (9), RCX5 (8), Garmin: other Forerunners (8), RCX3 (7), Forerunner 910XT HR (7), Forerunner 235 WHR (7), Forerunner 205 (6), Forerunner 220 (6), vivoactive (6), Forerunner 110 HR (5), other GPS-enabled sport watch (5)
D ₃ : Heart rate monitor (37)	Polar (27)	Polar heart rate monitor: other (8), heart rate monitor: other (7), A300 (6)
D ₄ : Smart watch (14)	Apple (12)	Apple Watch (12)
D ₅ : Wristband activity tracker (27)	Garmin (11), Polar (8)	Loop (6), vivofit (5), vivosmart HR (5)
D ₆ : Other devices (47)	No specific vendor (36)	Stopwatch (25), watch (6)

Figure 32. Table extract from “Accuracy and Adoption of Wearable Technology Used by Active Citizens: A Marathon Event Field Study”, which focused on the accuracy of different devices.

These watches were tested and investigated for accuracy in a study on the Trollinger-Marathon, an annual running event in Heilbronn, southern Germany (1). They found a Mean

absolute error of 0.12km for the half-marathon (21.31km) and full-marathon (41.61km) distances. The study concluded that these GPS-enabled sports watches were accurate for recorded course distances.

Another study performed on the 2017 Two Oceans Marathon, a 56 km road race in Cape Town, South Africa, concluded that GPS sports watches are a valid and feasible method for sports

scientists and coaches to measure performance and track training load if the associated error with each brand is considered (2). This is followed by testing various models from different manufacturers, including Garmin, Polar, Suunto and TomTom.

For the purposes of this study, the participants will need to use chest heart rate straps. This is due to concerns about the accuracy of wrist-based optical sensors (3). Therefore, the devices will need to have accompanying heart rate chest straps.

Other devices may be considered only if their accuracy can be verified.

References

1. Pobiruchin M, Suleder J, Zowalla R, Wiesner M. Accuracy and Adoption of Wearable Technology Used by Active Citizens: A Marathon Event Field Study. JMIR MHealth UHealth [Internet]. 2017 Feb 28 [cited 2020 Dec 13];5(2). Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5350460/>
2. Johansson RE, Adolph ST, Swart J, Lambert MI. Accuracy of GPS sport watches in measuring distance in an ultramarathon running race. Int J Sports Sci Coach. 2020;15(2):212–9.
3. Chow HW, Yang CC. Accuracy of Optical Heart Rate Sensing Technology in Wearable Fitness Trackers for Young and Older Adults: Validation and Comparison Study. JMIR MHealth UHealth. 2020 Apr 28;8(4):e14707.

Appendix 16

Time Trial Procedure & Water Condition Mitigation

Participants were to perform time trials during the study.

Participants should choose a stretch that is as isolated from wind or current to the extent that it is reasonably possible. The stretch should be familiar, not requiring the participant to learn a specific path. The route and distance should be the same for each TT attempt.

Figure 33 depicts a circular or out-and-back TT course. These are ideal when there is a variable prevailing wind or current condition. The circular nature of the course allows it to mitigate the environmental impact on the time trial by cancelling out effects based on a set direction of current or wind, which would benefit or worsen another attempt occurring in a straight line. This makes the effort more reproducible during multiple attempts.

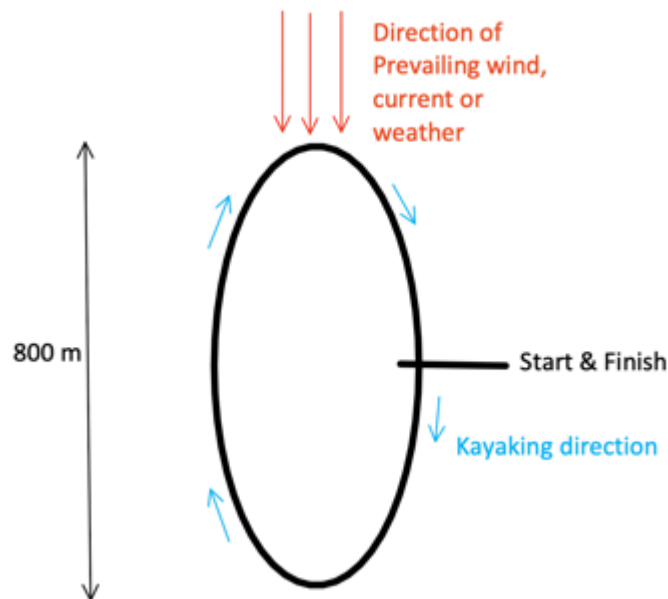


Figure 33. A schematic of a potential TT course which mitigates the potential influence of water conditions arising from wind or current.

Appendix 17

Rusko Orthostatic Test Protocol

The following are the specific instructions which were given to the participants.

Please conduct the test as follows:

In the **seated** position (after sitting for 5 mins):

1. **Turn on** the sports watch and ensure it is **ready to record**. If your sports watch has multiple sports modes, select the mode you normally use for paddling.
2. Ensure your watch is **detecting your heart rate**.
3. **Start the watch** and let the timer run for **2 minutes** while **seated, at rest**, and not moving.
4. At **2 minutes, stand up abruptly** and **hit the LAP function** on your watch.

In the **standing** position:

5. Let the timer **run for 2 minutes, standing still** after standing abruptly.
6. After the 2 minutes, **select STOP and save the activity** on your sports watch.

Appendix 18

Bulk Data Export

1. Signing up for a Strava Account:

You will need to go to the following web address: [Strava | Run and Cycling Tracking on the Social Network for Athletes](#) you can then choose an option to sign up with Strava.

2. Linking your device data with Strava:

Once you have signed up for Strava, you will be prompted to connect it to your device vendors portal. You can link multiple devices if you choose. If you are not prompted to add a device go to [Strava](#) to see how to link your specific device. Please ensure you **allow Strava to access your heart rate data**.

3. Bulk export your items from Strava.

[Exporting your Data and Bulk Export – Strava Support](#))

1. Log into the account on Strava.com from which you wish to bulk export data.
2. Hover over your name in the upper right-hand corner of the Strava page. Choose "Settings," then find the "[My Account](#)" tab from the menu listed on the Left.
3. Select "Get Started" under "Download or Delete Your Account."
4. Select "Request your archive" on the next page. (Option 2)
5. You will receive an email with a link to download your data (this may take a few hours.) For this reason, it's important that you have access to the email account attached to your Strava profile.
 1. If you need to change your email, see [here](#).
 2. If you signed up via Facebook, the email address is the same as the one linked to your Facebook account.

Your data archive will include the following:

- A zipped folder with all of your activities in their original file format.
- A folder with all the photos you've uploaded to Strava.
- A folder with all of the routes you've created in GPX format.
- CSV files that include the following
 - All the posts and comments you've posted.
 - Contacts you've synced to Strava.
 - Clubs and events, you've created
 - The information in your profile including your gear and goals.
 - Your current settings.
 - Actions you've performed including kudos given and routes or segments you've starred.
 - All of your Relative Effort data.
 - Athletes you follow and those athletes who are following you as of the date of download.
 - All of your session logs and device information.
 - The type of information that we shared with our service providers during the past 12 months.

