Establishing the Validity of Methods for Quantifying Training Load in Endurance Athletes

A thesis submitted for the degree

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by

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CERTIFICATE OF AUTHORSHIP AND ORIGINALITY OF THESIS

I certify that the work contained in this thesis has not been previously submitted either in whole or in part for a degree at the University of Technology, Sydney or any other tertiary institution.

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

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PREFACE

This thesis for the degree of Doctor of Philosophy is in the format of published or submitted manuscripts and abides by the 'Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology, Sydney; Policies and Directions of the University'.

Based on the research design and data collected by the candidate, four manuscripts have been submitted for publication in peer reviewed journals. These papers are initially brought together by an *Introduction*, which provides background information, an explanation of the research problem and the aims of the series of studies. A *Literature Review* then follows to provide an overview of quantifying training load and systems modelling research. The body of the research is presented in manuscript form, in a logical sequence following the development of research ideas in this investigation. Each manuscript outlines and discusses the individual methodology and the findings of each study separately. Figures, tables and reference numbering in all manuscripts have been retained. These chapters are formatted according to the journal requirements and as such may be slightly different from each other. The *Summary* chapter integrates the flow of research ideas and conclusions from each project and outlines directions for future research.

LIST OF ARTICLES SUBMITTED FOR PUBLICATION

Refereed Journal Publications

1. **Wallace, L.K.**, Slattery, K.M., & Coutts, A. J. (2011). A comparison of methods for quantifying training load: relationships between modelled and actual training responses. *Medicine and Science and Sports and Exercise.* In review.

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3. **Wallace, L.K.**, Slattery, K.M., & Coutts, A. J. (2008). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *Journal of Strength and Conditioning Research*: *23*(1): 33-8.

4. **Wallace, L.K.**, Slattery, K.M., Simpson, N., Bell. J., & Coutts, A. J. (2008). Using session-RPE to monitor training load in swimming. *Strength and Conditioning Journal: 30*(6):72 - 76.

5. Slattery, K.M, **Wallace L.K.** and Coutts, A.J. (2011). Nutritional practices of elite swimmers during an intensified training camp: with particular reference to antioxidants. *Journal of Sports Medicine and Physical Fitness.* accepted.

6. Slattery, K.M., **Wallace, L.K.**, Bentley, D.J. and Coutts, A.J. (2012). Effect of training load on simulated team sport match performance. *Applied Physiology, Nutrition and Exercise Metabolism.* in review.

Conference Proceedings & Abstracts

1. **Wallace, L.K.,** Slattery, K.M. Coutts, A.J. (2011*). A comparison of methods for quantifying training load: relationships between modelled and actual training responses*. Paper presented at the 16th Annual Congress of the European College of Sports Science, Liverpool, UK.

2. Slattery, K. M**., Wallace, L.K.**, Coutts, A. J., & Bentley, D. J. (2007). Effects of HIGH vs. LOW training loads on metabolic, immune and oxidative markers in team sport athletes. *Journal of Science and Medicine in Sport, 10*(6 (Supplement)), 117.

3. Coutts, A.J., K.M. Slattery, **L.K. Wallace** & Sirotic, A.C. (2007). *Influence of between-match training load on match running performance and markers of recovery in team sport athletes.* Journal of Science and Medicine in Sport*, 6* (Supplement 10), 23.

4. Slattery. K.M., **Wallace. L.K**, Coutts. A.J. & Bentley. D. (2007). *Effects of High vs Low training loads on metabolic, immune and oxidative markers in team sport athletes.* Paper presented at the Australian Conference of Science and Medicine in Sport, Adelaide, Australia.

5. **Wallace, L.K.,** Slattery, K.M., & Coutts, A.J. (2007). A comparison between methods for quantifying training load during endurance exercise. *Journal of Science and Medicine in Sport, 10* (6 (Supplement)), 118.

6. **Wallace, L.K.**, Slattery, K.M. and Coutts, A.J. (2005). *The efficacy of psychological state measures for the early detection of overreaching.* Paper presented at the 2005 Australian Conference of Science and Medicine in Sport, Melbourne, Australia.

7. Slattery, K.M., **Wallace, L.K.** and Coutts, A.J. (2006). *Nutritional practices of elite swimmers during an intensified training camp: with particular reference to antioxidants.* Poster presented at the 2006 Australian 2nd Conference of the Australian Association for Exercise and Sport Scientists, Sydney, Australia.

8. Slattery, K.M., **Wallace, L.K.** and Coutts, A.J. (2005). *Practical tests for monitoring fatigue and recovery in triathletes.* Paper presented at the 2005 Australian Conference of Science and Medicine in Sport, Melbourne, Australia.

ABSTRACT

Athletic performance is improved via the systematic application of successive bouts of exercise. However, there is no current consensus on the most accurate method to assess the cumulative effects of physical training. Therefore, the overall aim of this thesis was to determine the criterion validity and reliability of commonly used training load methods to quantify the dose-response relationship between physical training and athletic performance. To achieve this, a series of three studies were completed. Study 1 determined the ecological validity of the session-RPE method for quantifying training loads in elite swimmers. The findings demonstrated strong relationships between session-RPE, heart rate (HR) methods and distance. These results suggest that session-RPE may provide a practical, non-invasive method for quantifying internal training load in competitive swimmers. The purpose of Study 2 was to compare the criterion validity and test-retest reliability of common methods for quantifying training load in endurance exercise. Participants completed either steady state or interval cycle training sessions where oxygen consumption, HR, rating of perceived exertion (RPE) and blood lactate measures were taken to assess the workload of each exercise bout. The results of this investigation showed that external work was the most valid and reliable method for quantifying training load. Heart rate measures were found to be the most valid and reliable measure of internal training load. Finally, the ability of these measures to quantify the training load accumulated over successive training sessions was examined in Study 3. A mathematical model was applied to the physical training completed by male runners over a 15 week period. The findings of this study showed that each of the training load methods investigated are appropriate for quantifying endurance exercise. Collectively, this thesis shows that the validity of the training load measure is influenced most by the reliability of the device used for measuring training intensity and the degree to which the weighting factors for the calculation of the training load methods are customised to individualised performance parameters.

KEYWORDS

Endurance

Fatigue

Fitness

Heart rate

Heart rate variability

Monitoring training

Performance

Psychological questionnaires

Rating of perceived exertion

Reliability

Session-RPE

Systems models

Training load

TRIMP

Validity

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AU	arbitrary units
b	male / female weighting factor for TRIMP calculation
beats·min^{-1}	beats per minute
[BLa^{-}]	blood lactate concentration
[BLa^{-}]$_{peak}$	peak blood lactate concentration
CI	confidence interval
cm	centimetre
CR	category ratio
CV	coefficient of variation
d	Cohen's d effect size
D	duration of training sessions
DALDA	Daily Analysis of Life Demands for Athletes
FT	fast twitch
g	grams
GOVSS	gravity ordered velocity stress score
GPS	global positioning system
h	hour
HF	high frequency
HR	heart rate
HR$_{ex}$	heart rate during exercise
HR$_{max}$	maximal heart rate
HR$_{mean}$	mean heart rate
HR$_{rest}$	resting heart rate
HRV	heart rate variability
HR-$\dot{V}O_2$	heart rate-oxygen uptake
ICC	Interclass correlation coefficient
ip	positive influence of training on performance
J·kg^{-1}	joules per kilogram

k	TRIMP coefficient
kg	kilogram
kJ	kilojoule
km	kilometre
km·h^{-1}	kilometres per hour
L	litre
LF	low frequency
LIR	low-intensity running
L·min^{-1}	litres per minute
m	metre
min	minute
min·s^{-1}	metres per second
mL·kg^{-1}·min^{-1}	millilitres per kilogram per minute
mmol·L^{-1}	millimoles per litre
m·min^{-1}	metres per minute
ms	millisecond
m/s	metres per second
n	number
np	negative influence of training on performance
p	performance
POMS	profile of mood states
r	correlation coefficient
RCP	respiratory compensation point
RPE	rating of perceived exertion
rpm	revolutions per minute
rTSS	running Training Stress Score
s	seconds
SD	standard deviation
sRPE	session-RPE
SS	steady state
t	time

TE	typical error
TEM	technical error of measure
TEM%	percentage technical error of measure
t_g	time prior to competition for maximal performance
TL	training load
t_n	time prior to competition when training is reduced
TQR	Total Quality of Recovery Questionnaire
TRIMP	training impulse
TSS	training stress score
$\dot{V}CO_2$	carbon dioxide expired
VE	ventilation
V_{max}	peak aerobic running velocity
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_2max$	maximal oxygen uptake
$\dot{V}O_2mean$	mean oxygen uptake
$\dot{V}O_2peak$	peak oxygen uptake
VT	ventilatory threshold
VT_1	first ventilatory threshold
VT_2	second ventilatory threshold
w	work
W	watt
W_{final}	workload in the final completed stage of an incremental test
W_{inc}	workload increment of an incremental test
$W{\cdot}kg^{-1}$	watts per kilogram
W_{max}	maximum work capacity
$W{\cdot}min^{-1}$	watts per minute
wt	worktime
y	year
µL	microlitre
%	percentage
%BM	percentage of body mass

%W_{max}	percentage of maximum work capacity
°	degrees
~	approximation
ΔHR ratio	average change in heart rate reserve
∑	sum

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Chapter 1

General Introduction

BACKGROUND

In endurance sports, it is generally believed that increases in training load are accompanied by improvements in athletic performance. However, sudden increases in physical training have also previously been associated with an increased likelihood of illness, injury and staleness (Foster 1998; Foster and Lehmann 1997; Foster et al. 1999). It is therefore important that coaches and athletes are able to accurately titrate the training load imposed by successive bouts of exercise. Consequently, the role of scientific research has become increasingly focused on improving the understanding of the relationships between physical training loads, adaptation, recovery and athletic performance. Many previous studies have established the relative influence that manipulation in training variables such as duration, intensity and frequency have on the adaptive response to an isolated physical training session (for reviews see: Kiely 2010; Issurin 2010; Zaryski and Smith 2005). However, it is more difficult to ascertain the cumulative training effect over prolonged periods of time. This may be due to factors such as the individual response to training, timing between sessions and the impact of external life stressors.

In 1975 Banister proposed a mathematical model in an attempt to quantify overall performance changes of individuals undergoing regular physical training by tracking changes in measures of fitness and fatigue (Banister et al. 1975). The model considered the input dose effect that training has on the two response elements of fitness and fatigue. The difference between these variables was suggested to reflect the performance of an individual at a given time. This concept has since been improved and successfully applied to a number of different athletic cohorts (For review see: Taha and Thomas 2003). However, despite these advances, systems models have been unable to consistently predict performance on an individual basis in an ecological setting (Busso and Thomas 2006; Taha and Thomas 2003). This may be attributed to the lack of consensus as to the most appropriate method for quantifying performance parameters (i.e. training load, fitness and fatigue) and the weightings given to these variables within the models. There is currently much debate as to the most valid method for quantifying training load in endurance exercise. Training theory suggests that measures which reflect an individual's internal response (i.e. heart rate, RPE etc.) during an exercise bout may be more appropriate for quantifying the dose of a training session (Viru and Viru 2000; Impellizzeri et al. 2005). Furthermore, measures which only assess the external training dose (e.g. distance, power output, speed etc.) do not take into consideration each individual's level of fitness or the level of prior exercise-induced fatigue. Despite these limitations, external measures of physical training have become increasingly popular due to improvements in technologies that provide direct and instantaneous feedback (e.g. power meters, GPS devices, accelerometers etc.) (Jobson et al. 2009). However, at present, it is not known which method for quantifying training load is the most appropriate for monitoring the training process, or which relates best to training outcomes (i.e. performance, fitness and fatigue) in a real-world setting.

RESEARCH PROBLEM

Physical training load may be influenced by a number of different variables including the type, frequency, duration and intensity of each exercise bout. There are a variety of methods available to quantify the training loads undertaken by athletes. These methods are based on internal (e.g. heart rate, perception of effort, etc.) and external (e.g. power, speed, etc.) measures of exercise intensity and are weighted according to generic or individualised physiological / performance parameters. Despite the widespread use of these methods, it is not yet known which method is the most valid for quantifying training loads in endurance exercise.

RESEARCH OBJECTIVES

The key aims of the series of investigations included in this thesis are to:

1. Examine the ecological validity of the session-RPE method for quantifying training load in swimming using heart rate and distance as criterion measures;
2. Demonstrate the efficacy and practical application of the session-RPE method for monitoring the training process in competitive swimmers;
3. Establish the criterion validity and reliability of internal (i.e. HR and RPE-based) and external (i.e. speed and distance-based) methods for quantifying training loads in endurance exercise; and,
4. Establish the construct validity of commonly used methods for quantifying training loads by examining their influence on the accumulated effects of training.

PURPOSE AND HYPOTHESES OF THE STUDIES

Chapter 3 - The ecological validity and application of the session-RPE method for quantifying training loads in swimming.

- The purpose of this investigation was to establish the ecological validity of the session-RPE method for quantifying internal training load in competitive swimmers.
- The second purpose of this study was to examine the correspondence between athlete and coach perceptions of internal training load using the session-RPE method.

Chapter 4 - Using session-RPE to monitor training load in swimming.

- The purpose of this paper was to demonstrate the practical application of the session-RPE method for monitoring the training process in competitive swimmers.

Chapter 5 - Establishing the criterion validity and reliability of common methods for quantifying training load.

- The purpose of this investigation was to compare the criterion validity and test-retest reliability of common methods for quantifying physical training load.

Chapter 6 - A comparison of methods for quantifying training load: relationships between modelled and actual training responses

- The purpose of this study was to further examine the validity of commonly used methods for quantifying training loads using a mathematical model.
- This study will also examine the validity of commonly used methods for evaluating fitness and fatigue in athletes.

RESEARCH PROGRESS LINKING THE MANUSCRIPTS

This research project established the validity of commonly used methods for quantifying training loads in endurance exercise. To achieve this, three separate research projects were undertaken (Figure 1.1, over page). *Study 1* determined the ecological validity of the session-RPE method for quantifying training load in competitive swimmers. This research showed strong relationships between session-RPE and criterion measures for quantifying training load in swimming (i.e. HR methods and distance). *Study 2* examined the criterion validity and established the reliability of the session-RPE method as well as other commonly used methods for quantifying training loads in athletes (i.e. HR methods and external work). The criterion validity of these methods was established through comparisons with oxygen consumption ($\dot{V}O_2$) in a laboratory setting. Each method for quantifying training load showed strong relationships with criterion measures. However, this study showed poor levels of reliability for the session-RPE method and HR methods. *Study 3* further examined the validity of common methods for quantifying training loads in a practical setting. This study applied each method for quantifying training load to a mathematical model in an attempt to assess the accumulated effects of training.

Construct validity was established for each training load input with strong relationships between actual performance and modelled performance predicted by the model. This study also examined the validity of commonly used methods for assessing fitness and fatigue. This was achieved by comparing actual measures of fitness and fatigue with those predicted by the model.

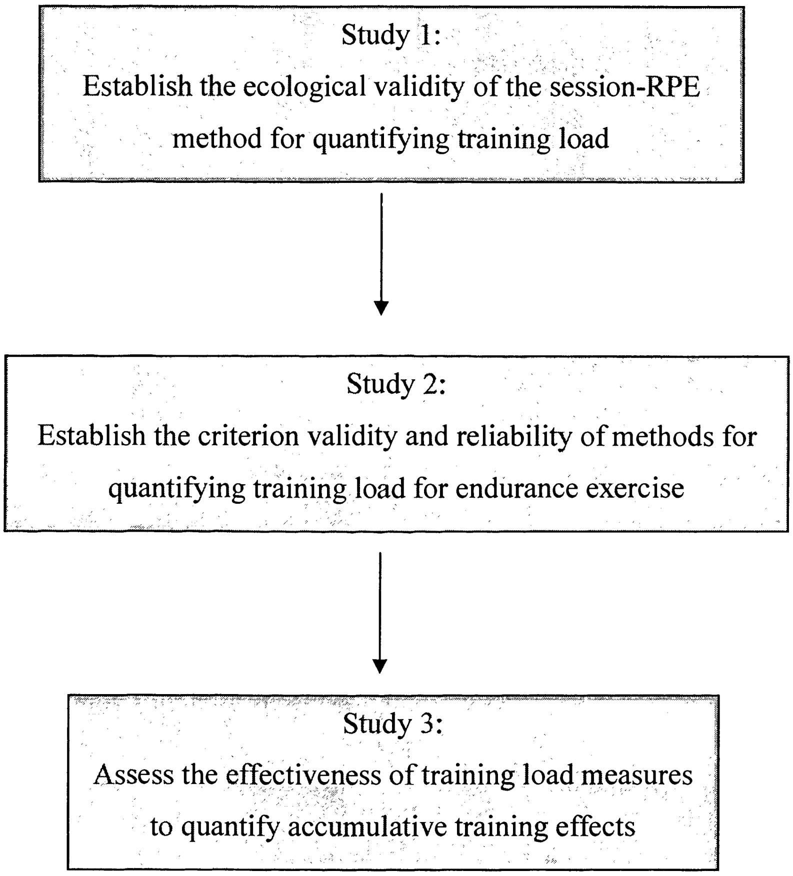

Figure 1.1: General outline of the research progress linking the three major studies undertaken in this thesis.