4. Delete your account (optional)

If you do not wish to keep your account, you may delete the account. This will remove all of your data from Strava.

1. Log into the account on Strava.com from which you wish to delete.
2. Hover over your name in the upper right-hand corner of the Strava page. Choose "Settings," then find the ["My Account"](#) tab from the menu listed on the Left.
3. Select "Get Started" under "Download or Delete Your Account."
4. Select "delete account" on the next page. (Option 3)

Appendix 19

Upload Form

Upload form

Please upload the zip version of this folder if possible.

1. Participant code

2. What are you uploading

Mark only one oval.

- ☐ Bulk strava export
- ☐ Activity files from your device vendors portal (e.g. Garmin connect, etc)

3. Upload the file here

Files submitted:

4. If you would like to share the link to the file (if you chose the bulk export option, you may simply copy paste the link in the answer box.

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Appendix 20

Python Script

The script contained in Figure 34, Figure 36 and Figure 35 was obtained from <https://github.com/dtcooper/python-fitparse#egg=python-fitparse> and modified to suit the data collection needs of this study. The Python script was hosted in Jupyter Notebook version 6.1.4, a server-client application for editing and running notebook documents via a web browser. The script converted Flexible and Interoperable Data Transfer (FIT) file format from sports watches used for GPS tracks and routes into comma-separated values (CSV) files that can be opened and edited further in Excel.

The script functioned to capture the following data fields from a FIT file into a CSV format.

- timestamp
- position_lat
- position_long
- distance
- enhanced_altitude
- altitude
- enhanced_speed
- speed
- heart_rate
- cadence
- fractional_cadence
- temperature

The output from this document went into multiple separate .csv files, which were merged into a large file using the command terminal command:

The terminal was opened, and each line was typed and followed by the enter key:

```
pwd
```

```
cd /users/ /Desktop/CSVmergecopy/combined100
```

```
cat *.csv>combined.csv
```

This creates a merged .csv of all .csv files from the Python script (Figure 34). These can then be further processed by the Macros from Appendix 21.



```

In [4]: import csv
import os
#to install fitparse, run
#sudo pip3 install -e git+https://github.com/dtcooper/python-fitparse#egg=python-fitpar
import fitparse
import pytz
from copy import copy

#for general tracks
allowed_fields = ['timestamp', 'position_lat', 'position_long', 'distance',
'enhanced_altitude', 'altitude', 'enhanced_speed',
'speed', 'heart_rate', 'cadence', 'fractional_cadence',
'temperature']
required_fields = ['timestamp']

#for laps
lap_fields = ['timestamp', 'start_time', 'start_position_lat', 'start_position_long',
'end_position_lat', 'end_position_long', 'total_elapsed_time', 'total_time',
'total_distance', 'total_strides', 'total_calories', 'enhanced_avg_speed',
'enhanced_max_speed', 'max_speed', 'total_ascent', 'total_descent',
'event', 'event_type', 'avg_heart_rate', 'max_heart_rate',
'avg_running_cadence', 'max_running_cadence',
'lap_trigger', 'sub_sport', 'avg_fractional_cadence', 'max_fractional_caden',
'total_fractional_cycles', 'avg_vertical_oscillation', 'avg_temperature',
#last field above manually generated
lap_required_fields = ['timestamp', 'start_time', 'lap_trigger']

#start/stop events
start_fields = ['timestamp', 'timer_trigger', 'event', 'event_type', 'event_group']
start_required_fields = copy(start_fields)
#
all_allowed_fields = set(allowed_fields + lap_fields + start_fields)

UTC = pytz.UTC
CST = pytz.timezone('US/Central')

#files beyond the main file are assumed to be created, as the log will be updated only
ALT_FILENAME = True
ALT_LOG = 'file_log.log'

def read_log():
    with open(ALT_LOG, 'r') as f:
        lines = f.read().split()
    return lines

def append_log(filename):
    with open(ALT_LOG, 'a') as f:
        f.write(filename)
        f.write('\n')
    return None

def main():
    files = os.listdir()
    fit_files = [file for file in files if file[-4:].lower()=='fit']
    if ALT_FILENAME:
        if not os.path.exists(ALT_LOG):
            os.system('touch %s' % ALT_FILENAME)
            file_list = []
        else:
            file_list = read_log()
    for file in fit_files:
        if ALT_FILENAME:
            if file in file_list:
                continue
            new_filename = file[:-4] + '.csv'
            if os.path.exists(new_filename) and not ALT_FILENAME:
                #print('%s already exists. skipping.' % new_filename)
                continue
            fitfile = fitparse.FitFile(file,
                data_processor=fitparse.StandardUnitsDataProcessor())

```

Figure 34. Page one (line 1 – 74) of a Python script hosted in Jupyter Notebook, which was used to convert the Flexible and Interoperable Data Transfer (FIT) training session data files to a comma-separated value (CSV) format file, compatible with Excel.

```

def main():
    files = os.listdir()
    fit_files = [file for file in files if file[-4:].lower()=='fit']
    if ALT_FILENAME:
        if not os.path.exists(ALT_LOG):
            os.system('touch %s' % ALT_FILENAME)
            file_list = []
        else:
            file_list = read_log()
    for file in fit_files:
        if ALT_FILENAME:
            if file in file_list:
                continue
            new_filename = file[:-4] + '.csv'
            if os.path.exists(new_filename) and not ALT_FILENAME:
                #print('%s already exists. skipping.' % new_filename)
                continue
            fitfile = fitparse.FitFile(file,
                data_processor=fitparse.StandardUnitsDataProcessor())

            print('converting %s' % file)
            write_fitfile_to_csv(fitfile, new_filename, file)
    print('finished conversions')

def lap_filename(output_filename):
    return output_filename[:-4] + '_laps.csv'

def start_filename(output_filename):
    return output_filename[:-4] + '_starts.csv'

def get_timestamp(messages):
    for m in messages:
        fields = m.fields
        for f in fields:
            if f.name == 'timestamp':
                return f.value
    return None

def get_event_type(messages):
    for m in messages:
        fields = m.fields
        for f in fields:
            if f.name == 'sport':
                return f.value
    return None

def write_fitfile_to_csv(fitfile, output_file='test_output.csv', original_filename=None):
    messages = fitfile.messages
    data = []
    lap_data = []
    start_data = []
    if ALT_FILENAME:
        #this should probably work, but it's possibly
        #based on a certain version of the file/device
        timestamp = get_timestamp(messages)
        event_type = get_event_type(messages)
        if event_type is None:
            event_type = 'other'
        output_file = event_type + '_' + timestamp.strftime('%Y-%m-%d_%H-%M-%S.csv')
    for m in messages:
        skip=False
        skip_lap = False
        skip_start = False
        if not hasattr(m, 'fields'):
            continue
        fields = m.fields
        #check for important data types
        mdata = {}
        for field in fields:
            if field.name in all_allowed_fields:
                if field.name=='timestamp':
                    mdata[field.name] = UTC.localize(field.value).astimezone(CST)

```

Figure 35. Page two (lines 54-110) of a Python script hosted in Jupyter Notebook, which was used to convert the Flexible and Interoperable Data Transfer (FIT) training session data files to a comma-separated value (.csv) format file, compatible with Excel.

```

def write_fitfile_to_csv(fitfile, output_file='test_output.csv', original_filename=None):
    messages = fitfile.messages
    data = []
    lap_data = []
    start_data = []
    if ALT_FILENAME:
        #this should probably work, but it's possibly
        #based on a certain version of the file/device
        timestamp = get_timestamp(messages)
        event_type = get_event_type(messages)
        if event_type is None:
            event_type = 'other'
        output_file = event_type + '_' + timestamp.strftime('%Y-%m-%d_%H-%M-%S.csv')
    for m in messages:
        skip=False
        skip_lap = False
        skip_start = False
        if not hasattr(m, 'fields'):
            continue
        fields = m.fields
        #check for important data types
        mdata = {}
        for field in fields:
            if field.name in all_allowed_fields:
                if field.name=='timestamp':
                    mdata[field.name] = UTC.localize(field.value).astimezone(CST)
                else:
                    mdata[field.name] = field.value
        for rf in required_fields:
            if rf not in mdata:
                skip=True
        for lrf in lap_required_fields:
            if lrf not in mdata:
                skip_lap = True
        for srf in start_required_fields:
            if srf not in mdata:
                skip_start = True
        if not skip:
            data.append(mdata)
        elif not skip_lap:
            lap_data.append(mdata)
        elif not skip_start:
            start_data.append(mdata)
    #write to csv
    #general track info
    with open(output_file, 'w') as f:
        writer = csv.writer(f)
        writer.writerow(allowed_fields)
        for entry in data:
            writer.writerow([ str(entry.get(k, '')) for k in allowed_fields])
    #lap info
    with open(lap_filename(output_file), 'w') as f:
        writer = csv.writer(f)
        writer.writerow(lap_fields)
        for entry in lap_data:
            writer.writerow([ str(entry.get(k, '')) for k in lap_fields])
    #start/stop info
    with open(start_filename(output_file), 'w') as f:
        writer = csv.writer(f)
        writer.writerow(start_fields)
        for entry in start_data:
            writer.writerow([ str(entry.get(k, '')) for k in start_fields])
    print('wrote %s' % output_file)
    print('wrote %s' % lap_filename(output_file))
    print('wrote %s' % start_filename(output_file))
    if ALT_FILENAME:
        append_log(original_filename)

if __name__ == '__main__':
    main()

```

Figure 36. Page three (lines 84 – 154) of a Python script hosted in Jupyter Notebook, which was used to convert the Flexible and Interoperable Data Transfer (FIT) training session data files to a comma-separated value (.csv) format file, compatible with Excel.

Appendix 21

Excel VBA Macroinstructions

Excel Visual Basic for Applications (VBA) is a programming language that allows users to automate tasks and develop customised solutions directly within Microsoft Excel. Below is a list of macroinstructions (macros) used to process the large volumes of data gathered from the participants. Table 21 contains assigned code names and brief descriptions of the functions they perform. The complete macro instructions are also provided beneath the table.

Table 21. The Macroinstruction subfunctions (Macros) used in Excel Visual Basic for data sorting tasks, with brief descriptions of their procedures.

Macro	Description
<i>RawtoMulOTT</i>	This converts a sheet of data unprocessed from Strava fit file and converts the OTT sheets to a summary of relevant numbers, does multiple sheets.
<i>RawtoSesMul</i>	This converts a sheet of data unprocessed from Strava fit file and converts the SES sheets to a summary of relevant numbers, does multiple sheets.
<i>CombtoSes</i>	Takes merged CSV to a sheet with multiple CSVs, also gives you a sheet which counts the size of all sheets
<i>CombtoSes2</i>	Takes merged CSV to a sheet with multiple CSVs, also gives you a sheet which counts the size of all sheets
<i>Shtdiff</i>	Counts unmerged CSVs, gives rows and Max HR
<i>Shtdiff2</i>	Counts unmerged CSVs, gives rows and Max HR
<i>AcctoProc</i>	Adds the accelerations calculation to each sheet and ads them to the summary sheet
<i>SpeedSD</i>	Find the sd of each session pastes in column AH
<i>ProcSheetupdates</i>	Corrects the Proc part of the sheet- may be merged with <i>ACCToproc</i>
<i>delBlankrows1</i>	Allows <i>Procsheet</i> update to happen, removes the errors at end of column
<i>GPX09toSes</i>	Prepares the sheets GPX to undergo the <i>combtoSes</i> conversion to multiple sheets
<i>GPXOTT</i>	GPX multiple sheets to the final product with summary sheet
<i>GPXSES</i>	GPX multiple sheets to the final product with summary sheet
<i>Sortcode</i>	Filers participants into different sheets according to participant code
<i>final sort</i>	Puts summary sheet into new current workbook
<i>prepcolumb</i>	Prepares Ses to comp with SSQ

The [Full macroinstructions VBA](https://docs.google.com/document/d/13AKWg_1AbsL8NADPIKEPGerQzrKFv9Z5Er9iV56lhLM/edit?usp=sharing)⁹ code can be found by following the link. Figure 37 is a snippet of the Visual Basic for Applications (VBA) code described in Table 21.