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Chapter 2

Literature Review

INTRODUCTION

An athlete's performance capacity may be influenced by their ability to adapt to increasing training loads. Consequently, coaches and athletes are continually challenged to find the delicate balance between training and recovery in order to optimise athletic performance. There are a variety of methods available to quantify the training loads undertaken by athletes (Saltin and Hermansen 1966). These methods have been described based on a measure of external training load (a measure of training load independent of individual internal characteristics), and a measure of internal training load (the response of an athlete to a training stimulus) (Winter and Fowler 2009). Despite the widespread use of these methods, it is not known which method for quantifying training load is more appropriate for monitoring the training process, or which relates best to training outcomes (i.e. performance, fitness and fatigue).

Previous authors have suggested that mathematical modelling (i.e. systems modelling) can be used for describing and estimating the influence of physical training on athletic performance (Banister et al. 1975; Taha and Thomas 2003; Borresen and Lambert 2009). Simplified models have shown each exercise bout to provoke both a positive fitness response and a negative fatigue response on athletic performance. An increased understanding of the relationship between training load, fitness and fatigue is therefore important for coaches and athletes to be able to design more efficient training regimes and obtain peak performance for a desired competition.

This literature review will describe the various quantitative and qualitative methods currently used for quantifying training load. It will also examine existing training models and ultimately provide a greater understanding of the effects of physical training on performance.

Training Theory

Despite many innovations in clothing, equipment and modern nutritional trends, the major influence on improving physical performance still appears to be the type and amount of physical training completed by the athlete (Rowbottom 2000). An optimal balance between training and recovery is essential in order to optimise athletic performance (Kreider et al. 1998). It is for this reason that a well-planned training program is the key to increased physical performance in athletes.

The potential for performance improvement may be determined by the athlete's ability to tolerate the demands of training and competition and adapt to the stressor placed upon it by the training program (see Figure 2.1, over page) (Fry et al. 1992b). During overload training (Fry et al. 1992b), physical exercise places the body under stress, leading to a disturbance in cellular homeostasis (Kuipers and Keizer 1988). Following overload, there is a period where the body attempts to re-establish homeostasis. The length of this period depends on a number of factors, primarily the extent to which homeostasis has been disrupted (Fry et al. 1992b).

It has been suggested that the recovery process does not stop when homeostasis is restored but will continue until a small supercompensation has occurred (Kuipers and Keizer 1988). During the supercompensation phase, physiological adaptation is greater than prior to the stimulus. For adaptation and supercompensation to occur appropriate rest must be allowed before a stressful stimulus is again applied (Kuipers and Keizer 1988).

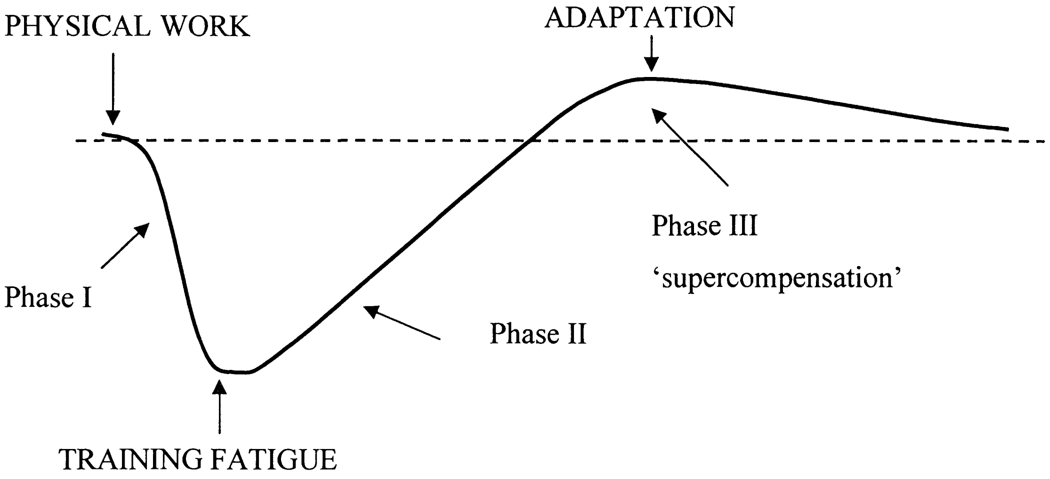


Figure 2.1: General adaptation syndrome theory explaining response to a stressor (Selye 1956).

If the athlete trains before or after the compensation curve reaches its peak, the training benefit may not be optimal. If the rest period between stress stimuli is too long, overcompensation will not occur and gained performance capacity may dissipate. Conversely, if the rest period is too short, the athlete may be fatigued from previous stress and displace homeostasis even further which does not allow the body to achieve the desired work outputs (Rowbottom et al. 1998; Snyder et al. 1995; Fry et al. 1992c). If continual repeated disturbances in homeostasis are not matched with adequate recovery then maladaptive training may occur (see Figure 2.2). Maladaptive training can lead to periods of reduced performance such as overreaching and overtraining.

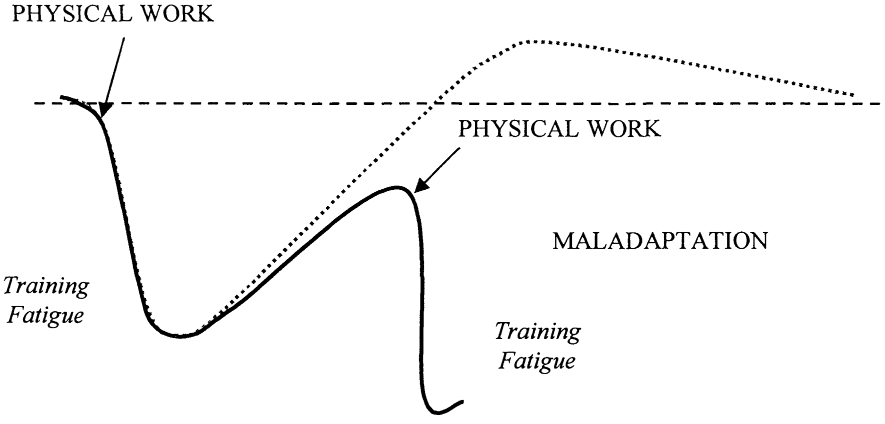


Figure 2.2: Maladaptive training due to an imbalance between training and recovery following a training bout (Calder 1991).

OVERREACHING AND OVERTRAINING

In an attempt to improve performance, many athletes often incorporate high training volumes and limited recovery periods into their training regimes (Kreider et al. 1998). This exercise stress may exceed an athlete's finite capacity of internal resistance often resulting in overreaching (Halson et al. 2002). The term short-term overreaching (functional overreaching) is used to describe an intensified period of physical training designed to result in a temporary reduction in performance (Meeusen et al. 2006). When appropriate recovery is prescribed, a supercompensation effect may occur and improve the performance capacity of the individual. However, if the intensified training period is maintained for a prolonged period of time, a state of non-functional overreaching or the Overtraining Syndrome may manifest (Meeusen et al. 2006). Non-functional overreaching is defined as the accumulation of both training and non-training stress resulting in a short-term decrement in performance capacity with or without related physiological and psychological signs and symptoms (e.g. hormonal dysregulation, psychological disturbances, reduced immune function, sleep disorders) with the restoration period often lasting from several days to several weeks (Kreider et al. 1998). An important difference between functional and non-functional overreaching is that non-functional overreaching is usually unplanned. The signs and symptoms of the Overtraining Syndrome are similar to those observed in non-functional overreaching. However, the main difference between the conditions is that the length of time taken for performance capacity to return during the Overtraining Syndrome may be several months (Kreider et al. 1998).

The Overtraining Continuum describes the non-distinct phases in the development of overtraining (see Figure 2.3, over page) (Fry et al. 1991b). The first stage along this continuum reflects the fatigue present following a single training session. Continued heavy training with the absence of adequate recovery periods will move the athlete towards a state of overreaching where the symptoms become more complex and severe. Finally, if high training loads are continued without adequate recovery from the overreached state, symptoms will become chronic and the Overtraining Syndrome may develop (Fry et al. 1991a). Therefore, from a practical perspective, it is important to be able to accurately quantify and control the training load applied to athletes.

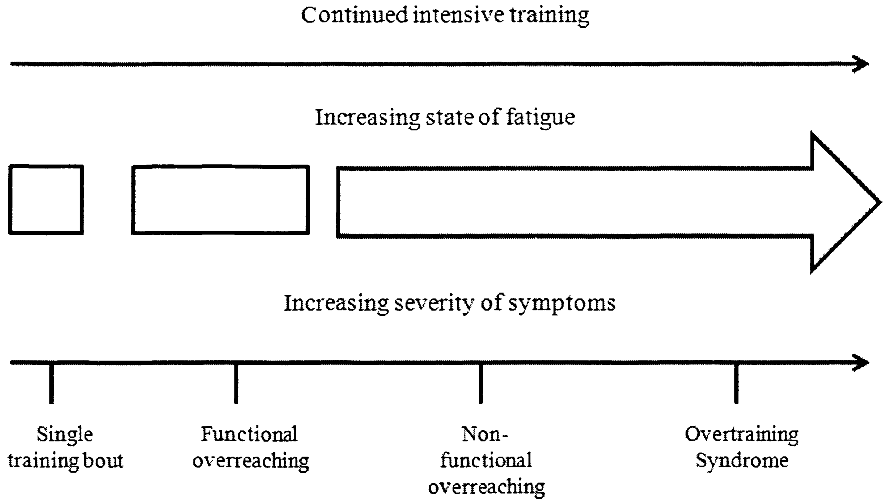


Figure 2.3: The Overtraining Continuum; updated to include non-functional overreaching (Meeusen et al. 2006).

QUANTIFYING PHYSICAL TRAINING

Training programs typically quantify physical training with reference to the type, frequency, duration and intensity of each exercise bout. Traditionally, training load has been described as a measure of external load (e.g. training duration, speed distance covered) (Impellizzeri et al. 2005). Recently, technologies such as Global Positioning Systems (GPS), accelerometers and power meters have allowed for increasingly detailed information to be collected on the external dose completed by the athlete. These advances have increased the application of external measures for the quantification of training in endurance based and team sports (Carling et al. 2008; Jobson et al. 2009; Borresen and Lambert 2009). However, the associated cost, time-consuming data analysis and required expertise has limited the wider use of such devices to individuals with significant financial reserves. Additionally, external load may not accurately depict the physiological stress imposed on individual athletes, as other factors such as genetic background and pre-training level must be taken into consideration.

Accordingly, it is the relative physiological stress imposed on the athlete (internal training load) and not the external training load completed by the athlete that determines the stimulus for training adaptation (Viru and Viru 2000). The relationship between internal and external training load measures and training outcome is shown in Figure 2.4 (Impellizzeri et al. 2005). Measures of internal training load have therefore become increasingly popular for quantifying training outcomes in athletic populations (Borresen and Lambert 2009). There have been many attempts by researchers to develop a suitable method for quantifying internal training load that incorporates both training duration and individual training intensity. At present, the most commonly used methods for quantifying internal training load utilise HR as a measure of exercise intensity. However, other methods for quantifying relative training intensity include blood lactate and RPE (Borresen and Lambert 2009; Impellizzeri et al. 2005). These methods for quantifying training intensity and their application to training load methods are discussed in the next section.

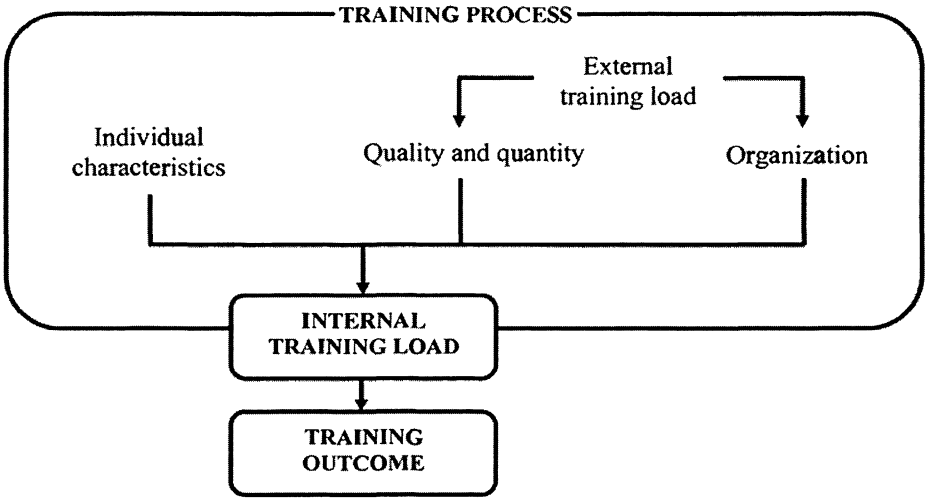


Figure 2.4: The relationship between internal and external training load on training outcomes (Impellizzeri et al. 2005).

Heart rate

In order to monitor an athlete's internal training load, the intensity of each training bout needs to be accurately assessed (Foster et al. 2001a; Fry et al. 1991b; Kuipers 1998; O'Toole et al. 1998). The use of HR information to determine exercise intensity is based on the linear relationship between HR and the $\dot{V}O_2$ over a wide range of steady-state submaximal workloads (Åstrand and Rodahl 1986). By determining the relationship between HR and $\dot{V}O_2max$, HR can be used to estimate $\dot{V}O_2$, giving an indication of the work being performed (Achten and Jeukendrup 2003). This relationship between HR and $\dot{V}O_2$, along with the development of portable, wireless HR monitors, has seen HR become the most commonly used method for determining exercise intensity in the field (Achten and Jeukendrup 2003). General classifications such as the Karvonen method (Gilman 1996) have been developed using $\%HR_{max}$ and $\%HR_{reserve}$ ($HR_{max} - HR_{rest}$) information to estimate exercise intensity expressed as

$\%\dot{V}O_2max$ or metabolic equivalents, without determining the individual relationship between HR and $\dot{V}O_2$. However, since the HR response to a given exercise bout is largely individual, the optimal use of HR information is reached when the direct relationship between HR and $\dot{V}O_2$ is measured directly in the laboratory.

In summary, HR shows an almost linear relationship with $\dot{V}O_2$ during a wide range of submaximal exercise intensities. Therefore, HR information may provide a simple and accurate estimation of exercise intensity across a wide range of exercise modes. In addition, HR information may be useful for predicting and monitoring fitness levels and prescribing training loads (Achten and Jeukendrup 2003; Zavorsky 2000)

Heart rate based methods for quantifying training load

There have been several attempts to monitor the internal load placed on an athlete using a single term. Cooper (1968) first proposed a concept of 'aerobic points', which integrated exercise duration and the absolute intensity of aerobic training activities. Although this method provided an index of how likely a given exercise bout was to induce a training effect, it lacked the ability to interpret relative training intensity and therefore adequately describe training load. Banister et al. (1975) developed the concept of training impulse (TRIMP) as a strategy for integrating all the components of training into a single arbitrary unit suitable for a systems model approach to training. Physical training was considered to be impulsive in character, with each training bout exerting an immediate training effect which dies away exponentially until the next training bout (Banister et al. 1975). This method was successful in providing a greater understanding of the dose-response of training and was later extended by Busso et al. (1997), Lucia et al. (2003), Mujika et al. (1998; 1996a) and

Foster et al. (1998; 1996; 1995; 1997). These methods will be further discussed in more detail in the following sections.