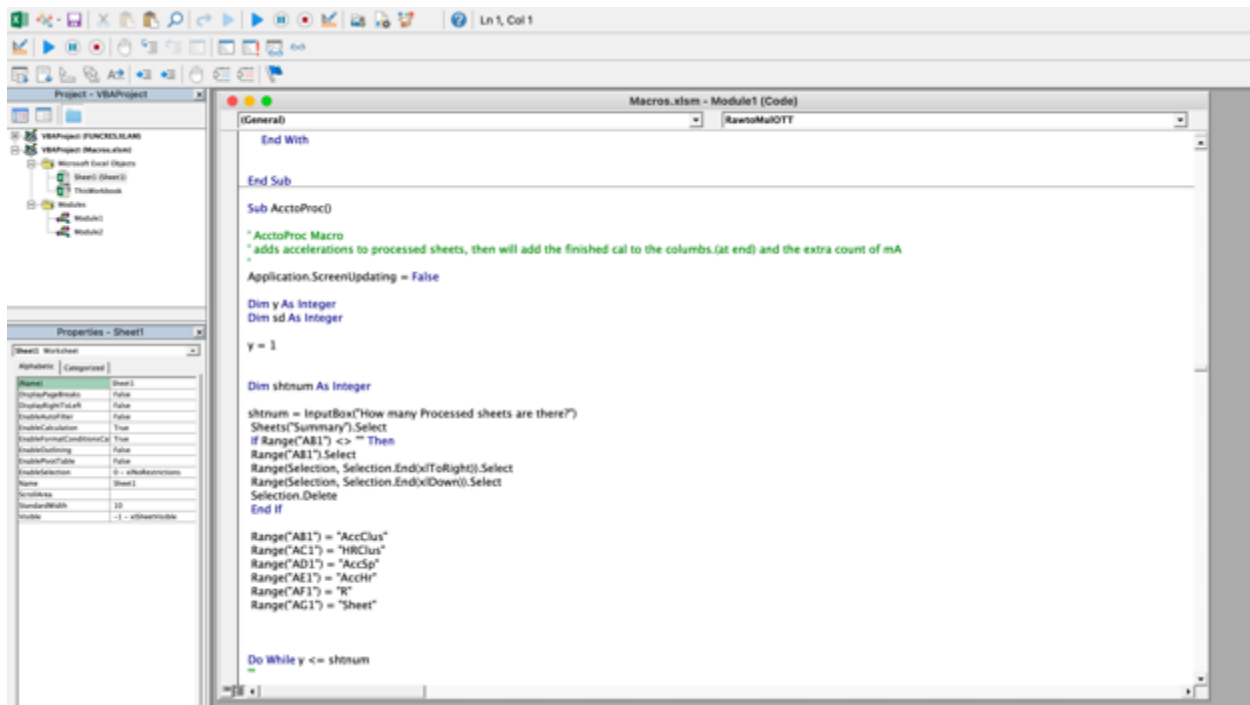


Figure 37. A snippet of VBA code from the "AcctoProc()" macro, responsible for processing a segment of training session data.

⁹ https://docs.google.com/document/d/13AKWg_1AbsL8NADPIKEPGerQzrKFv9Z5Er9iV56lhLM/edit?usp=sharing

Appendix 22

Eliteness Scoring

Table 22. The scoring rubric from Swann et al.¹⁰ adapted and used in the study

Variable / Score	1	2	3	4
<i>A. Athlete's highest standard of performance level</i>	Regional level; university level; semi-professional; 4th tier leagues or tours	Involved in talent development; 3rd tier professional leagues or tours	National level; selected to represent nation; 2nd tier professional leagues or tours	International level; top tier professional leagues or tours
<i>B. Success at the athlete's highest level</i>	Success at regional, university, semi-professional, or 3rd/4th tier	National titles or success at 2nd/3rd tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognised competition
<i>c. Years of Experience at the athlete's highest level</i>	< 2	$2 \leq x < 5$	$5 \leq x < 8$	$8 \leq$

¹⁰ Swann C, Moran A, Piggott D. Defining elite athletes: Issues in the study of expert performance in sport psychology. Psychol Sport Exerc. 2015 Jan 1;16:3–14.

Appendix 23

Orthostatic Tolerance Test Issues

An ideal result would have been a test performed under the same conditions with a heart rate monitoring device that recorded high-resolution ($>1\text{Hz}$) heart rate data for the duration of the test. This data would have allowed the researchers to examine the participant's Orthostatic tolerance, which is the sensitivity of the heart rate to the change from the supine to the standing position. A quicker heart rate recovery is a sign of better overall heart control by the autonomic nervous system after changes in body position (1). Looking at these slight differences week to week might have given insight into the status of the autonomic nervous system. See Table 23 for an example of the test for a participant with a regular result.

Table 23. An expected Orthostatic tolerance test (OTT) results for a participant with sufficient data resolution from the test, performing the test aligned with the protocols and without significant stress differences week to week.

Participant	Test	Session date	OTThrT*
1045	1	2021-09-13	19
1045	2	2021-09-20	20
1045	3	2021-09-27	22
1045	4	2021-10-04	21
1045	5	2021-10-11	20
1045	6	2021-10-18	23
1045	7	2021-10-25	22

**OTThrT = the orthostatic tolerance (recorded difference in heart rate from seated to standing position)*

However, the test is sensitive to minor disturbances. As the measurements lack the necessary resolution to detect these changes, the results cannot be considered to reflect meaningful differences as opposed to variations related to measurement error. Table 24 provides an example of such an error. Figure 38, a screenshot of recorded data, shows the cause of the reported result in the previous table.

Table 24. An example of the data from an Orthostatic tolerance test from participants without sufficient data resolution. Here, the outcomes should be supraphysiological variation, which is highly unlikely to be an actual physiological reading but the result of measurement error. The data shows heart rate values at various points and orthostatic tolerance.

Participant	Test	Session date	OTThrT*
1029	1	8/15/21	215
1029	2	8/16/21	17
1029	3	8/23/21	-120
1029	4	8/26/21	57
1029	5	8/30/21	1
1029	6	9/27/21	23
1029	7	9/3/21	640

*OTThrT = the orthostatic tolerance (Duration (s) to reach max heart rate after the shift from seated to standing position)

Test time (s)	Heart Rate	
A. 0:00:00	75	
0:00:18	73	
0:00:19	70	
0:00:20	67	
0:00:23	68	
0:00:24	67	
B. 0:00:28	64	
0:00:31	63	
0:00:34	60	
0:00:37	63	
0:00:40	60	

Figure 38. An example of test data acquired from participants with insufficient resolution. The screenshot shows that the heart rate data was recorded at irregular time intervals. A. shows a difference of 18 s, and B. shows a difference of 4 s. Both these differences are too large for a fair test.

References

1. Molina GE, da Cruz CJG, Fontana KE, Soares EMKV, Porto LGG, Junqueira Jr LF. Post-exercise heart rate recovery and its speed are associated with cardiac autonomic responsiveness following orthostatic stress test in men. Scand Cardiovasc J. 2021 Jul 30;55(4):220–6.

Appendix 24

Method of Quantifying Significant Changes in Speed and Heart Rate in Kayaking Using GPS Sports Watch Data

Abstract

Background:

Measuring training volume in water sports, such as kayaking, is difficult. Currently, kayakers widely use GPS devices to assess training volume. However, factors like water depth, current, and wind can have considerable but inconsistent effects on commonly used GPS-derived metrics such as speed and distance. This poses challenges when using these data to interpret the intensity of training accumulation.

Aims & Objectives:

To create a metric for kayaking intensity that used existing monitoring technologies (GPS sport watches) data, enhancing their usefulness.

Methods:

The GPS sports watch data from 12 kayaking sessions from a well-trained kayaker were used to develop a set of calculations which could infer the number of sprints (bouts of significantly elevated effort) from the sports watch speed and heart rate data.

Results:

The procedure developed calculated 215 of the 218 reported sprints across the 12 trails $\{r = 0.99\}$. The calculated acceleration size was associated with the reported type of session $\{0.8 \pm 0.1 \text{ m.s}^{-2}$ with LSD/sprint; $1.5 \pm 0.1 \text{ m.s}^{-2}$ with high-intensity intervals; $2.1 \pm 0.1 \text{ m.s}^{-2}$ with sprint intervals $P < 0.001\}$

Conclusions:

These results indicate a potentially cost-effective way to augment existing measures to understand kayaking session characteristics and intensity better. However, much work is

needed to make the procedure capable of predicting the characteristics of kayakers of different abilities.

Table 25. Table of terms used in the study to describe aspects of importance within the study.

<i>Term</i>	<i>Description</i>
<i>5ave</i>	Moving average(mean) of 5 seconds of speed or heart rate values
<i>30ave</i>	Moving average(mean) of 30 seconds of speed or heart rate values (preceding the 5ave)
<i>Speed Spike threshold</i>	$5ave - 30ave > 0.56 \text{ m/s}$
<i>Speed spike cluster</i>	Consecutive seconds where the speed spike threshold is met, counted as a single event.
<i>Acceleration</i>	A period of increasing speed, indicated by a speed spike or multiple consecutive speed spikes
<i>Acceleration magnitude ($m.s^{-2}$)</i>	Mean change in speed of all the speed spikes in a session per second ($m.s^{-2}$)
<i>HRspike cluster</i>	Consecutive seconds where the HR spike threshold is met, counted as a single event.
<i>HRspike magnitude ($bpm.s^{-1}$)</i>	The average(mean) change in HR of all the HRspikes in a session per second ($bpm.s^{-1}$)

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Introduction

It is well established that exercise training improves exercise performance (1,2). The specific modality of this training, including the volume, intensity and timing, varies depending on the demands of a particular sport (3–6). Informing the balance between rest and stress is very important (2,7–10). Moreover, it is difficult to tell individuals' training status without exhaustive tests in kayaking.

Sports scientists have turned to submaximal markers and metrics to monitor athletes and teams. This is done by using multiple markers to determine an individual's state of fatigue or recovery (11). These markers collectively measure what is commonly termed training load. This encompasses training volume (intensity, duration) and the training stress on the individual. Monitoring metrics include speed, distance, duration, heart rate measures, power output, and perceptive measures of tiredness, muscle soreness and effort, which are also common (12). Importantly, these metrics can be used effectively when comparing values from multiple time points and sessions.

Training in water sports, such as kayaking, can be difficult to measure. Marathon kayaking races occur on rivers, flat water (such as dams or lakes), and the open ocean. Even if training is done on the same body of water, there can be changes in water depth, wind, current, or flow. Therefore, there can be a disconnect between the speeds measured and the distance covered compared to kayakers' effort or intensity.

A characteristic of most marathon kayaking, which is different from other marathon distance racing, is the radical shifts of intensity that occur throughout a race. In other marathon distance events, such as running, the top competitors tend to hold a constant speed, which is very close to the athlete's high-intensity endurance threshold. The athletes who can hold the highest pace for the longest will likely win. Although this type of racing can also occur in marathon kayaking, not infrequently, sharp increases in pace at multiple

points through a race are expected. Due to wash riding, this is true in all marathon kayaking disciplines to varying degrees.

Wash riding is where a competitor can position themselves alongside or behind a kayak and draft them by riding the wake of their craft. This practice has been shown to reduce energy costs by as much as 31% (13). This way, a competitor is incentivised to ride the wave as they can conserve energy. Moreover, the absolute energy saving of the wash riding is primarily determined by the position, so competitors need to contend with other paddlers to maintain the best wash riding positions. This contributes to the racing style in marathon kayaking, characterised by a generally steady submaximal pace with frequent sharp increases of speed, followed by a return to a submaximal pace. Figure 39 depicts a typical bunch configuration. Paddlers will work to try to get the positions closest to the leader. Therefore, some training sessions the kayakers do will also need to improve this ability to sprint mid-marathon.

Therefore, a marathon kayaking race or training session might have an average speed or measure of distance, which misrepresents the kayaker's intensity or effort. Ultimately, using measures of power might be desirable. It has shown some promising results in slalom kayaking (14). However, this technology is not yet widely integrated into the sport. Therefore, despite the drawbacks, GPS sports watches are currently widely used by kayakers. These devices track kayakers' position changes over time, allowing them to obtain data such as speed (m/s) and distance covered. Additionally, many modes can also track the wearer's heart rate (either via a wrist sensor or a chest strap). These metrics are used by many different kayakers as in-session tools to inform intensity and to help calculate training volume.

Team sports have also used GPS data to help quantify training volumes. Here, the devices can be integrated with accelerometers. These can quantify distance covered, relative speed, accelerations and even certain impact variables(15). In these sports, the GPS data's

usefulness in understanding demand is enhanced by looking at specific factors such as accelerations or time in intensity zones (16). Taking these insights to kayaking, where there are certain issues with using simply relative speeds to quantify an intensity, has its drawbacks.

Moreover, incorporating a measure of accelerations may enhance the ability to accurately track a session's intensity and, ultimately, training volume. Therefore, the frequency of periods where the speed increased and returned to an average should be counted to quantify the intensity of a given paddle better. It could serve as an additional indirect measure of session intensity (as it describes how a participant might have increased boat speed, and therefore paddling intensity, on several occasions.)

Therefore, the purpose of this investigation is to propose a metric designed to measure accelerations, which can contribute to measuring training volume. It Assigns a value to accelerations, so any significant increase in speed can be noted and assigned a value. This way, events such as starting an interval or sprinting at a steady pace can be measured. This can give a researcher another objective tool for measuring the session intensity and type. This can be done without additional equipment but by simply using the data provided by a GPS monitoring device such as a sports watch.

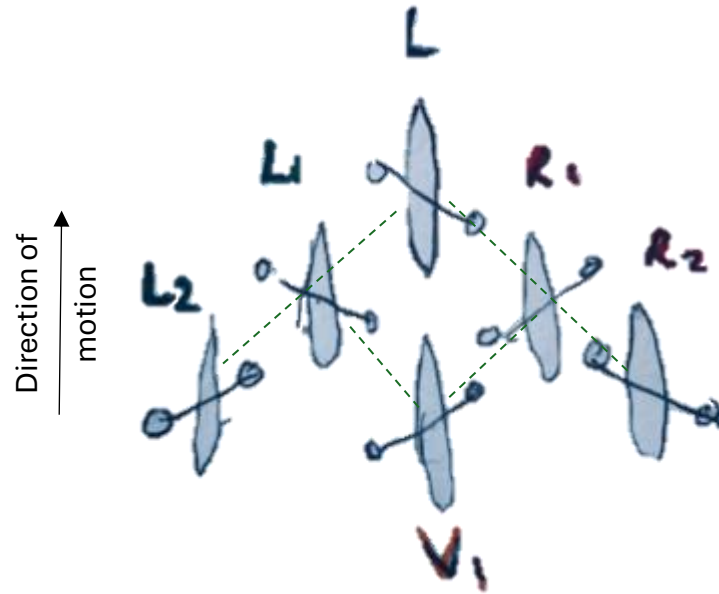


Figure 39. A typical wash riding configuration of a bunch of kayakers. L = leader, then L1 = Left first wave, R1 = Right first wave, L2 = left second wave, R2 = right second wave and V1= First V directly behind the leader. The dashed line represents the boat wave. The positions closest to the leader (L1, R1 and V1) have optimal energy saving, decreasing energy saving on positions further away (L2, R2).