Banister's HR-Based TRIMP

The TRIMP method was initially applied to swim training where an arbitrary training load was calculated by distance swum multiplied by a subjective intensity factor (Banister et al. 1975). A similar method was used to calculate the dry-land component of training with the sum of both types of training equating to the overall training load for the individual swimmer. The same group of researchers (Banister et al. 1999; Morton et al. 1990; Banister and Fitz-Clark 1993; Banister and Hamilton 1985) later developed a more objective method for estimating exercise intensity using average HR to determine the average level of HR reserve (ΔHR ratio) during each session. This method required the recording of HR information for each training session as well as knowledge of maximum and resting HR (HR_{rest}) values. A weighting factor was also incorporated to emphasise the relatively greater stress of high-intensity training. This factor was determined as the exponential of the product of average ΔHR ratio and a constant (*b*) reflecting the generalised blood lactate to exercise intensity curve. The expression of training load was represented by the equation:

$$\textit{Training load} = D(\Delta HR\ ratio)e^{b(\Delta HR\ ratio)} \qquad (1)$$

where D = duration of training session, and b = 1.67 for females and 1.92 for males (Morton et al. 1990; Banister and Fitz-Clark 1993).

This TRIMP method for monitoring training load was shown to be effective and was later extended in further investigations (Foster 1998; Foster et al. 1996; Foster et al. 1995; Foster and Lehmann 1997; Busso et al. 1997; Mujika et al. 1996a; Mujika 1998). For example, Busso et al. (1997) compared each training session by considering each session to correspond to the same training dose when exercises were performed at a prescribed intensity. Work undertaken during the recovery periods was not considered in the computation of the training dose. Each training session would correspond to either 100 or 50 units for intense and reduced training, respectively, when it was performed at reference intensity: between 100% and 85% of maximal aerobic power (MAP) dependent on the interval length. The training dose was then corrected to the true exercise intensity by multiplying either 100 or 50 units by the difference between the average MAP of the subject whilst completing the interval and the prescribed MAP corresponding to the interval length. For example, if an exercise session during an intensive training period consisted of 3 min intervals at an intensity of 95% MAP, and the subject completed the session at 90% MAP, then the exercise dose would be 100 multiplied by the ratio between 90 and 95 = 94.7 units.

Alternatives to Banister's HR-Based TRIMP

Based on the work of Edwards (1993), Foster et al. (1995) proposed an alternative approach to TRIMPS that involved integrating the total volume of a training session with the total intensity of the exercise session relative to five intensity phases. An exercise score for each training bout was calculated by multiplying the accumulated duration in each HR zone by a multiplier allocated to each zone (50–60% = 1, 60–70% = 2, 70–80% = 3, 80–90% = 4 and 90–100% = 5). This approach was further developed by Lucia et al. (2003) using the HR phases I, II and III representing below ventilatory threshold (VT), between VT and the respiratory compensation point (RCP) and above RCP, respectively. By dividing HR values into zones, the previous researchers allowed exercise intensity to be calculated in a less complicated and more practical manner. Additionally, these methods placed a greater emphasis on the contribution of high-intensity training on global training load.

Collectively, the previous research demonstrates that HR methods for quantifying training loads have been quite successful for monitoring training loads in modelling studies. However, several limitations in the use of these methods have prevented widespread use by coaches, athletes and fitness enthusiasts. These limitations are presented in the next section.

Limitations to the heart rate based methods to quantify training load

The use of HR information has been widely accepted as a useful method for predicting and monitoring fitness levels (Achten and Jeukendrup 2003; Zavorsky 2000). Accordingly, HR has been used to quantify training intensity in many studies investigating the accumulated effects of training (Lucía et al. 2003; Morton et al. 1990; Banister and Hamilton 1985; Calvert 1976). However, other previous studies have proposed several limitations in using HR information for this purpose (Bourgois and Vrijens 1998; Foster et al. 1995; Bourgois et al. 2004; Lucia et al. 1999). For example, obtaining HR information requires expensive equipment and a level of expertise in interpreting the results.

Foster et al. (1995) proposed at least two further limitations in the previously described HR methods for quantifying training load. Firstly, if a HR monitor is lost or has a technical failure, then valuable information regarding that training session will be lost. Secondly, HR response is a relatively poor method for evaluating intensity during high-intensity exercise such as weight, interval and plyometric training

(Akubat and Abt 2011). For example, in a study incorporating 210 runners, Conconi et al. (1982) reported the expected linear relationship between HR and running speed at submaximal workloads, but a plateau in HR at high running speeds. The previous authors also reported that the deflection point in the HR-running speed relationship occurred at the same time as the anaerobic threshold (Conconi et al. 1982). However, other researchers attempting to repeat this study only found the plateau in a percentage of the individuals tested (Bodner and Rhodes 2000). Furthermore, numerous authors have reported that the HR deflection point overestimates the directly measured lactate threshold (Bourgois et al. 2004; Bourgois and Vrijens 1998; Lucia et al. 1999).

The consensus from the research suggests that HR may be useful for quantifying intensity during aerobic activity. However, exercise involving weight training, plyometric training and select interval sessions which often do not involve high HRs but are very intense may be underestimated using these methods. Therefore, HR appears most useful for monitoring training loads in athletes undertaking endurance exercise. Alternative methods such as measures of blood lactate concentration have also been developed to quantify exercise intensity and used to monitor training loads in athletes.

Blood lactate based methods for quantifying training intensity

Muscle and blood lactate accumulation occurs during exercise when there is a greater production than clearance of lactate (Billat et al. 2003; Brooks 1985). The amount of blood lactate present during submaximal and maximal exercise has previously been used to predict endurance performance and to prescribe physical training intensities

(Coyle 1999; Tanaka et al. 1983; Mader 1991; Jacobs 1986; Jones and Carter 2000). Additionally, blood lactate has been used to assess adaptations to physical training (Jacobs 1986; Bosquet et al. 2001; Snyder et al. 1993; Foster et al. 1988). Accordingly, the use of blood lactate measures has been suggested as a useful method for quantifying training intensity during prolonged modelling studies (Mujika et al. 1996a; Avalos et al. 2003). For example, Mujika et al. (1996a) used weighted coefficients based on individual lactate curves to quantify training load in elite swimmers. Training was divided into five intensity zones based on swimming speeds that elicit known blood lactate levels. Training load for a particular session was calculated by multiplying the time spent at each swimming speed by the coefficient representing that intensity zone. Dry-land training was also calculated in the same training units by multiplying the time spent doing each exercise by an estimated intensity rating for that exercise.

In a further study, Avalos et al. (2003) also adopted a lactate based system for quantifying training load whilst modelling the training-performance relationship in 13 competitive swimmers. However, instead of using weighted coefficients, each intensity level was expressed as a percentage of the maximum intensity recorded during the study. The global weekly training load was determined as the mean of the normalised weekly training intensities. However, since this method requires retrospective analysis of data, it is not suitable for predicting performance.

Collectively, the research suggests that blood lactate measures may provide an accurate measure of exercise intensity in athletes. However, blood sampling procedures require expensive equipment, expertise when analysing results and are highly invasive. In addition, the few performance modelling studies that have adopted this method have focussed on swim training. Therefore, the use of blood lactate measures for modelling the training-performance relationship may only be valid in athletes undertaking swim training.

Rating of perceived exertion based method to quantify training load

An alternative method for determining exercise intensity is through an individual's RPE. According to Borg (1982b), the overall RPE integrates information elicited from peripheral working muscles and joints, central cardiovascular and respiratory functions, and from the central nervous system. The first effective methods for measuring perceptual intensities were the ratio-scaling methods developed by Stevens (1970, 1957). One such method is the 'ratio production' method where subjects are asked to increase or decrease a certain variable stimulus until it is perceived to be a certain fraction or multiple of a standard stimulus. From this, a scale describing how perceived intensity varies with actual physical intensity was created. Another popular ratio-scaling process is the 'magnitude estimation' method (Stevens 1970). Using this method, subjects are asked to assign a number to a range of different intensities relating to how intensely they perceived the effort.

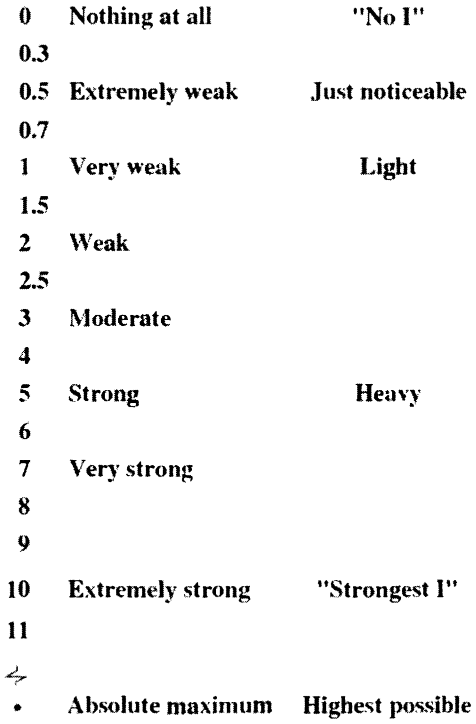
One of the major draw backs of the ratio-scaling method is that it does not provide any direct 'levels' for individual comparison. Therefore, since subjects are only asked to make relative comparisons, it is difficult to compare perceived efforts between individuals. To overcome the problems associated with the ratio-scaling methods, Borg (1962) used a category-scaling approach to develop a 21-grade rating of perceived exertion scale with verbal anchors. The exact metric properties of this scale are less important, however, each rating of intensity becomes greater than the previous intensity. Therefore, it can be assumed that if a subject records an intensity to be light this subject would perceive the intensity to be relatively lighter than a subject that records the intensity to be hard.

An alternative category-scale was developed by Borg (1970) where perceptual ratings increase linearly with power output and HR on a cycle ergometer (see Figure 2.5). The difference in intensity between each score is identical. Due to the relationship with HR, the Borg 15-point scale is primarily used for quantifying intensity during endurance exercise. For simplicity purposes, the scale values range from 6–20 and by adding a zero to the score it can be used to denote HRs from 60–200 beats·min^{-1}. For example, an RPE score of 14 would reflect a HR of 140 beats·min^{-1} in subjects aged 30–50 years. However, this relationship was not intended to be taken literally as HRs are largely individual and are greatly affected by external influences.

6	**No exertion at all**
7	**Extremely light**
8	
9	**Very light**
10	
11	**Light**
12	
13	**Somewhat hard**
14	
15	**Hard (heavy)**
16	
17	**Very hard**
18	
19	**Extremely hard**
20	**Maximal exertion**

Figure 2.5: The 15-point scale for ratings of perceived exertion (Borg 1970).

Although the Borg 15-point scale relates to physiological variables such as HR which increase linearly with exercise intensity, some physiological variables such as lactate production relate to exercise intensity in a non-linear fashion. For example, when lactate is plotted as a function of the Borg 15-point scale, lactate concentration increases approximately three times more at the top of the scale (ratings 16–17) than the bottom (Borg 1970). Therefore, to identify fatigue associated with non-linear physical responses (i.e. lactate metabolism), Borg (1982a) developed the category-ratio perceived exertion scale, a new category scale with ratio scale properties that would increase in a positively accelerating fashion (see Figure 2.6). For simplicity, the Borg category-ratio 10 scale uses values ranging from 0–10 and as with other category scales, these values are anchored by verbal expressions to allow for individual comparisons. Furthermore, each of these verbal expressions has been placed in the correct position on a ratio scale and carries the inherent meaning of twice the intensity as the previous value (e.g. very weak and weak).



0	**Nothing at all**	**"No I"**
0.3		
0.5	**Extremely weak**	**Just noticeable**
0.7		
1	**Very weak**	**Light**
1.5		
2	**Weak**	
2.5		
3	**Moderate**	
4		
5	**Strong**	**Heavy**
6		
7	**Very strong**	
8		
9		
10	**Extremely strong**	**"Strongest I"**
11		
•	**Absolute maximum**	**Highest possible**

Figure 2.6: The category-ratio scale of perceived exertion (Borg 1982a).

Previous investigations have shown a high correlation between the Borg category-ratio scale and both blood and muscle lactate during exercise (Noble et al. 1983). For example, Noble et al. (1983) studied the relationship between the Borg category-ratio scale, blood lactate, muscle lactate and HR in ten physically active males during exercise. All ratings showed a positively accelerating increase with exercise intensity as did both blood and muscle lactate, while HR increased linearly. The previous researchers confirmed the usefulness of this scale during high-intensity exercise when the glycogenolytic contribution to energy production is greatest. Furthermore, significantly higher perceptual responses were observed in the subjects with a greater percentage of fast-twitch (FT) muscle fibres. Given that a greater lactate accumulation during high-intensity exercise has been shown in subjects with a greater percentage of FT muscle fibres (Tesch et al. 1978), Noble et al. (1983) concluded that subjects with a greater percentage of FT muscle fibres may perceive high-intensity exercise to be more intense and therefore qualitative changes in motor unit recruitment may be perceived.

In summary, there does not appear to be one perfect scale for measuring perceived exertion in all situations. The Borg 15-point scale remains the most widely used scale for perceiving exercise intensities during most exercise-based activities. However, it does appear that the Borg category-ratio scale may be more suited to high-intensity exercise where fatigue is associated with non-linear physical responses such as lactate production. More recently, RPE has been used in conjunction with other measures in an attempt to quantify internal training load in athletes. The most widely used RPE-based method for quantifying training load is the session-RPE method, which will now be discussed.

The Session-RPE method

The session-RPE method was first proposed by Foster et al. (1995) as a modified version of the TRIMPS method for monitoring physical training. As with the TRIMPS method, session-RPE involves multiplying training intensity by training duration to create a training impulse score for each training session. However, due to the difficulty of measuring HR during training sessions involving large subject numbers, and the concerns of using HR scores to accurately monitor training loads during high-intensity training sessions, Foster et al. (1995) used a subjective measure to evaluate global training intensity. The session-RPE method requires subjects to rate the intensity of the entire training session using an RPE score according to the scale of Borg et al. (1987). The intensity value is then multiplied by the total duration (mins) of the training session to create a measure of training impulse. This measure of training impulse represents the internal training load of the individual.

Previous investigations examining the validity of session-RPE for measuring internal training load has been successful over a variety of exercise intensities. For example, during pilot studies, Foster et al. (1995) reported a moderate correspondence between percentage HR reserve during 30 min steady state runs. Further investigations by Foster et al. (1995) revealed a good correspondence between session-RPE and the behaviour of HR below, between and above commonly used blood lactate transition zones (2.5 and 4.0 $\text{mmol}\cdot\text{l}^{-1}$) during 30 mins of interval and steady state exercise. Accordingly, the authors concluded that the session-RPE method provided approximately the same information regarding training intensity as the HR TRIMP method.

In a further study, Foster et al. (2001a) compared session-RPE with the summated HR-zone method of Edwards (1993) in 14 collegiate male basketball players during basketball practice and competition. The author reported a strong relationship between the two methods, with the session-RPE giving a significantly higher score than the HR approach. These results show that although there is a good relationship between the two methods, they are not interchangeable due to a difference in scale. The previous findings were also consistent and similar to a related study by Foster et al. (2001a) evaluating training responses to steady state and interval cycling exercise. The previous authors supported the use of session-RPE as a subjective measure of internal training load in team sport athletes during practice and competition.

More recently, session-RPE has been used to quantify internal training load in team sport athletes (Impellizzeri et al. 2004; Coutts et al. 2003; Foster et al. 2001a; Alexiou and Coutts 2008; Gomez-Piriz et al. 2011; Manzi et al. 2010). For example, Impellizzeri et al. (2004) first used session-RPE to quantify internal training load in nineteen young soccer players during a seven week training period. Session-RPE was correlated with training load measures from three different HR methods suggested by Edwards (1993), Banister et al. (1991) and Lucia et al. (2003). All individual correlations between HR methods and session-RPE were statistically significant (from $r=0.05$ to $r=0.08$, $p<0.01$). The authors concluded session-RPE to be a good indicator of global internal training load in soccer players and a practical tool for the development of successful periodisation strategies. Collectively, the previous studies suggest that similar information may be obtained using the subjective session-RPE method compared with objective HR approaches for quantifying a global measure of internal training load.

To date, only one study has examined the reliability of the session-RPE method for quantifying internal training load (Herman et al. 2006). The authors reported no difference between test-retest values for session-RPE, $\dot{V}O_2$ and HR during 30 min constant load exercise bouts in 14 physically active participants. However in a related study by the same researchers (Foster et al. 2001a), an upward drift in session-RPE values were reported during prolonged exercise. These results highlight the need to assess the validity and the reliability of the session-RPE method during intense training periods and prolonged exercise bouts.

In conclusion, the present research suggests a large consistency exists between session-RPE and other HR approaches for quantifying internal training loads in athletes. It has also been suggested that session-RPE may provide a more valid approach during high-intensity exercise bouts (e.g. sprint, resistance and plyometric training) which cannot be objectively evaluated using HR methods. Furthermore, session-RPE does not require the use of expensive equipment or knowledge of maximal exercise responses. Therefore, the simplicity of the session-RPE method adds to the practical value of this technique.

Training Stress Score for quantifying training load

An alternative to methods for quantifying training load using internal measures is the Training Stress Score (TSS). The TSS was first proposed by Allen and Coggan (2006) as a method to assess training load based on data collected using cycling power meters. The TSS is an adaptation of Banisters' TRIMP (Banister et al. 1975) whereby HR measures are replaced with power output. Specifically, the TSS is equal to the duration of exercise (min) multiplied by the normalised average power of the exercise bout and by a power-dependent intensity weighting factor (IF). The TSS can therefore provide a single estimate of the overall training load and physiological stress created by that training session. Currently, commercially available software is used to calculate TSS using downloaded data from a cycling power meter combined with the individual's average power output during a well-paced maximal 1 h cycling time trial. This can then be used to calculate the IF. Recent research by Garvican et al. (2010) used the TSS to monitor the training load in 10 elite female cyclists throughout a competitive season. The previous findings showed that the changes in haemoglobin mass, a proposed indicator of aerobic capacity, were significantly related to changes in TSS. These findings suggest that TSS is able to adequately assess the demands and associated physiological responses to physical training. However, more published data is required to establish the validity and reliability of TSS in an ecological setting.

The TSS concept has also been modified for running using speed/distance measures and a unique algorithm based on the demands of running has been developed (Skiba 2006). The running TSS (rTSS) calculates the training dose via multiplying training duration by training intensity which is based on an intensity factor calculated from a percentage of 'threshold' running pace usually determined from a series of running time-trials. Similar to the TSS, once the individual's threshold running pace is established, the rTSS can also be calculated using commercially available software and data collected via GPS devices or accelerometers. A case study by McGregor et al (2009) used a modified rTSS in an input-response model to successfully track the fitness and fatigue of an elite 1500m runner over a 7 y period. Whilst this method seems viable for assessing training load, its efficacy is yet to be properly tested. However, further research is required to assess the validity and reliability of rTSS to quantify a training dose.

Due to recent technological developments both the TSS and rTSS are becoming increasing popular amongst athletes and coaches as measures of training load.

However, despite their popularity, they are yet to receive critical scientific evaluation. The accuracy of these measures may be dependent on the correct calibration of the equipment used to measure power output and running velocity. Likewise, the ability of each individual to correctly pace the time trials used to predict IF will affect the calculation of the TSS. Therefore, more research is required to establish the usefulness of these measures to quantify training load in a practical environment.

QUANTIFYING PERFORMANCE

Accurate quantification of performance is necessary to understand the influence that physical training and other external stressors have on an athlete. Indeed, several studies have used mathematical models to describe the effects of training on performance in terms of a dose-response relationship (Banister et al. 1975; Taha and Thomas 2003; Busso and Thomas 2006). Physical training represents the dose or systems input and performance represents the response or systems output. While some modelling studies have obtained performance values during competition (Avalos et al. 2003; Hellard et al. 2005), the majority have used regular performance tests under controlled conditions. These tests include; time trials (Banister et al. 1975; Banister et al. 1999; Morton et al. 1990; Banister and Hamilton 1985; Calvert 1976), incremental tests to volitional fatigue (Banister et al. 1975; Busso et al. 1991; Banister et al. 1999; Busso et al. 1997), iso-inertial tests (Busso et al. 1990; Busso et al. 1992; Busso et al. 1994), constant durations tests (Busso et al. 2002) and subjectively rating competition performance (Millet et al. 2002).

A simple method for quantifying performance was developed by Busso et al. (1991) and involves converting performance values into an arbitrary performance unit so that the initial performance value forms a baseline for future performances. These values were expressed on a common scale to avoid distorting the performance level when comparing individuals. This arbitrary unit system for quantifying performance has been used in several modelling studies with great success (Mujika et al. 1996a; Avalos et al. 2003; Busso et al. 1991). For example, Busso et al. (1991) modelled responses to training in eight sedentary males during a 14 week cycling endurance training program. The performance test was based on the power each subject could sustain for 1 h on a bicycle ergometer. A score of 100 arbitrary performance units was allocated to the first measured performance in each subject. All subsequent performances trials were expressed relative to the first. Furthermore, other studies in swimmers have successfully modelled the training-performance relationship by expressing the performance values as a percentage of personal best times for that event (Mujika et al. 1996a; Avalos et al. 2003).

The arbitrary performance unit method for quantifying performance is simple and easy to calculate. However, Morton et al. (1990) suggested this method may only be useful when changes in performance values are linear. In a practical setting, changes in performance values are predominantly non-linear. For example, in elite athletes, large training loads often result in relatively small improvements in performance compared with sedentary people where relatively large improvements in performance occur upon commencement of a training program (Foster and Lehmann 1997). Therefore, in cases where changes in performance values are non-linear, a criterion point scale developed by Banister and Hamilton (1985) has been applied (Banister and Hamilton 1985; Morton et al. 1990; Mujika et al. 1996a).

The criterion point scale system involves allocating an arbitrary score to all performances along a curve from a theoretical ultimate performance to an assumed able-bodied performance. For example, Banister and Hamilton (1985) modelled the variations in hematologic responses in five female distance runners during a 300 day training period. A criterion performance time trial was completed as many times as possible by each subject during the training period and measured on a point scale allocating 1000 points to 110% of the world record at any distance. By comparing the modelled performance with actual performance the authors defined fitness and fatigue curves for each athlete providing insight into the dose/response effect of training on iron status.

In a further investigation, Mujika et al. (1996a) followed 18 elite swimmers during a competitive season and modelled performance utilising both the criterion point scale and the arbitrary unit system. Initially, all performance values were converted into a percentage of personal best performances from the previous season. Performance values were also converted to a criterion point score based on personal best times and world record times for each event. Both methods for quantifying performance produced time constants and fatigue and fitness magnitude coefficients that were statistically equivalent. These findings suggest that the sensitivity of the model to variations in performance is low (Taha and Thomas 2003).

INTRODUCTION TO MODELLING TRAINING LOAD

Researchers have long been in search of a predictive model that may provide a better understanding of the physiological and psychological responses to a given training program. However, due to the complex interaction between these factors, the majority of modelling studies detailing the training-performance relationship have used models based on simplified abstractions of more complex underlying structures. Previous research has revealed reactions to a given training stimulus are highly individualised (Mujika et al. 1996b) and may be influenced by a number of factors which ultimately determine athletic performance (Banister et al. 1975; Calvert 1976). These primary determinants of athletic performance include genetic factors (Wolfarth et al. 2000), training background (Mujika et al. 1996a; Johns et al. 1992), psychological factors (Banister et al. 1975) and technical factors (Toussaint and Hollander 1994). However, these influential components are often removed in modelling investigations due to difficulties in identifying and relating all the components and quantifying them on a common scale. Therefore, a greater understanding and quantitative assessment of all performance determinants is required to accurately describe and model the influence of physical training on performance. The following sections will provide a literature review of the existing systems approach to training.

Systems approach to training

Understanding the relationship between training and athletic performance is fundamental for athletes and coaches training to optimise performance. Many authors have studied the relative influence of physical training (Banister and Hamilton 1985; Mujika et al. 1996b; Banister et al. 1975; Banister et al. 1999; Busso 2003; Busso et al. 2002; Busso et al. 1997; Millet et al. 2002; Stewart and Hopkins 2000; Calvert 1976) and found that the response to training may be influenced by volume, intensity and frequency of training sessions (Mujika et al. 1996b). Initially much of the literature had been anecdotal or phenomenologically focussed, however, over the past few decades more scientifically based research incorporating delayed training effects and individual subject differences has emerged. This research has used a systems model approach to training.

The systems model approach to training was first proposed by Banister et al. (1975) incorporating a complex interaction of a number of factors contributing to everyday performance. According to this approach, the human body is represented as a system, reacting to different stimuli. The determinants of athletic performance outlined by Banister et al. (1975) included emotional outlook, level of skill and physical capacity, including both degrees of fitness and fatigue. The interaction between these factors and their relationship with performance is shown in Figure 2.7.

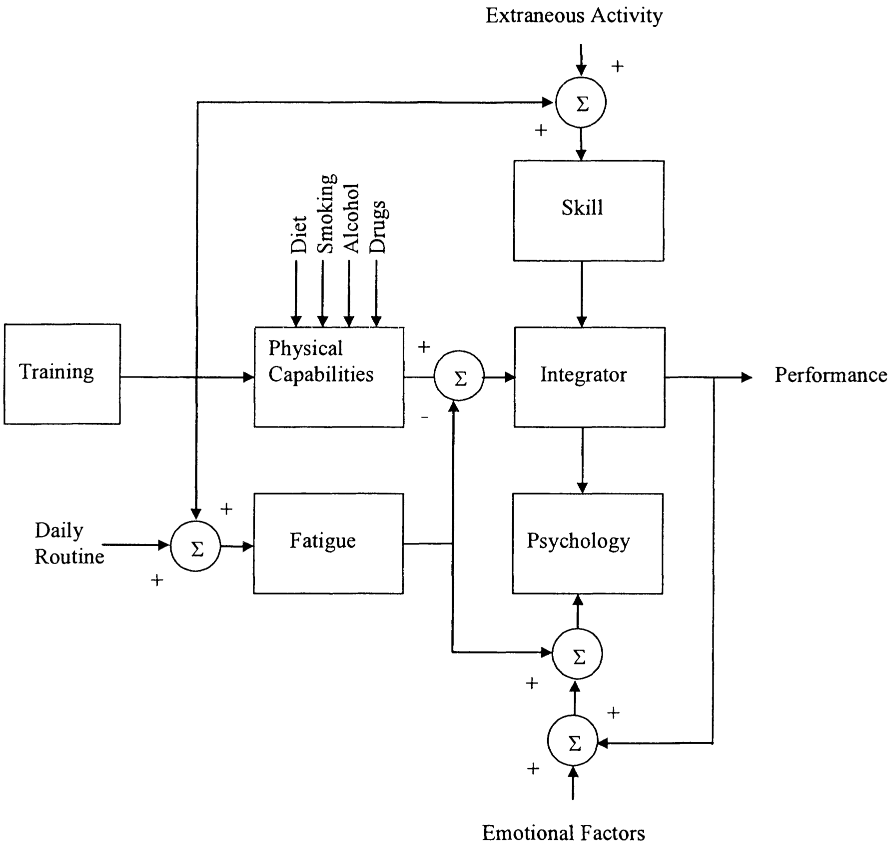


Figure 2.7: Hypothesised systems model of factors influencing performance (Banister et al. 1975).

The original model proposed by Banister et al. (1975) incorporated the effects of psychological influences and skill execution on athletic performance and seemed a logical approach. However, a limitation of this model is that such variables are difficult to measure precisely and quantitatively. Since physical capacity may be positively affected by the amount and type of training and negatively related to the amount of fatigue the training accumulates, Banister et al. (1975) considered physical capacity to be impulsive in character. Therefore, a simplified two-component model was proposed by Banister et al. (1975) and later extended by Morton et al. (1990) that only considers the input dose effect that training has on two response elements of fitness and fatigue (see Figure 2.8).

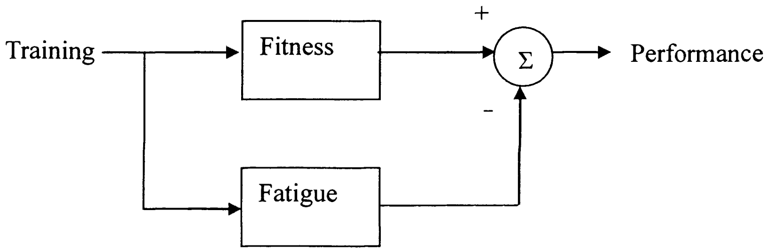


Figure 2.8: Simple two-component systems model of training and performance (Morton et al. 1990).

The execution of this model assumes emotional influences and skill level to remain constant. Therefore, an optimal performance occurs when fitness is maximised and subsequent fatigue minimised. Therefore, this simplified model can be shown as:

$$\text{Performance} = \text{Fitness} - \text{Fatigue}$$

The model theory is presented mathematically in the next section.

Mathematical methodology of a two-component systems model

The model proposed by Banister et al. (1975) assumes that a training impulse, or dose of training, contributes to both fitness and fatigue. The training impulse [*w(t)*] was initially measured quantitatively from variables including the duration (*D*) of training and the concomitant HR during a training session. The HR elevation may be regarded as an index of the factional utilisation of maximal oxygen consumption ($\dot{V}O_2max$) and may be expressed through the following equation:

$$\Delta HR\ ratio = \left[\!\left[\frac{[HRex]\ x}{[HRmax]\ x}\frac{(HRrest)}{(HRrest)}\right]\!\right] \qquad (2)$$

where *HRex* is the average HR during exercise, *HRrest* is the resting HR and HR_{max} is the maximal HR.

For each exercise segment for which HR is relatively constant, the product of the segment duration and the concomitant fractional elevation in HR provides a quantitative assessment of the attendant volume of training. These products may be summed over the duration of the whole training bout.

$$w(t) = D(\Delta HR\ ratio) \qquad (3)$$

Furthermore, *w(t)* is weighted by a multiplying factor *Y*, which emphasizes high-intensity training where blood lactate levels are commonly observed to rise exponentially. The *Y* factor may be expressed through the following equation:

$$Y = e^{bx} \qquad (4)$$

where x is $\Delta HR\ ratio$ and b representing the difference in male and female blood lactate responses during exercise.

Therefore, the equation for training impulse (TRIMP) becomes:

$$w(t) = D(\Delta HR\ ratio)Y \tag{5}$$

Systems response to training impulse

Predicted performance is considered to be the difference between the two determinants of fitness and fatigue at any point in time. The simplified model isolates the components of fitness and fatigue and assumes other determinants (i.e. psychological factors and skill) remain constant during the training process. This process may be calculated by a transfer function composed of two first order filters representing a fitness impulse and a fatigue impulse, both calculated by the training impulse. The effect is described by the equation:

$$g(t) = g(t - i)e^{-i/r1} + w(t) \tag{6}$$

and

$$h(t) = h(t - i)e^{-i/r2} + w(t) \tag{7}$$

where $g(t)$ and $h(t)$ are arbitrary fitness and fatigue response levels, respectively, at the end of day t, i is the intervening period between the current and previous training bout and $r1$ and $r2$ are decay time constants for these respective effects.

Fitness has a positive influence on performance and fatigue has a negative influence on performance. Therefore, at any stage in the training cycle performance [$P(t)$] may reflect the difference between the training effect and the fatigue effect. Thus performance may be calculated by the following equation:

$$P(t) = k_1 \, g\,(t) - \; k_2 \, h\,(t) \qquad (8)$$

where k_1 and k_2 are positive dimensionless weighting factors for fitness and fatigue, respectively.