Experimental Approach to the Problem

The method was developed from a series of pilot trials where the researcher attempted to create a model that would count every time the kayaker put in an effort and sprinted by looking at the GPS sport watch data. This could better record a session volume and may also be able to tell a researcher which kind of session the kayaker performed. When a kayaker sprinted, their speed increased; when they backed off, the speed would decrease again. Therefore, when looking at the kayak speed vs time figure, the number of sprint efforts the kayaker performed was well represented by the number of local maximum turning points on the figure. The next challenge was identifying a method to count these spikes without needing to represent the data and then count it visually. The researchers were more interested in the ascending portion of the maximum (i.e., where the speed was increasing). The method must be applied to large data sets, so a manual method would be too inefficient. The method needed to be possible inside existing software such as Microsoft Excel. With these constraints and data from different trails, a method of counting the sprint efforts or accelerations was developed.

Method

The researcher obtained data from a kayaker performing 12 kayaking sessions. The sessions were based on three types of paddling sessions that occur. These session types are steady intermediate threshold paddling, high-intensity, and sprint intervals. The researcher's design asked the participant to include sprint periods in the submaximal steady sessions, which could simulate what would occur in marathon kayak racing. The other change to ordinary paddling was that the participant used resistance for one of each type of session (attaching bungy cords to increase drag in the water and, in effect, slow boat speed). This was an attempt to replicate the sessions at slower absolute speeds. In all trials, the same warm-up procedure was followed. The participants would paddle for approximately 10 minutes at a self-determined moderate pace, Foster's RPE 3-4, and then perform their program-directed sessions. The sessions conducted are summarised in Table

26. The participant counted the number of sprints performed and reported after the session. The reported accelerations were further confirmed by looking at the session framework (from Table 26.). This was then compared to the accelerations calculated from the GPS data. The sessions were performed on a flat-water dam or estuary with negligible current or swell. The wind for each trail was moderate (less than five knots).

Table 26. Describes the session structures which the participants performed. The main set describes the bulk of the paddling sessions. Each session was repeated 4 times by the participant.

Session type	Race simulation (control)	High intensity intervals	Sprint intervals
Warm up	WU 10 mins (moderate 3-4 RPE)	WU 10 mins (moderate 3-4 RPE)	WU 10 mins (moderate 3-4 RPE)
Main set	60 mins steady (RPE-4) with: (repeated every 5 mins) -sprint 15s (RPE 9-10) -non-paddling rest 10s	10 x 4 mins (RPE 7-9), 2 mins stationary rest	10 x 15s (RPE 9-10), 45s stationary rest. 10 x 20s (RPE 9-10), 45s stationary rest. 10 x 15s (RPE 9-10), 45s stationary rest. (3 mins non paddling rest between)
Characteristics	Accelerating from an already moving pace. Most like marathon kayak racing.	Medium accelerating from a stationary start and maintaining the speed.	Large acceleration from a stationary start, followed by a stationary period

Speed data from GPS sports watches was initially collected on the device, and the original files were exported via a bulk download from either the device vendors' online portal or via Strava's bulk download option. The original files from the device were recorded in a Flexible and Interoperable Data Transfer (FIT) format or a GPS Exchange (GPX) format. The data

were converted to a comma-separated values (CSV) file for further processing in Microsoft Excel.

The frequency of data collection varies depending on the device's model (e.g., a GPS sports watch), the software used in the device, and its communication with the satellite. Where the data is collected at a rate slower than 1 Hz, it is interpolated to have a speed (km/hr) and heart rate (BPM) value for each second. The data is then used to create a method of calculating the number of these periods of acceleration.

The goal was to find acceleration periods. This would be when the speed increased significantly to a previous period. Therefore, the researchers initially looked at the data, comparing adjacent seconds (i.e., speed at $t = 1$ s to speed at $t = 2$ s). However, the variability in data at such a scale was too large to obtain meaningful results. The researcher then reformed the comparison with adjacent periods of multiple seconds, taking a moving average (mean) of the speed for these periods. The averages of these sequential periods were then compared. (e.g. Mean of speed $t=1$ s – 5s compared to mean of speed $t=5$ s – 10s.) By taking a **moving average of five seconds** ($5ave$) of boat speed and comparing it to **the previous 30 seconds** ($30ave$), the researchers consistently calculated the actual number of accelerations based on what had been reported. See Figure 42.

$$Speed\ spike = \bar{n} [speed\ at\ T_1 + \dots + T_5] - \bar{n} [speed\ T_0 + \dots + T_{-29}] \geq Spike\ threshold$$

Equation 3. For calculating a speed spike with speed data over a given duration.

Additionally, when comparing these different periods, the researchers had to decide when the magnitude of the difference between adjacent periods was large enough to count as a period of acceleration. This cut point was decided on by looking at the standard deviation of speed values for eight trials where the environmental conditions were not significantly affecting the paddle speed.

A standard deviation of 0.56 m/s (about 2km/h) was calculated in these trials. This was the magnitude difference used to determine when a true acceleration had occurred, as it would mean that the average speed difference between two measured differences was at least one standard deviation. In this way, only more sustained increases in speed were counted. Using this magnitude difference, a comparison period of the mean of speed {t = 1 – 30} and mean of speed {t = 31 – 35} was used as it resulted in the best agreement between the calculated number of acceleration periods and actual periods. When the difference between the two periods was greater than or equal to the calculated threshold (0.56m/s), it was deemed a ‘speed-spike’ (i.e. Moving average of 5 seconds (5ave) – Moving average of the previous 30 seconds (30ave) $\geq$ 0.56 m/s). The Speed-spike is recorded at the first timepoint (T₁) of the 5ave. See Figure 40. This calculation is repeated for the next second of data. The previous T₂ becomes T₁. The speed values in the calculation of the 5ave and 30ave all increment by one second. An example is shown in Figure 41.

The speed-spikes were validated further by the corresponding changes in HR. An *effect size* of the change in heart rate values from the same periods (5ave-30ave) was calculated to validate the speed spikes. A value of at least 0.3 Standard deviations is needed to correspond to the same period for the speed spike to be valid and counted. This would indicate that in the period where the acceleration was happening the heart rate increased by at least 0.3 Standard deviations. This indicates the participants were exerting themselves more when the acceleration was occurring. This ensured that an environmental condition wasn’t entirely responsible for the acceleration.

$$Effect\ size\ (HR) = \frac{\bar{n}\ [heart\ rate\ of\ 5s](bpm) - \bar{n}\ [heart\ rate\ of\ previous\ 30s]\ (bpm)}{\sigma[heart\_rate\ of\ entire\ session]}$$

Equation 4. To calculate the effect size of a heart rate difference between a five-second mean from the previous 30 seconds which were calculated to validate acceleration periods further.

When speed spikes are recorded at multiple consecutive timepoints, the entire contiguous group of speed spikes is counted as a single acceleration. Therefore, an acceleration can

consist of a single speed spike or multiple contiguous seconds of speed spikes. Note that more consecutive speed spikes would only mean that the acceleration takes place over a longer period; it does not tell us the magnitude of the acceleration.