Experimental validation of Banisters two-component systems model

The systems model approach has since been used in studies involving a variety of training modes including running (Morton et al. 1990; Wood et al. 2005; Suzuki et al. 2006; McGregor et al. 2009), cycling (Busso et al. 1991), swimming (Banister et al. 1975; Mujika et al. 1996a), weight lifting (Busso et al. 1990), and hammer throwing (Busso et al. 1994). For example, Banister et al. (1975) first applied a systems model approach to predict performance in a trained swimmer. The developed model provided optimal values for the training and fatigue effects, enabling a prediction of performance level at a particular training period. The previous authors also observed the onset of physical training to have a debilitating effect on performance with fatigue becoming predominant by the 15th day of the training program. A reduction in training for 21 days saw the training effects become predominant and an improvement in subsequent performance occur.

In a recent study, Wood et al. (2005) applied a mathematical model to training adaptation in a well-trained male distance runner throughout a 12 week training period. Fitness and fatigue parameters were estimated by fitting the model-predicted performance with actual performance. The modelled fitness component was correlated with extrapolated $\dot{V}O_2max$, running economy and running speed at ventilatory threshold while the fatigue component was correlated with the fatigue subset of the POMS. The fit between the model and actual performance was significant ($r^2 = 0.92$, $p<0.01$). These findings are consistent with another previous study where a modelling approached was used to guide the training process in one elite 400 m runner (Suzuki et al. 2006). The authors reported a strong relationship between modelled and actual performance where the session-RPE method was used as the training input ($r^2 = 0.88$, $p<0.001$). Collectively, these findings are in accordance with other previous research (Calvert 1976; Morton et al. 1990) suggesting a systems model approach to training may adequately explain training adaptation in a variety of athletes.

Variations in existing systems models

The initial training model described by Banister et al. (1975) was later extended by Morton et al. (1990) to include two antagonistic first-order transfer functions representing fitness and fatigue. In this two-component model, performance was represented by the balance between the fitness and fatigue responses at any given time. Although this method has been applied to various athletic cohorts with great success, other previous literature has shown performance to be related to changes in training loads in models containing between one and three first-order transfer functions. For example, Calvert et al. (1976) used a three-component model to quantify the training and performance relationship of an elite swimmer during a six month period. Using this model, a single training impulse elicited two fitness responses that would increase performance, and a fatigue response that would decrease performance (see equation 9). The two components of fitness were used to allow for both the long and short-term effects that fitness has on performance. Using a 100 m swimming time trial as a criterion performance test, the authors concluded that performance was related to the difference between the fitness and fatigue functions at a given time. Furthermore, the fitness function was related to a first order system with a time constraint of 50 days and the fatigue function related to training with a time constraint of 15 days.

3-comp model $P^n = p^* + k_1 \sum w^i \left[e^{-(n-i)/r1} - e^{-(n-i)/r1}\right] - k_2 \sum w^i \, e^{-(n-i)/r2}$

(9)

where performance *p(t)* on day n is obtained by the convolution product of the training doses *w(t)* on day i with the impulse response added to the basic level of performance noted p^*.

In contrast to these findings, other research has linked actual and model performance using only one first-order transfer function (Le Bris et al. 2006; Busso et al. 1991; Millet et al. 2002). For example, Busso et al., (1991) examined the statistical adequacy of the systems approach to training in eight initially untrained subjects who undertook a 14 week endurance training program. A model containing only one first-order transfer function representing the fitness component (see equation 10) provided a significant fit with the performance in every subject. Moreover, the inclusion of a second component representing the negative (fatigue) effects of training only improved the fit in two subjects. The inclusion of a third or fourth component did not allow a better fit of performance in any subject. However, since the subjects were mostly non active at the beginning of the study and exercise demands were rather moderate, it was suggested that stronger and more frequent exercise demands would produce a greater fatiguing effect. Therefore, it was concluded that the two antagonistic component model proposed by Banister et al. (1975) provided a good representation of the training response (Busso et al. 1991).

$$\text{1-comp model: } p^n = p^* + k_{21} \sum w^i \, e^{-(n-i)/r1} \tag{10}$$

where performance *p(t)* on day n is obtained by the convolution product of the training doses *w(t)* on day i with the impulse response added to the basic level of performance noted p^*.

In accordance with these previous results, Millet et al. (2002) modelled the cross-transfer of training effects between disciplines in four elite triathletes during a 40 week training season. A one-component model containing only the fitness function related performance with training load in swimming and cycling, whist a two-component model containing fitness and fatigue parameters provided a better fit for running. The addition of a third component did not significantly improve the fit in any of the athletes. The authors attributed the lack of negative effects in both swimming and cycling to the lack of precision in the quantification of both the training and performance, and by the smaller fatigue induced in these two disciplines compared to running.

In summary, previous applications of the systems model have been successful with models containing between one and three first-order transfer functions. However, it appears a model composed of two antagonistic first-order transfer functions of fitness and fatigue provides the most accurate representation of the training response in athletes undertaking heavy training periods. Because of its adequacy at describing the training response, this approach appears to be suitable for assessing the efficacy of different methods for quantifying training load and their relationship to performance.

Alternative approaches to systems models

An alternative approach to the systems model is the use of influence curves as proposed by Fitz-Clark et al. (1991). An influence curve is a map or template showing how a function, distributed over a domain, affects a response at a specific point (Fitz-Clarke et al. 1991). Although the actual model proposed by Fitz-Clark et al. (1991) is no different to the models previously described in the literature, the use of influence curves enables a clear picture of the affects a training bout has at a given time on performance at a later time. Utilising the model and data described by Morton et al. (1990), Fitz-Clark et al. (1991) derived a period of time in two recreational athletes where training should be stopped or reduced to achieve an optimal performance (*tn*) (see equation 11).

$$tn = r_1 \, r_{2}/r_1 - r_2 \, In \, k_{2}/k_1 \tag{11}$$

where In is a natural logarithm.

The authors reported that following the last bout of strenuous exercise, 15.8 ± 6.5 days of reduced training was required to achieve optimal performance in competition. The upper limit of recovery days (~23 days) required for optimal performance in the previous investigation was comparable to tapers performed by elite swimmers (21 days) and the time taken to achieve optimal performance (30 days) on an endurance test in moderately trained men and women who trained for ten weeks followed by a reduction in training load by 70% for a further 15 weeks.

Using the parameters described by Morton et al. (1990), Fitz-Clark et al. (1991) also examined the time period before competition about which physical training is maximally beneficial for competition (*tg*). The authors observed *tg* to be greatest 40 days prior to competition. The collective findings indicate that the use of *tn* and *tg* may be useful for optimising performance prior to competition. *tg* may be expressed using the following equation:

$$tg = r_1 \, r_{2}/r_1 - r_2 \, In \, k_{2}/k_1 \; r_{1}/r_2 \qquad (12)$$

In a further investigation, Busso et al. (1997) examined *tn* in three separate studies containing athletes of different ages and training experience. The authors observed a *tn* of 23 days for an elite hammer thrower who trained once or twice a day and had trained for seven years. Additionally, a *tn* of 8 and 11 days was estimated for two subjects following an intensive program of running 40-50 min for 28 days and 1-3 days for eight subjects performing moderate endurance training of one hour sessions at 60-70% $\dot{V}O_2$max on a cycle ergometer each week for 14 weeks. Indeed, the comparisons of the published model parameters showed that differences in *tn* could be dependent on the severity of the training doses (Busso et al. 1997). It appears that greater and more frequent training doses would contribute to a greater magnitude and duration of the fatigue induced by each training bout. Therefore, model parameters estimated for an athlete performing moderate training are unlikely to be representative of the responses for the same athlete during heavy training.

Previously described models have assumed that fitness and fatigue parameters within the model remain constant over time and were determined by fitting the model performances to actual performances. However, this assumption is not consistent with observed time-dependent alterations in response to training (Banister et al. 1999; Busso et al. 1997; Mujika et al. 1996a). Consequently, the linear time-invariant functions used in previous models may be unsuitable for describing responses to training using different regimes. Busso et al. (1997) suggested day-to-day variations in model parameters may lead to a better fit in performance and may describe more accurately adaptations to training and long-term fatigue. Therefore, to explore the modification of the training responses to a single training bout according to past training doses, Busso et al. (1997) proposed a recursive least squares algorithm with model parameters free to vary over time. Using this method, Busso et al. (2002) analysed the effects of an increase in training frequency on exercise induced fatigue in six previously untrained subjects during a 15 week training period. The variations over time in the model showed an increase in the magnitude and duration of fatigue induced by a single training bout. Furthermore, the time needed to restore performance increased from 0.9 ± 2.1 days following low-intensity training to 3.6 ± 2.0 days following high-intensity training. The authors concluded that shortening the recovery time between training sessions progressively yielded a more persistent fatigue induced by each training session. Consequently, it was concluded that the model initially proposed by Banister et al. (1975) may provide an imperfect description of training induced fatigue.

It was therefore proposed that a new formulation of the systems model was needed to take into account the increase in fatigue effect resulting from repeated physical training doses (Busso 2003). In this model, the performance response to a single training bout was dependent on the intensity of past training. In this context, Busso et al. (2003) developed a systems model with time-invariant parameters by introducing variations in the fatiguing effect of a single training bout. The proposed model assumed that the gain term of the fatigue effect is mathematically related to the training dose using a first-order filter. The new formulation of the model was compared with one- (Busso et al. 1991), two- (Banister et al. 1975) and three-component (Calvert 1976) models previously described in the literature. The models were applied to six previously untrained subjects over a 15 week endurance training program. The training program resulted in 30 ± 7% improvement in performance. The most recent model proposed by Busso et al. (2003) exhibited a significantly improved fit with actual performance in each subject, with a standard error of 6.47 ± 0.71 W compared with 9.20 ± 2.27 W to 10.31 ± 1.56 W for earlier models. The previous results indicated an inverted-U-shape relationship between daily amounts of training and performance.

The model proposed by Busso et al. (2003) assumed that the gain term of the fatigue effect was mathematically related to the training dose using a first-order filter. Performance output was described as:

$$\hat{p}^n = p^* + k_1 \sum_{i=1}^{n-1} w^i e^{-(n-i)/\tau 1} - \sum_{i=1}^{n-1} k_2^i \, w^i e^{-(n-i)/\tau 2} \qquad (13)$$

in which the value of k_2 at day i is estimated by mathematical recursion using a first-order filter with a gain terms k_3 and a time constant $\tau 3$:

$$k_2^i = k_3 \sum_{j=1}^{i} w^j e^{-(i-j)/\tau 3} \tag{14}$$

The parameters for the model were determined by fitting the model performances with actual performances using the least squares method. The set of model parameters was determined by minimizing the residual sum of squares between modelled performance and actual performances (RSS):

$$RSS = \sum_{n=1}^{N} [p^n - \hat{p}^n]^2 \tag{15}$$

where n takes the N value corresponding to the days of measurement of the actual performance. Successive minimization of the *RSS* with a grid of values for each time constant gave the total set of model parameters.

In summary, previous research suggests that the expression of a performance response to a single training bout is dependent on the dose of previous training sessions. Accordingly, the model proposed by Busso et al. (2003) where fatigue parameters are based on previous training bouts more closely describes the complexity of the accumulated effects of training. These findings support the use of this model as best practice for describing the dose-response relationship of physical training and performance.

Applications of systems modelling to improve athletic performance

To achieve optimal athletic performance a systematic reduction in physical training is first required prior to major competition (Mujika et al. 1996a; Houmard and Johns 1994; Neufer et al. 1987; Johns et al. 1992). This systematic reduction in physical training is known as tapering (Costill et al. 1991; Houmard and Johns 1994; Shepley et al. 1992; Yamamoto et al. 1988). Although tapering following periods of heavy training has been widely accepted as an integral part of optimising athletic performance, the specific form and size of the training impulse and the time course and format of tapering is highly individual and often difficult to determine (Banister et al. 1999; Mujika et al. 2004).

Previous investigations have suggested that a systems model approach to training may provide useful information regarding an athlete's physical response during tapering (Mujika et al. 1996a; Banister et al. 1999). For example, Mujika et al. (1996a) modelled responses to training and tapering in 18 elite swimmers (8 female, 10 male) during a 44 week competitive swim season. The decrease in training load during a 3 or 4 week taper resulted in a 3% increase in performance. This increase in performance was attributed to a decrease in the negative influences of training rather than an increase in the positive influences. This is most likely due to the slower decay period associated with the fitness component compared with the fatigue component. Furthermore, the fit between the model and the actual performance was significant for 17 subjects (r^2 ranged from 0.45–.85, $p < 0.05$). On the basis of these findings, it was concluded that the systems model approach to training could be helpful for studying specific physiological reactions of swimmers to a particular training stimulus.

In another study, Banister et al. (1999) used a systems approach to training to predict the effectiveness of four different taper profiles in 11 male triathletes. The four taper methods were simulated in a systems model to predict performance resulting from a standard square-wave quantity of training for 28 days. The authors confirmed findings from previous investigations (Hooper et al. 1998; Shepley et al. 1992), that a higher intensity lower volume taper will give optimal performance outcomes. It was also suggested that during a taper, a greater reduction in training volume should occur at its beginning to eliminate the fatiguing effects of physical training as quickly as possible (Banister et al. 1999). More recently, McGregor et al. (2009) demonstrated the practical application of the modelling approach in a 1500 m runner. The authors reported strong correlations between actual and predicted performance using a model during seven running seasons. These findings further highlight the usefulness of modelling and its application for prescribing training programs.

Collectively, the previous studies illustrate that a systems approach to training may effectively predict performance based on a standard block of training. Therefore, modelling responses to training may be highly beneficial for coaches and athletes, in order to design more effective taper and recovery periods which are required to optimise athletic performance.

SUMMARY OF LITERATURE REVIEW

The preceding literature review provides a synopsis of the methods for describing training load and the relationship between training dose, fatigue and athletic performance.

- Physical training may be influenced by a number of different variables including the type, frequency, duration and intensity of each exercise bout. Measures of training duration, frequency and mode can be easily established. However, it is more difficult to accurately quantify the intensity of physical training.

- Training programs which are prescribed based on external training load measures (e.g. distance and duration) do not take into consideration the relative stress imposed on the individual and may not be as effective for describing training dose compared with measures of internal training load (e.g. HR and RPE). However, this notion has not been comprehensively investigated.

- Various indices of exercise intensity such as HR, $\dot{V}O_2$, blood lactate and RPE have previously been used to describe the intensity of exercise. Nonetheless, no one measure of intensity is universally used amongst athletes, coaches and investigators. This is most likely due to the inherent limitation in each measure to accurately assess intensity in all modes of exercises in a practical, timely and inexpensive manner.

- The use of RPE as a simple non-invasive measure of exercise intensity has recently increased in popularity.

- The session-RPE method utilises the RPE scale as a measure of exercise intensity and has recently been suggested as a useful method for quantifying training load and monitoring the training process in a variety of training modalities.

- The criterion validity and reliability of the session-RPE method is yet to be fully determined.

- The most valid method for quantifying the accumulated effects of endurance training is yet to be established.

- Mathematical models have been suggested as a useful method for describing the dose-response relationship between physical training and performance.

- The majority of previous research has focused on developing mathematical models to predict optimal performance windows. However, no data exists that compares the efficacy of the models for describing training outcomes using the different training load inputs.

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Chapter 3

The ecological validity and application of the session-RPE method for quantifying training loads in swimming

As per the peer-reviewed paper published in the *Journal of Strength and Conditioning Research.*

Wallace, L.K., Slattery, K.M., & Coutts, A. J. (2008). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *Journal of Strength and Conditioning Research*: *23*(1): 33-8.

ABSTRACT

There are few practical methods available for evaluating training loads (TL) during swimming. The purpose of this study was to examine the ecological validity of the session-RPE method for quantifying internal TL in competitive swimmers using heart rate-based (HR-based) methods and distance as criterion measures. This study also examined the correspondence between athlete and coach perceptions of internal TL using the session-RPE method. Twelve (6 male; 6 female) well-trained swimmers (mean ± SD: age 22.3 ± 3.1 y, mass 71.8 ± 11.6 kg, height 175.0 ± 9.0 cm) participated in this study. All subjects completed a swimming step test to evaluate individual HR zones and blood lactate profile before undertaking 20 swim training sessions where rating of perceived exertion (RPE), HR and distance covered recorded. Training load was then calculated for each session using the session-RPE, HR-based methods and session distance. The session-RPE scores were correlated to HR-based methods for measuring internal TL as well as training distance for each swimmer. All individual correlations between session-RPE, HR-based methods ($r = 0.55–0.94$), ($p<0.05$) and distance measures ($r = 0.37–0.81$), ($p<0.05$). Two-way ANOVA showed that there was a significant interaction for training intensity x coach-athlete perception, indicating the coach-RPE being lower than athlete-RPE for low-intensity sessions and the higher than athlete-RPE at high-intensity sessions. The results of this study suggest that session-RPE may provide a practical, non-invasive method for quantifying internal TL in competitive swimmers.

Key Words: swimmers; training load; monitoring

INTRODUCTION

There are a variety of monitoring methods used by coaches to measure the physical training loads (TL) undertaken by athletes. However, in sports such as swimming, few valid and reliable methods are available to evaluate the TL undertaken. Typically, the majority of training programs are prescribed using a measure of external TL. External TL is defined as the work completed by an athlete measured independently of their internal characteristics. For example, in swimming, coaches often prescribe training with reference to external measures (i.e. distance swum [m] and/or swimming velocity [m/s]) (e.g. 10 x 100 m at 1:40 min:s holding 1:05 min:s). However, it is the relative physiological stress imposed on the athlete (internal TL) and not the external TL completed by the athlete that determines the stimulus for training adaptation (Viru & Viru, 2000). For example, a similar training session prescribed in terms of an internal TL would be based on physiological measures (eg. 10 x 100 m on 1:40 min:s holding ~90% HRmax).

Currently, the most widely used methods for evaluating internal TL utilise heart rate (HR) information as a measure of exercise intensity (Banister, Calvert, Savage, & Bach, 1975; Edwards, 1993; Lucía, Hoyos, Santalla, Earnest, & Chicharro, 2003; Morton, Fitz-Clarke, & Banister, 1990). However, the application of HR as a measure of exercise intensity in swimming has several limitations. For example, the HR response can be a poor method for evaluating intensity during high-intensity exercise such as weight, interval, intermittent and plyometric training (Foster et al., 2001). Many of these training methods are regularly implemented in swimming programs. Furthermore, HR monitoring devices often incur technical failure in water and manual pulse palpitation requires interruption in exercise.

The session-RPE method was proposed by Foster et al. (1995) as a practical tool for evaluating internal TL in athletes. This method requires subjects to subjectively rate the intensity of the entire training session using a rating of perceived exertion (RPE) according to the category ratio scale (CR 10-scale) developed by Borg et al. (1985). This intensity value is then multiplied by the total duration (min) of the training session to create a single measure of internal TL in arbitrary units (AU). Previous investigations have shown session-RPE to compare favourably with more complicated methods of quantifying training load in endurance (Foster, Florhaug, et al., 2001), team sport (Coutts, Reaburn, Murphy, Pine, & Impellizzeri, 2003; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004) and resistance trained athletes (Day, McGuigan, Brice, & Foster, 2004).

Based on the collective research, it appears session-RPE may provide a suitable method for evaluating internal TL in swimming. However, no study has examined its validity and application in competitive swimmers. Therefore, the purpose of this investigation was to compare the session-RPE method with traditional HR-based (internal TL) and distance (external TL) measures for evaluating physical TL in competitive swimmers. Furthermore, this investigation will also examine the correspondence between athlete and coach perceptions of internal TL using the session-RPE method.

METHODS

Approach to the Problem

To date, no study has previously measured the ecological validity of the session-RPE method for quantifying internal TL in swimming. Additionally, to our knowledge, only one study has previously compared coach and athlete perceptions of internal TL using the session-RPE method (Foster, Helmann, Esten, Brice, & Porcari, 2001). Therefore, this study will investigate the ecological validity of the session-RPE method for quantifying internal TL in competitive swimmers. To achieve this, the athlete's perception of exercise intensity (RPE) will be compared to commonly used HR methods for quantifying internal TL. Heart rate-based methods were chosen as a criterion measure as HR has previously been established as a valid measure of evaluating exercise intensity (Achten & Jeukendrup, 2003). Furthermore, this study will also compare the perceptions of internal TL between athlete and coach using the session-RPE method.

Subjects

Twelve (6 male; 6 female) well-trained swimmers (mean ± SD: age 22.3 ± 3.1 y, weight 71.8 ± 11.6 kg, height 175.0 ± 9.0 cm) volunteered to participate in this study. All subjects had been competing regularly in national competitions for at least four years. Six of these subjects were current members of the provincial Institute of Sport Swim Team and two of the subjects had competed for their country as part of the open national swim team during the previous 12 months. Two qualified swimming instructors also agreed to participate in this study. Preceding the commencement of the study, all subjects were made aware of the potential risks and benefits associated with participation, and written informed consent was obtained by each subject. Ethical approval was granted by the University Human Research Ethics Committee for all experimental procedures.

Experimental Protocol

The present study was completed between December 2005 and March 2006. Each training session was designed and implemented by the swimming instructor with no input from the researcher. Following a one month familiarisation period using the session-RPE method, each subject completed 20 individual training sessions consisting of a variety of different training distances and training intensities.

Physical Training

All physical training undertaken during this study took place in a 50 m heated pool (27°C) and was performed as part of the general conditioning phase in the yearly plan. Physical training sessions were designed by the instructors to elicit a variety of training adaptations with emphasis on improving aerobic conditioning, anaerobic threshold, $V0_2$max and speed. The majority of physical training was performed in the form of interval work, where swimming laps were broken down into repeat distances ranging between 25 m and 800 m. All physical training sessions lasted between 30 min and 2 h with swimming distances ranging between 2 km and 6km.

Testing Procedures

Lactate Threshold Assessment

Each subject completed a swimming step-test to establish individual HR zones and blood lactate profiles The swimming step test consisted of 7 x 200 m efforts, progressing from aerobic swimming to maximal intensity swimming (Pyne, Lee, & Swanwick, 2001). Immediately following each incremental workload, capillarised blood samples (30 μL) were taken from the ear lobe to assess blood lactate concentration [BLa$^-$] and analysed using a Lactate Scout® Portable Lactate Analyser (Boehringer, Mannheim, Germany). Maximum HR was recorded as the highest HR achieved during the test. The Lactate Analysis macro add-in in Microsoft Excel (SASI, Adelaide Australia) was used to calculated lactate thresholds from fixed [BLa$^-$] values of 2 mmol·L^{-1} and 4 mmol·L^{-1} (Svedah & MacIntosh, 2003).

Monitoring Training Load

Daily training load was calculated using the session-RPE method (Foster, Florhaug, et al., 2001). This method involved multiplying the training duration in minutes by the mean training intensity (Foster, Florhaug, et al., 2001). The training intensity was measured by the 10-point Rating of Perceived Exertion Scale (CR-10: RPE) (1985) shown in Table 3.1 (over page).

Table 3.1: The 10-point Rating of Perceived Exertion Scale (Borg, et al., 1985).

Rating	Description
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal

To ensure the subjects reported a global RPE for the entire training session, the RPE was taken 30-minutes after the completion of the session. For comparison of internal TL measures between athlete and coach, individual session-RPE (both RPE and duration) estimates were also taken from the coach prior to each training session.

Training intensity during each swim training session was also recorded using Polar Team heart rate monitors (Polar, OY, Finland) where HR was recorded every five seconds. To reduce heart rate recording error during training, all subjects were asked to check their heart rate monitors following each set (approximately 10 min). Following each training session, heart rate information was then downloaded to a computer using Polar Advantage Software (Polar, OY, Finland).

Criterion methods for quantifying physical training loads

Several HR-based methods for quantifying internal TL were used as a criterion measure in this investigation. The TRIMP method proposed by Banister et al. (1991) was used as the first criterion measure of internal TL and was determined using the following formula:

$$\text{Training load} = D(\Delta\text{HR ratio})e^{b(\Delta\text{HR ratio})}$$

where: D = duration of training session, and b = 1.67 for females and 1.92 for males (Banister & Fitz-Clark, 1993; Morton, et al., 1990).

The HR-based method proposed by Edwards (1993) was also used as a criterion measure of internal TL in this study. This method involves integrating the total volume with the total intensity of each physical training session relative to five intensity phases. An exercise score for each training bout was calculated by multiplying the accumulated duration in each heart rate zone by a multiplier allocated to each zone (50-60% HR_{max} = 1, 60-70% HR_{max} = 2, 70-80% HR_{max} = 3, 80-90% HR_{max} = 4 and 90-100% HR_{max} = 5) and then summating the results.

The final criterion measure of internal TL used in this study was the lactate threshold (LT) zone method previously described by Impellizzeri et al. (Impellizzeri, et al., 2004). This method involves multiplying the time spent in three heart rate zones (zone 1: below lactate threshold (LT), zone 2: between LT and the anaerobic threshold (AT); and zone 3: above AT) by a coefficient relative to each intensity zone (k = 1 for zone 1, k = 2 for zone 2, and k = 3 for zone 3) and then summating the results. In addition to these HR-based methods, a measure of swimming distance (m) was used as the criterion measure of external TL.

Statistical Analyses

The relationship between session-RPE and previously used HR-based methods for measuring internal TL and measures of external TL were analysed using Pearson's product moment correlation. Statistical comparisons of session-RPE were also made between coaches and athletes during the investigation period. Training sessions were divided into those intended by coaches to be easy (RPE <3), moderate (RPE 3-5) and difficult (RPE >5). A two-way Analysis of Variance (ANOVA) was then used to compare coach and athlete perceptions for intensity, duration and training load at each intensity level. Statistical significance was set at $p<0.05$. Effect sizes (ES) (Cohen's d) were also calculated to analyse potential trends in the data comparing respective coaches perception of planned exercise intensity to the swimmers perception of actual exercise intensity. An ES of <0.2 was classified as a 'trivial', 0.2–0.4 as a 'small', 0.4–0.7 as a 'moderate' and >0.8 as a 'large' effect. SPSS statistical software package version 11.5 (SPSS Inc., Chicago, USA) was used for all statistical calculations.

RESULTS

Various HR, RPE and distances measures were collected from 248 training sessions during a 3 month period. However, due to problems with obtaining clean HR data during swimming only 8 subjects completed the desired 20 training sessions in the time frame required. Therefore, individual correlations between HR, RPE and distance methods for quantifying training load were based on 20 individual sessions whilst group correlations were based on a total of 160/248 training sessions.

Correlations between session-RPE and HR-based methods were all significant (P<0.01). Individual correlations are presented in Table 3.2.

Table 3.2: Individual correlations between session-RPE, HR-based and distance measures for quantifying physical training load.

Subjects	Distance	Session-RPE coach	Banister's TRIMP	Edward's TRIMP	LT Zone
S1	0.37	0.84	0.76	0.76	0.64
S2	0.76	0.88	0.79	0.82	0.73
S3	0.85	0.86	0.92	0.91	0.94
S4	0.70	0.93	0.63	0.63	0.78
S5	0.80	0.73	0.81	0.84	0.87
S6	0.35	0.91	0.56	0.57	0.71
S7	0.57	0.96	0.55	0.56	0.59
S8	0.81	0.94	0.92	0.91	0.91
Mean	0.65	0.88	0.74	0.75	0.77
± SD	0.20	0.07	0.15	0.15	0.13

Coaches and athletes evaluation of session-RPE (internal TL, duration and intensity) were also examined during the investigation period. There were moderate-to-strong correlations observed between coaches and athletes for training duration ($r = 0.86$, $p < 0.01$), training intensity ($r = 0.84$, $p < 0.01$) and internal TL ($r = 0.85$, $p < 0.01$). Repeated measures ANOVA also revealed significant interaction effects for training intensity group x coach-athlete perception group for RPE ($F = 6.458$, $p = 0.003$). The interaction effect indicated that the RPE difference depends on the exercise intensity at which the session is completed. The estimated coach-RPE was lower than actual athlete-RPE during low intensity sessions and the estimated coach-RPE was higher than actual athlete-RPE during high-intensity sessions (see Figure 3.1, over page). Additional ES analysis revealed moderate sized effects at the low ($d=0.67$) and high ($d=-0.50$) intensity sessions with only trivial ES differences at moderate ($d=-0.14$) intensity sessions.

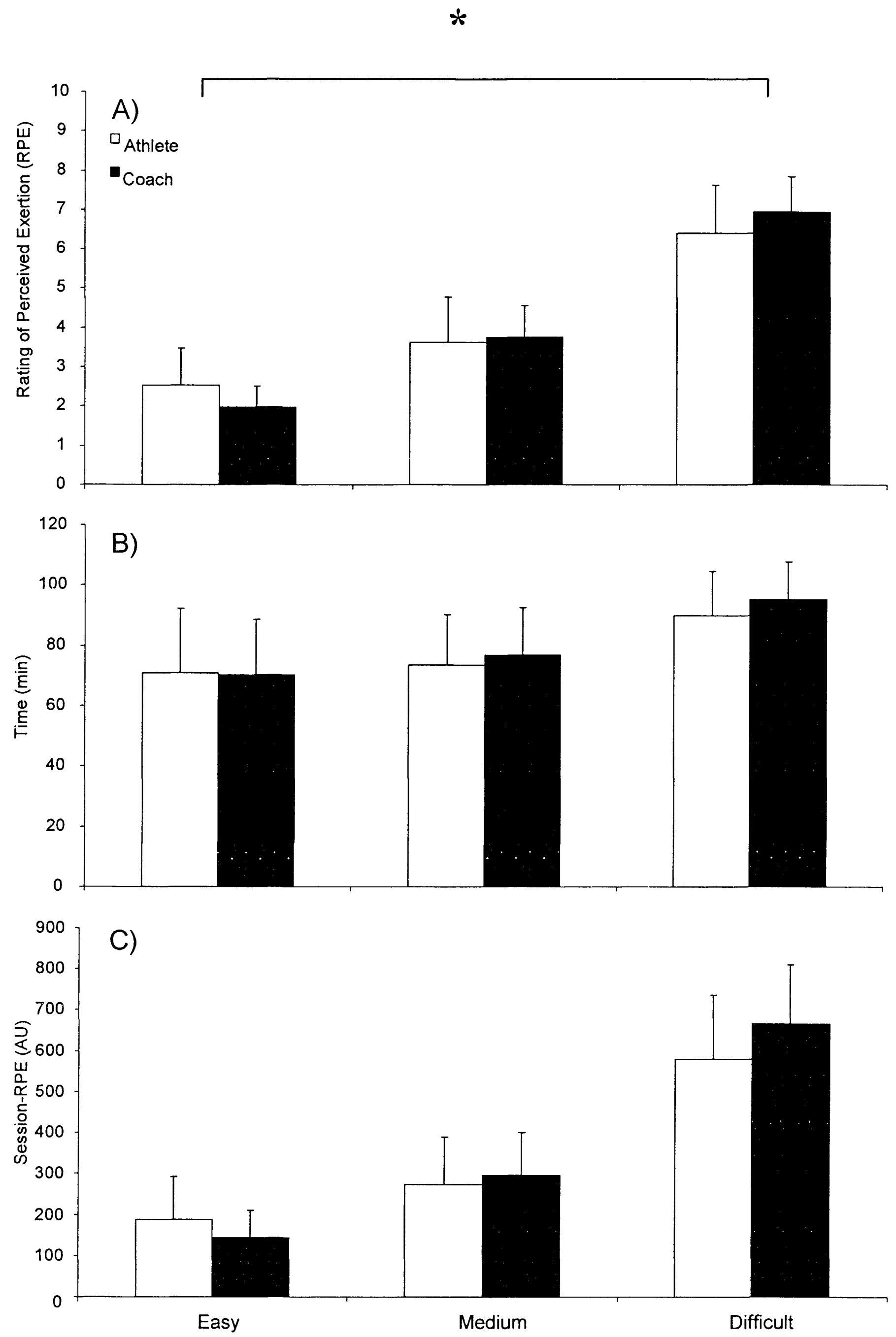

Figure 3.1: Comparison between athlete and coach perceptions of intensity (A), duration (B) and internal TL (C) using the session-RPE method during easy, moderate and difficult training sessions (mean ± SD). * Significant interaction effect, $p < 0.05$)

DISCUSSION

The present investigation examined the ecological validity and practical application of the session-RPE method for quantifying training loads in swimmers. Our results are consistent with previous investigations that have shown a high correspondence between session-RPE and HR-based methods for evaluating internal TL in athletes (Foster, 1998; Foster, Daines, Hector, Snyder, & Welsh, 1996; Foster, et al., 1995). In the present study, we found significant individual correlations between session-RPE and commonly used HR-based methods (egg. TRIMP [r = 0.55 – 0.92], Edwards [r = 0.57 – 0 .91] and LT zone method [r = 0.59 – 0.94]) for quantifying internal TL (Edwards, 1993; Lucía, et al., 2003; Morton, et al., 1990). However, the strength in the correlations between session-RPE and the HR-based methods were slightly lower than those reported in previous investigations in endurance-based athletes [r = 0.75 – 0.90] (Foster, 1998) and slightly higher than those reported in young soccer players [r = 0.50 – 0.85] (Impellizzeri, et al., 2004). These findings may be attributed to the type of training undertaken by the athletes in the present study (e.g. interval training).