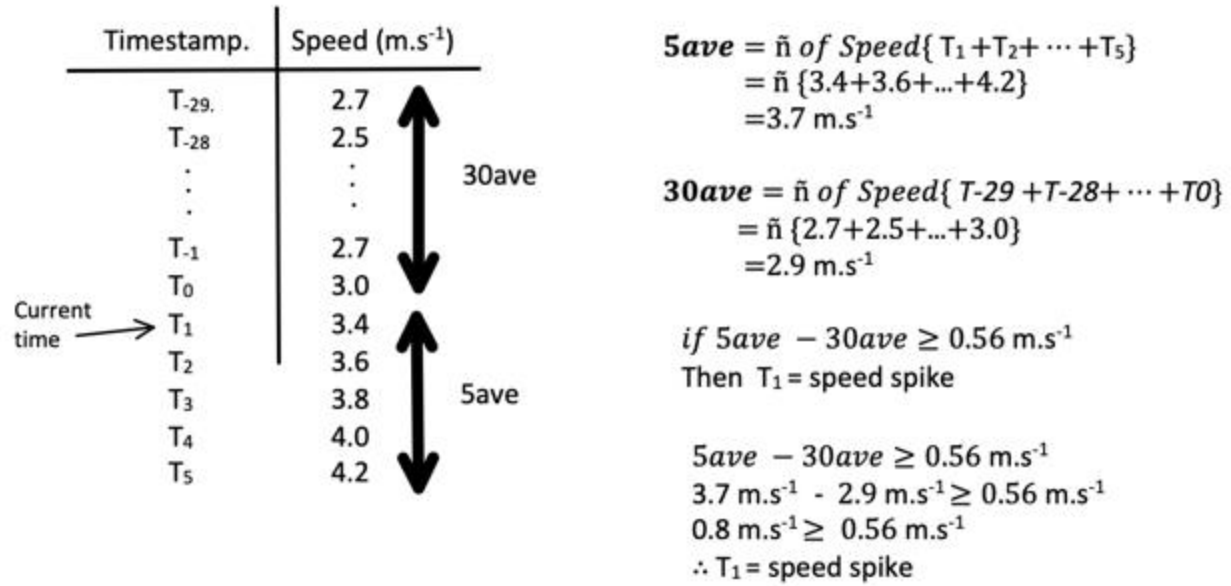


Figure 40. A theoretical example of where a speed spike is calculated. The T₁ is the current time. This is the time point at which the calculated speed spike is recorded. The 5ave is the average speed of the 5 seconds following T₁ (including T₁), and the 30ave is the previous 30s. {5ave = moving average of speed values for T₁ to T₅ ; 30ave = moving average of speed values for T₋₂₉ to T₀}

The magnitude of the spikes was calculated (Equation 5) as the average of all the consecutive speed spikes in a single acceleration (see Figure 41 for example). This number accompanies the total number of accelerations and gives insight into the average size of each acceleration. The spike magnitude is reported in m.s⁻². The number indicates how much faster the participant moves every second of the acceleration.

Acceleration(m.s⁻²)

$$= \frac{\sum_{\bar{n}=1} (\bar{n} [\text{speed of 5s}](\text{m.s}^{-1}) - \bar{n} [\text{speed of previous 30s}](\text{m.s}^{-1})) \text{ if } \geq 0.56 \text{ m.s}^{-1}}{\text{total speed spikes}}$$

Equation 5. Calculation of the magnitude of an acceleration which describes the size of the acceleration

1st period	2nd period	3rd period	timestamp (s)	speed(m/s)				5ave - 30ave (m/s)	Speed spike	
-29	-30	-31	0:56	3.1				-	X	
-28	-29	-30	0:57	3.1				-	X	
-27	-28	-29	0:58	3.1				-	X	
-26	-27	-28	0:59	3.1				-	X	
					30ave					
						30ave				
							30ave			
-1	-2	-3	1:03	3.2				-	X	
0	-1	-2	1:04	3.3				-	X	
1	0	-1	1:05	3.3				0.8	✓ Speed spike	
2	1	0	1:06	3.7				0.9	✓ Speed spike	
3	2	1	1:07	4.0	5ave			0.9	✓ Speed spike	
4	3	2	1:08	4.2		5ave		0.7	✓ Speed spike	
5	4	3	1:09	4.3			5ave	0.7	✓ Speed spike	
6	5	4	1:10	4.4				0.6	✓ Speed spike	
7	6	5	1:11	4.2				-0.1	X	
8	7	6	1:12	4.0				-0.2	X	
9	8	7	1:13	3.8				-0.3	X	
10	9	8	1:14	3.9				-0.4	X	
11	10	9	1:15	3.3				-0.7	X	
12	11	10	1:16	3.1				-0.7	X	

Figure 41. A calculation example. The mean of the previous 30 seconds of speed values(30ave) is subtracted from the five-second mean of speed values(5ave). If the resulting number is greater than 0.56 m/s, then a speed-spike is registered at T_1 for that period. The 30ave and 5ave periods are incremented by one second, and the calculation is repeated. If the resulting number is again above the threshold, a speed spike is reported at 2nd period T_1 . Multiple contiguous spikes are counted as a single acceleration. This figure does not include the heart rate validation.

Results

Table 27 shows the various trials, including the four controls and eight non-controlled trials. The reported sprints are the number of times the participant accelerated from a slower speed. The acceleration is the total number of spike clusters or non-consecutive spikes.

The magnitude of the accelerations appears to be linked to the type of session, with the control session showing the most minor accelerations. Intervals displaying a larger acceleration than control ($t_{\text{Interval vs Control}(6)} = 9.2, p < 0.001^{11}$) and sprint intervals indicating the largest accelerations ($t_{\text{Sprint vs Control}(6)} = 20.6, p < 0.001^{12}$) relative to control.

Table 27. The mean speed and heart rate kayaking sessions for the trials, the number of accelerations and HRspikes counted by the method, and the magnitude of the acceleration and HRspikes. Note the magnitude is the average difference over 5 seconds.

Trial no.	Session	Speed (km/h)	HR(bpm)	Reported sprints	Accelerations	HRSpikes	Acceleration (km/h/s)	Hrspike (bpm/s)
4	control	11.9	156	14	14	14	3.1	10
5	control	10.7	143	15	15	16	2.7	11
6	control	10.3	144	10	9	8	2.7	11
7	control	12.1	141	19	19	20	3.4	13
1	interval	9.6	149	8	9	15	4.8	15
2	interval	8.3	137	21	18	29	5.1	12
3	interval	8.3	131	10	10	19	5.4	18
12	interval	9.0	132	10	10	13	5.6	19
8	sprint	7.8	130	30	31	31	7.3	22
9	sprint	6.8	131	30	30	32	7.9	19
10	sprint	7.6	129	30	30	31	7.9	19
11	sprint	8.4	124	21	20	20	7.5	23

¹¹ Independent t-test in text ($t(df)$ = t-statistic; p-value)

¹² Independent t-test in text ($t(df)$ = t-statistic; p-value)

The control trials revealed a 2% difference between reported and calculated spikes, as illustrated in Figure 42. Meanwhile, the interval and sprint trials exhibited 4% and 0% errors, respectively.