Previous investigations have reported increases in RPE scores in subjects performing intermittent training compared with steady-state training where training sessions where matched for total work (Drust, Reilly, & Cable, 2000). These previous investigators have suggested that increases in RPE scores were due to increases in the anaerobic contribution to energy production during intermittent training. In accordance with these findings, Coutts et al. (2009) recently showed that the combination of HR and [BLa$^-$] measures taken during small-sided soccer games was better related to RPE than HR and [BLa$^-$] measures taken alone. These previous findings further support the argument that RPE may provide a valid global measure of training intensity during high-intensity, non-steady state training. In the present investigation, the majority of training was performed by the athletes in the form of interval training. For example, depending on the focus of the session, the coaches' often prescribed swim session that involved repeat swim efforts ranging from 25 – 800 m. These commonly resulted in the swimmers having to undertake highly-intermittent work. It is this intermittent work that may have been responsible for increasing in RPE scores in relation to HR measures. We suggest that the global nature of RPE that is modulated by various forms of stress during exercise that make it a suitable practical tool for monitoring internal TL in swimmers.

The present results also showed the session-RPE method to have the lowest correlation to distance measures for quantifying training load [r = 0.37 – 0.85]. This finding was an expected result as distance measures do not take into account the intensity of the training session. For example, it would be far less stressful for a swimmer to perform 10 x 100 m at an aerobic intensity than it would for the same swimmer to perform 10 x 100 m at maximal intensity. This finding suggests that distance measures may provide a poor method for evaluating TL in athletes undertaking high-intensity training programs.

Although, the session-RPE method may appear unsophisticated compared with HR-based approaches, both methods have been shown to be useful for evaluating internal TL in the majority of endurance-based sports. However, in agreement with previous investigations (Foster, Florhaug, et al., 2001; Impellizzeri, et al., 2004), the present results suggest that the session-RPE method may be more sensitive than HR-based or distance measures for describing the response to training during high-intensity or intermittent exercise. Furthermore, due to technical problems, we were only able to obtain good HR data from 160/248 individual training sessions demonstrating the level of difficulty in obtaining HR data during swimming. Therefore, given the importance of high-intensity exercise in swimming and the difficulties associated with collecting HR information in this environment, the session-RPE method may provide a more valid approach to monitoring internal TL in competitive swimmers.

The second purpose of this study was to examine the correspondence between athlete and coach perceptions of internal TL using the session-RPE method. No significant differences in internal TL were revealed between athletes and coaches during sessions designed to be easy (RPE < 3), moderate (RPE 3-5) and difficult (RPE > 5). However, in agreement with previous research (Foster, Helmann, et al., 2001), the present results showed a tendency for the athletes to report higher training intensities compared with coaches during sessions designed to be easy and lower training intensities compared with coaches during sessions designed to be difficult. These findings are consistent with other previous investigations showing a mismatch between athlete and coach perceptions of training intensity at low and high intensities (Foster, Helmann, et al., 2001).

A mismatch in perceived training intensity between athlete and coach has important implications for training athletes. This result demonstrates poor control of training variables and may place athletes at an increased risk of maladaptive training. It has previously been suggested that a decrease in the day-to-day variability in TL may increase the incidence of illness (Foster, 1998) and have a negative impact on performance (Bruin, Kuipers, Keizer, & Vander Vusse, 1994). For example, Bruin et al. (1994) observed symptoms associated with overtraining syndrome in race horses where 'easy' days were increased in a program constructed on a 'hard' day 'easy' day basis. The present results show how a system for monitoring internal TL such as the session-RPE method may improve control of training variables and provide a useful tool for quantifying the internal TL placed on athletes.

Practical Applications

At present, there are few valid and practical methods for monitoring internal TL during high-intensity, non-steady-state exercise such as swimming training. The session-RPE method may allow coaches to monitor the training process by quantifying the internal TL of athlete using a single term (Foster, Florhaug, et al., 2001). The benefit of using session-RPE includes allowing coaches to evaluate and compare the training stress imposed on individual athletes during each component of the training program (egg. swimming and dry land workouts). Furthermore, the use of RPE provides a cost efficient, non-invasive and reliable method for quantifying training intensity. The application of this method to swimming may also allow coaches to monitor training adaptations in individuals and verify periodisation strategies (Foster, Florhaug, et al., 2001; Foster, Helmann, et al., 2001). For example, an increased RPE to a regular standard work bout during each training cycle (i.e. weekly) may be used as a guide for coaches to monitor for either increases in fatigue or reductions in fitness levels within individual athletes. Conversely, a reduction in RPE to these standard work bouts may indicate training adaptation. However, further research is required to validate the effectiveness of this method for monitoring changes in performance, fitness and fatigue during swimming.

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Chapter 4

Using session-RPE to monitor training load in swimming

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Wallace, L.K., Slattery, K.M., Simpson, N., Bell. J., & Coutts, A. J. (2008). Using session-RPE to monitor training load in swimming. *Strength and Conditioning Journal: 30* (6):72 - 76.

INTRODUCTION

The ability for coaches to titrate increases in physical training loads (TL) with appropriate recovery is of critical importance for optimising athletic performance (Smith 2003). However, despite increases in coach education and an increasing focus on well-designed, evidence-based training programs; there still remains a relatively high occurrence of injury, illness and undesired competition outcomes in athletes (Pyne et al. 2005). It has been widely recognised that accurate monitoring of TL may improve an athlete's preparation for competition. Although in sports such as swimming, few simple methods are available for coaches to monitor the physical TL of their competitive swimmers.

Many swim coaches rely on their previous experience, intuition and perception of how hard an athlete is training when determining the amount of physical training that should be undertaken by each athlete. However, due to the complexity of interactions between the components that make up a swimming program (eg. endurance, technique, speed and strength), a coach's perception and intuition may not be the most reliable method for accurately monitoring physical TL. Therefore, the major difficulty lies in establishing the training stress imposed on the athlete by each component of the training program.

Current methods

There are a variety of methods available to coaches for monitoring physical TL in athletes. Typically, the majority of coaches prescribe training programs in terms of an external TL. External TL is defined as the work completed by an athlete (i.e. distance swum), and is measured independently of their internal characteristics (i.e. their physiology). For example, in swimming, coaches often prescribe training based on distance and/or time (e.g. 10 x 100 m at 1:40 min:s holding 1:05 min:s). However, it is the relative physiological stress imposed on the athlete (internal TL) and not the external TL completed by the athlete that determines the stimulus for training adaptation (Viru and Viru 2000). An example of the same session using a measure of internal TL may read 10 x 100 m on 1:40 min:s holding ~90% HR_{max}. It is widely recognised that the physical stress imposed on an athlete during each session is related to both the volume and the intensity of the exercise bout. In swimming, it is difficult to accurately measure the stress imposed on a swimmer during training using traditional measures such as HR.

The most widely accepted methods for evaluating internal training intensity in endurance athletes utilises heart rate (HR) as a measure of exercise intensity (Morton et al. 1990; Lucía et al. 2003; Banister et al. 1975; Edwards 1993). However, using HR to measure exercise intensity in swimming has several limitations. For example, the HR response is a relatively poor method for evaluating intensity during high-intensity exercise such as weight, interval and plyometric training (Foster et al. 2001a). These types of high-intensity training sessions are common in a typical swim program. In addition, we have found that the likelihood of technical failure whilst using traditional HR monitoring methods in an aquatic environment is increased. Due to these limitations, we suggest that there is a need for an alternative method that is simple, valid and reliable for quantifying training loads in swimmers.

The 'session-RPE' method

The session-RPE method is a simple system for monitoring internal TL load in athletes. This system requires athletes to subjectively rate the intensity of the entire training session using a rating of perceived exertion (RPE) according to the category ratio scale (CR 10-scale) of Borg et al. (1985) (see Table 4.1, over page). Following each training bout, the athlete is asked a simple question like 'How hard was your workout?' The athlete then indicates the intensity of the training session referring to a numerical value according to the RPE scale. This intensity value is then multiplied by the total duration (mins) of the training session to create a single measure of internal TL in arbitrary units (AU). To ensure the athletes report a global RPE for the entire training session, the RPE is taken 30-minutes following the completion of the session. We have presented an example of how to calculate internal TL using this method in Table 4.2 (over page).

A major advantage of quantifying training load using session-RPE compared to other reported methods is that it is simple and relatively easy to interpret. Furthermore, studies have shown session-RPE to compare favourably with more complicated methods of quantifying training load in endurance (Foster et al. 2001a), team sport (Coutts et al. 2003; Impellizzeri et al. 2004) and resistance trained athletes (Day et al. 2004). Based on the collective research, it appears session-RPE may provide a suitable method for evaluating internal TL in swimming, however, at present there is little data to support this suggestion.

Table 4.1: The 10-point Rating of Perceived Exertion Scale (Borg et al. 1985).

Rating	Description
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal

Table 4.2: Example of calculating internal training load using session-RPE.

Internal TL = Session-RPE x Duration (mins)

If an athlete indicated that an exercise bout lasting 60-minutes was hard (RPE = 5) the internal TL for that session could be determined using the following calculation:

Internal TL = 5 x 60 = 300 AU

Recently, we examined the usefulness of using session-RPE for quantifying internal TL in swimmers during a four month training period (Wallace et al. 2008). During this study, over 160 individual swim training sessions were examined. We found a significant correlation between session-RPE and commonly used heart rate methods (eg. Banister's TRIMP [r = 0.74 ± 0.15], Edward's TRIMP [r = 0.75 ± 0.15] and LT Zone method [r = 0.77 ± 0.13]) for quantifying internal TL (Lucía et al. 2003; Edwards 1993; Morton et al. 1990). However, the correlations between session-RPE and HR-based methods were slightly lower than those reported in previous investigations in endurance-based athletes [r = 0.75 – 0.90] (Foster 1998). These findings may be attributed to differences in training methods undertaken by competitive swimmers. For example, a large percentage of swim training is prescribed by coaches in the form of interval-based workouts. Interval-training has been associated with an increased reliance on anaerobic energy contribution compared with steady-state exercise (Drust et al. 2000). Therefore, since HR have previously been shown to be poorly related to high-intensity exercise, this may explain the reduced strength between the HR and RPE methods observed in this study. Our results also showed that session-RPE to be only moderately related to distance measures for quantifying physical TL [r = 0.65 ± 0.20]. This result was somewhat expected as distance measures taken independently do not take into account the total stress of exercise. For example, it would be far less stressful for a swimmer to perform 10 x 100 m at an aerobic intensity than it would for the same swimmer to perform 10 x 100 m at maximal intensity.

We have also recently investigated the ability for the athletes to perform each training session at the load intended by the coach. This was achieved by comparing the coaches estimated duration and RPE measures following each exercise bout with the values reported by the athletes. Our findings reveal significant differences in the athlete's subjective measures of internal TL compared with coach estimations. The major difference in internal TL was due to differences in training intensity. Interestingly, the athletes tended to report higher intensities during sessions designed to be easy (RPE ≤ 2) and reduced intensities during sessions designed to be hard (RPE ≥ 5). This observation provided important feedback to the coach that was then used to modify the training practices of their swimmers (i.e. closer attention was paid to providing appropriate motivation and instructions to their swimmers during training sessions).

PRACTICAL APPLICATIONS

To achieve successful swimming performances, athletes must complete periods of intense physical training interspersed with appropriate recovery periods. Typically, a swimming program involves a combination of interval-training, steady-state training and dry-land training. Previously, it has been difficult to quantify the internal training stress from the variety of training modalities and compare them on a common scale. Fortunately, the session-RPE method provides a simple, non-invasive method for quantifying and comparing internal TL under a wide range of exercise conditions. We have listed below the advantages of implementing session-RPE for quantifying physical TL in swimmers.

1. Summating training components to calculate overall internal TL

A typical swimming program consists of a variety of different exercise stimulus (egg. steady state, interval and dry-land training). The session-RPE system allows coaches to evaluate and compare the training stress imposed on individual athletes during each component of the training program. Figure 4.1 shows how individual components of a typical swim program can easily be summated to show the effects of each component on the total internal TL.

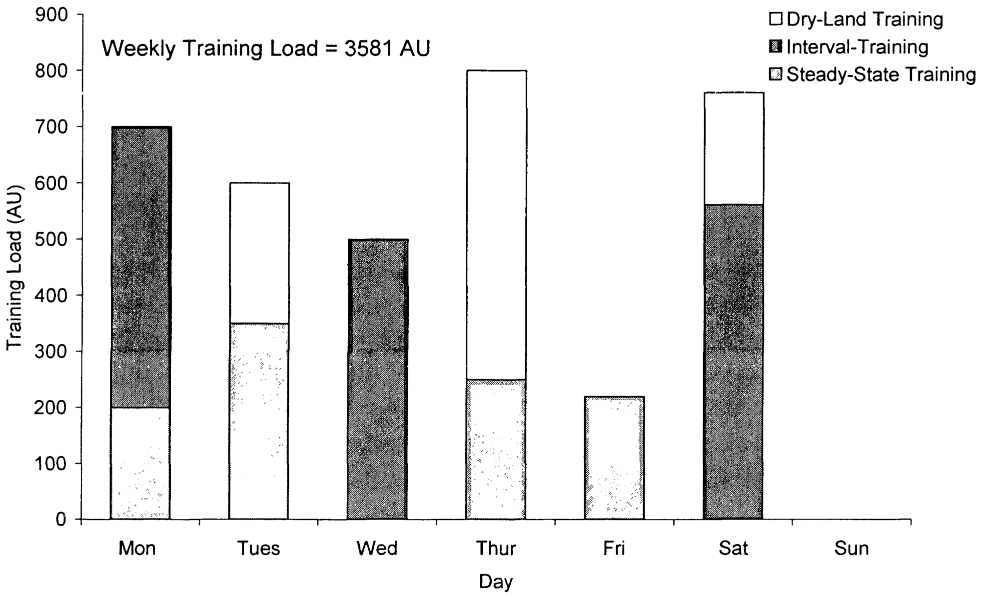

Figure 4.1: Summating training components to show overall internal TL.

2. Determining whether athletes perform the training loads prescribed by the coach

Our findings, supported by other research (Foster et al. 2001b), show that athletes frequently undertake training sessions at an intensity that is different to the intensity prescribed by the coach. It appears athletes often train too hard during recovery sessions inhibiting their ability to obtain the desired intensity during more difficult training sessions. The session-RPE method may provide coaches with a method for monitoring the intensity of each training session, ensuring increased intensity during high-intensity workouts coupled with improved recovery periods. Figure 4.2 shows a graphical representation of the pitfalls associated with athlete training intensity compared with the intensity prescribed by the coach.