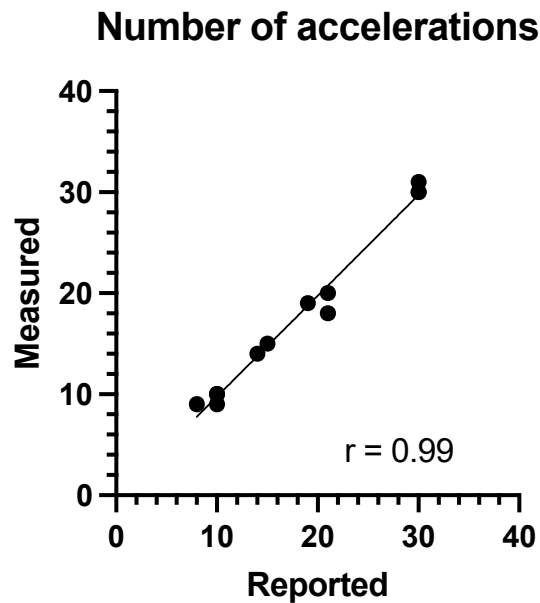


Figure 42. A figure showing the correlations between the reported and calculated accelerations for 12 trials.

Figure 43 shows the consistency of the method described to detect acceleration times and increasing heart rate. It shows the changes in speed and heart rate over the course of the trial. The figure overlays a line when the acceleration detection detects a notable acceleration. The line can be seen every time there is a notable acceleration, except for a few edge cases.

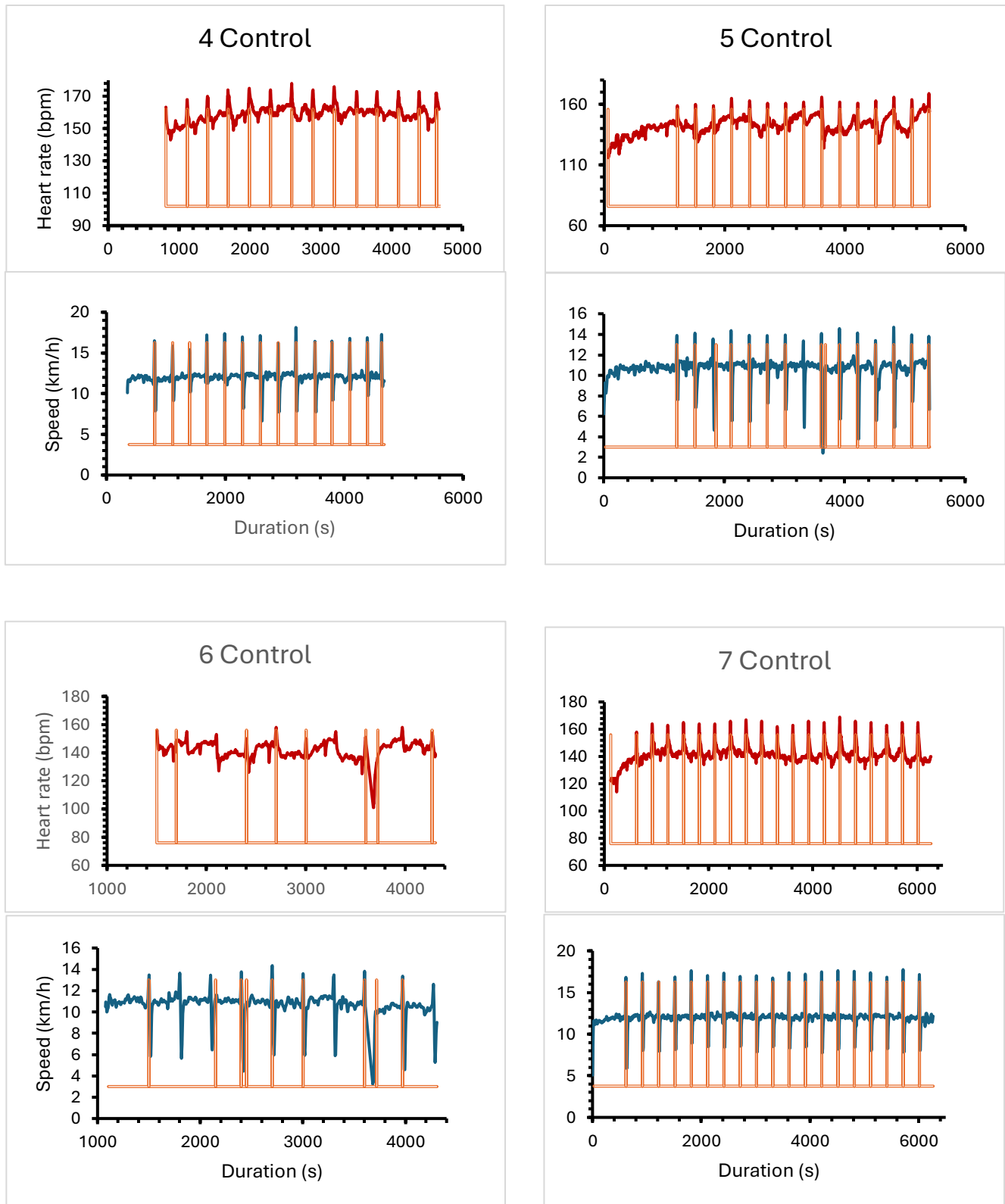


Figure 43. shows the speed (km/h) and heart rate(bpm) the control experiments (4-7 in Table 27) where the participants performed the directed sprints. The resulting calculated accelerations and HR spikes (non-solid lines) are overlaid. The time scales for each separate experiment are the same. Note that the size of the spike (orange) does not designate its magnitude, only

Discussion

The data presented in Figure 43 indicate that the spikes in acceleration and heart rate align with the peaks in speed observed in both the controlled and non-controlled trials.

Furthermore, the peak in heart rate corresponds closely with the peaks in speed. This suggests that the speed increases observed in all trials were likely due to participants trying to accelerate, rather than being influenced by the environment.

Table 27 shows that the different session types are characteristically different when applying calculations to determine accelerations. However, this difference is not apparent when looking at speed and heart rate as session-long averages. Therefore, these computations can make session data which already exists more useful.

The accuracy of these methods was extremely high in the trials conducted, with robust correlations between the calculated vs reported accelerations ($r=0.99$). However, there were no significant deviations from session structures, and the conditions of the trail were very calm. Where there were less substantial differences in speed, the computation method was not effective in detecting the difference (see Figure 43, 6 control at ~3200 s). However, such problems could be addressed with improved algorithms

Conclusions

These results indicate a potentially cost-effective way to augment existing measures to better understand kayaking session characteristics and intensity. These uses could extend from improving the reporting of a session's characteristics and improving the impact of the session on the athlete. Furthermore, allowing an athlete or coach a tool for retrospective analysis of sessions. While the current algorithm will likely need noticeable improvement to handle more complex sessions and to be applicable to different kayakers

Limitations

The method's resolution is not good if accelerations or HR spikes occur in close succession (within 30 seconds), a consequence of the 30ave. However, smoothing noise from GPS data is necessary.

One limitation is that accelerations from an already noteworthy speed and the change below the threshold will not be counted. These are more common in races where kayakers rarely accelerate from a stationary position. However, not reporting such effort would undermine the method's intention of enhancing the interpretation of the data.

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