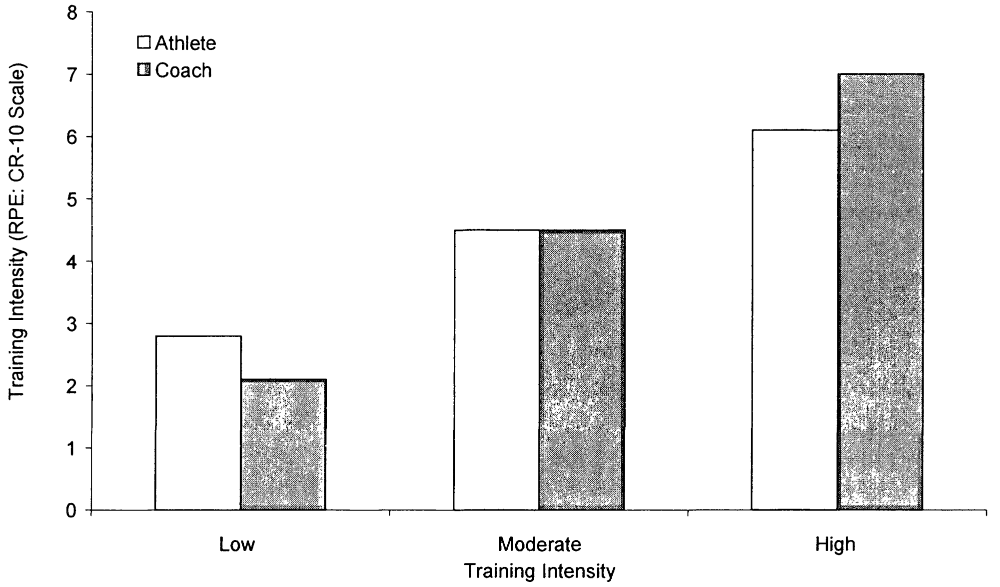

Figure 4.2: Mismatch in training intensity prescribed by the coach and the perception of training intensity of the swimmers for the same session.

3. Improving periodisation strategies

A decrease in the day-to-day variability in training load (i.e. alternated hard-day, easy-day training) may increase the incidence of illness in athletes (Foster 1998) and have a negative impact on performance (Bruin et al. 1994). For example, Bruin et al. (1994) observed reduced running performance in race horses where 'easy' days were increased in a program constructed on a 'hard' day 'easy' day basis. At present, there are few studies to support these findings; however, it does appear that a decrease in day-to-day training variability, together with an increase in overall training load may contribute to negative training effects in athletes. The session-RPE training monitoring system provides a simple method for quantifying the training dose of each exercise bout. This information can easily be graphed using a spreadsheet software program (e.g. Microsoft Excel) or through specific on-line training diaries (e.g. www.trainingload.com) to ensure appropriate day-to-day variability between training sessions is met. An example of how this can be done is shown in Figure 4.3 below. This figure shows how session-RPE can be used to improve training load placement with no change in overall training load between the first and last seven days.

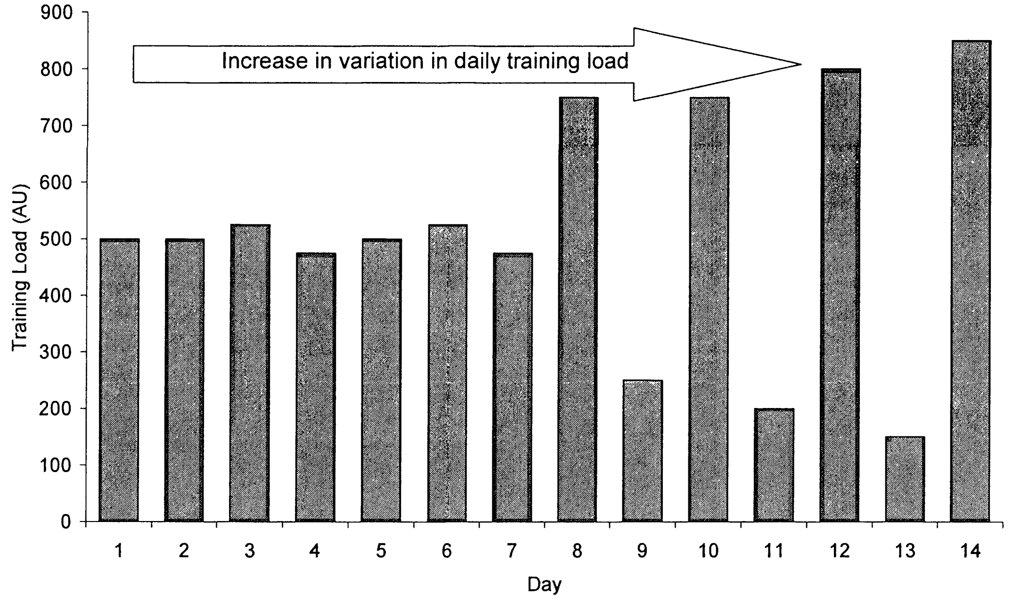

Figure 4.3: Example of how training loads can be modified to improve the variation in day-to-day training load.

4. Monitor individual training loads

The ability for athletes to adapt to increasing training loads is largely an individual process (Viru and Viru 2000). Swimming training is usually completed in a squad environment where similar training stimulus is prescribed to a group of individuals. Session-RPE allows coaches to closely monitoring the internal TL of each athlete and more clearly identify athletes who are coping or not coping to the set external training loads.

5. Monitoring training loads following a break from regular training

Often athletes will ignore the effects of reduced fitness and strength following a prolonged break from regular training. The session-RPE training monitoring system allows coaches to prescribe appropriate loads and avoid the negative effects of returning to regular training loads too rapidly.

SUMMARY

To obtain optimal performance in competitive swimming athletes must undertake periods of heavy training loads interspersed with appropriate recovery periods. Unfortunately, until now, swim coaches have not been able to accurately measure the internal TL undertaken by their swimmers. The session-RPE training monitoring system may be a useful tool for swimming coaches to monitor internal TL in athletes. This method can be used to provide coaches and athletes with instant feedback regarding the internal training stress imposed on an athlete from each exercise bout. This information can then be used to improve periodisation strategies, improve session execution and ultimately improve swimming performance.

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Chapter 5

Establishing the criterion validity and reliability of common methods for quantifying training load

As per the peer-reviewed paper under review in the *European Journal of Applied Physiology*.

Wallace, L.K., Coutts, A.J., Slattery, K.M. and Impellizzeri, F.M. (2012). Establishing the criterion validity and reliability of common methods for quantifying training load. *Euro J Appl Physiol.* in review.

ABSTRACT

The purpose of this investigation was to compare the criterion validity and test-retest reliability of common methods for quantifying training load. Ten (5 male; 5 female) healthy individuals completed 18 randomly-assigned steady state (SS) and interval (INT) cycle training sessions during a six week period. All SS sessions were 18 min and performed at 35%, 50% and 65% of maximum work capacity (W_{max}). Interval sessions were performed a 50%, 60% and 70% of W_{max} with a 1:1 work to rest ratio and matched for total work with the 50% SS session. Oxygen consumption ($\dot{V}O_2$) and heart rate were measured throughout all sessions whilst blood lactate concentration and rating of perceived exertion (RPE) measures were taken every 6 min. Session-RPE (sRPE) was collected 30-min following each exercise session. All within individual correlations between $\dot{V}O_2$ and external work (r=0.88–0.97), HR (r=0.65–0.90) and RPE methods (r=0.55–0.89) were significant. External work correlated best with total $\dot{V}O_2$ and was significantly different to the RPE methods. Poorer reliability was shown for Banister's TRIMP (15.6% CV), Lucia's TRIMP (10.7% CV) and sRPE (28.1% CV). Improved reliability was shown for HR (3.9% CV) and RPE 6-20 (8.5% CV) as a measure of exercise intensity. These results suggest external work to be the most valid and reliable method for quantifying training load. Poorer reliability was reported for the HR-based TRIMP methods and RPE-based methods. These methods may be improved through adjustments to generic weighting factors for calculating training load and the introduction of the RPE 6-20 scale for the calculation of sRPE during endurance exercise.

Key Words: session-RPE, TRIMP, training quantification, monitoring training.

INTRODUCTION

Physical training load can be described as the dose of training completed by an athlete during an exercise bout. There are a variety of methods available to quantify the training load undertaken by athletes (Saltin and Hermansen 1966). Traditionally, training programs have been described based on a measure of external training load, which is a measure of training load independent of individual internal characteristics. For example, in an endurance athlete, a coach may prescribe a physical training session with respect to a desired training distance (m) and / or training time (min) (e.g. 10 km run in 40 min). However, it is the relative physiological stress imposed on the athlete (internal training load) and not the external training load that determines the stimulus for training adaptation (Viru and Viru 2000). Indeed, if two athletes with different fitness characteristics and performance abilities both completed the same external training load, one athlete would inevitably find the training session more difficult than the other. Therefore, it is important for coaches to monitor internal training load so that training programs can be tailored to the needs of individual athletes.

There have been many attempts by researchers to develop a suitable method for quantifying internal training load that incorporates both training duration and individual training intensity. At present, the most commonly used methods for quantifying internal training load utilise HR as a measure of exercise intensity. For example, Banister et al. (1975) proposed the TRIMP method as a means to quantify the internal training load undertaken by athletes. This method is based on a product of training duration and a weighting factor determined by an individual's HR_{mean} for each exercise bout (Banister et al. 1975; Banister 1991). Other similar methods have calculated a measure of internal training load using knowledge of heart rate values around common inflection points such as ventilatory (Lucía et al. 2003) or lactate thresholds (Impellizzeri et al. 2004). However, the application of HR as a measure of training load has several limitations. For example, HR response may be a relatively poor method for evaluating intensity during very high-intensity exercise such as plyometrics, resistance training and interval training. Furthermore, HR methods can require the use of expensive equipment and operators with technical expertise and knowledge for interpretation.

To overcome the limitations associated with the use of heart rate information, Foster et al. (1995) proposed a simple method (session-RPE) for quantifying internal training load in athletes. This method requires subjects to subjectively rate the intensity of the entire training session using a rating of perceived exertion (RPE) according to the category ratio scale (CR 10-scale) of Borg et al. (1985). This intensity value is then multiplied by the training duration (min) to create a single measure of internal training load in arbitrary units (AU). It has been suggested that the session-RPE (sRPE) method may better reflect the internal training load placed on athletes than either heart rate of blood lactate measures during non-steady state exercise (Coutts et al. 2009) and has been shown to compare favourably with more complicated methods of quantifying internal training load in endurance (Foster et al. 2001a), team sport (Impellizzeri et al. 2004; Alexiou and Coutts 2008) and resistance trained athletes (Day et al. 2004).

The previous methods have been shown to be useful for quantifying the internal training load in athletes across a range of exercise intensities and activities. At present however, only one study has reported on the reproducibility of physiological data and perception of effort during standardised endurance training sessions or compared these methods using measures of oxygen consumption ($\dot{V}O_2$) (Herman et al. 2006). This study demonstrated strong correlations between $\dot{V}O_2$ (r=0.98), HR (r=0.96) and session RPE (modified 10-point scale) (r=0.88) measures of exercise intensity in repeat trials of 30 min steady state exercise at three different intensity levels (easy effort ~40 - 50% $\dot{V}O_2$peak, moderate effort ~60 - 70% $\dot{V}O_2$peak and hard effort ~80 - 90%$\dot{V}O_2$peak). Moreover, the correlation between the modified 10-point RPE scale and $\dot{V}O_2$ was suggesting good construct validity of this measure. To date, no study has compared the validity and reliability of the common methods for quantifying training load, rather than exercise intensity in endurance-based activities. Therefore, the purpose of this investigation was to compare the criterion validity and test-retest reliability of common methods for quantifying internal training load.

METHODS

Subjects

Ten (5 male; 5 female) healthy individuals (mean ± SD, $\dot{V}O_2$max: 37.0 ± 4.3 $mL\cdot kg^{-1}\cdot min^{-1}$, age: 23.8 ± 8.4 y) volunteered to participate in this study. Prior to the commencement of the study, all subjects were fully informed of the potential risks and benefits associated with participation. Written informed consent was obtained by each subject and ethical approval was granted by the University Human Research Ethics Committee for all experimental procedures.

Experimental Design

Each subject completed 18 randomly-assigned physical training sessions during a six week period. All physical training sessions and testing procedures were undertaken in the environmentally controlled laboratory. In the month preceding the investigation, all subjects were familiarised with the equipment and all testing methods used in the study. The physical training sessions consisted of three steady-state (SS) and three interval (INT) sessions that were each completed three times during a six week period. All physical training sessions were supervised by the principal researcher and were completed on an electronically braked cycle ergometer (Bosch ERG 601, Berlin, Germany). Steady-state sessions were 18 min and performed at 35%, 50% and 65% of maximum work capacity (W_{max}). These exercise intensities were designed to provide training sessions that would be performed at easy (RPE <3), moderate (RPE 3–5) and difficult (RPE >5) training intensities. Interval sessions were performed a 50%, 60% and 70% of W_{max} with a 1:1 work to rest ratio and matched for total work with the 50% SS session. These physical training sessions were designed to measure the physiological and psychological effects of interval training compared to steady-state training. At least 24 h of recovery was required before each training session. A summary of the exercise protocol can be seen in Table 5.1.

Table 5.1: Summary of exercise protocols used in this study.

Session Name	Session Type	Intensity	$\%W_{max}$	Duration (min)	Work:Rest Ratio	Total Work
SS 1	Steady-state	Low	35	18	–	Individual
SS 2	Steady-state	Moderate	50	18	–	Individual
SS 3	Steady-state	High	65	18	–	Individual
Int 1	Interval	Low	50	24	1:0.5	Matched for work with SS 2
Int 2	Interval	Moderate	60	–	1:0.5	Matched for work with SS 2
Int 3	Interval	High	70	–	1:0.5	Matched for work with SS 2

SS = steady state training bout, Int = interval training bout.

Oxygen consumption ($\dot{V}O_2$) and HR were measured continuously throughout all physical training sessions. The mean $\dot{V}O_2$ ($\dot{V}O_{2mean}$) was used as the criterion measure of internal training load. Blood lactate concentration ($[BLa^-]$) and rating of perceived exertion (RPE) measures were taken following 6 min, 12 min and 18 min for the SS sessions and following each interval for the INT sessions. Following each exercise bout, subjects were required to rate the perceived difficulty of the entire training session (global RPE) according to the category-ratio (CR-10) scale of Borg et al. (1985). No feedback regarding workload or physiological response was provided to the subject during any exercise session.

Testing Procedures

Each subject performed an incremental cycle test to exhaustion to establish maximal oxygen consumption ($\dot{V}O_{2max}$), maximum work (W_{max}), maximum heart rate (HR_{max}) and ventilatory thresholds (VT). An incremental test was also performed following the investigation period to adjust for changes in physiological characteristics. The incremental cycle test was performed on an electronically braked cycle ergometer (Bosch ERG 601, Berlin, Germany). Subjects were instructed to standardise food and fluid intake prior to each testing session.

The incremental cycle test began with a power output at 20 W and the workload increased by 25 $W{\cdot}min^{-1}$ until volitional fatigue (Lucia et al. 1998). The subjects were required to keep the pedal cadence of 70–80 revolutions per minute (rpm) constant throughout the duration of the test. The test was terminated when a pedal cadence could not be maintained at $\geq$70 rpm. Oxygen uptake was measured continuously throughout the incremental test using a Physio-dyne Gas analysis System (Physio-dyne® Fitness Instrument Technologies, Quogue, NY, USA). The gas analysis system was calibrated before and after each test with reference and calibration gases of known concentrations. The pneumotach was calibrated with ambient air using a 3 L syringe (Hans Rudolph Inc, Kansas City, USA). Maximum oxygen uptake was considered the highest 30-s average of oxygen volume recorded during the last minute of exercise. Heart rate (HR) was recorded throughout the test via Polar ® Team HR monitors (Polar, OY, Finland) and downloaded to a computer using Polar Advantage Software (Polar, OY, Finland). Maximum HR was taken as the highest HR recorded during the incremental test. W_{max} was determined using the equation:

$$W_{max} = W_{final} + (t/T) \cdot W_{inc} \qquad (1)$$

where: W_{final} (W) is the power output during the final stage completed, t(s) is the amount of time reached in the final uncompleted stage, T (s) is the duration of each stage, and W_{inc} is the workload increment (Halson et al. 2002).

The ventilatory threshold (VT) was determined using the criteria of an increase in both $\dot{V}E \times \dot{V}O_2^{-1}$ with no concomitant increase in $\dot{V}E \times \dot{V}CO_2^{-1}$. The respiratory compensation point (RCP) was determined using the criteria of an increase in both the $\dot{V}E \times \dot{V}CO_2^{-1}$ (Amann et al. 2006). These thresholds were visually determined by three experienced investigators and a consensus-derived value was used. Capillarised blood samples (30 μL) were taken from the fingertip to assess blood lactate concentration [BLa^-] and analysed using a Lactate Scout® Portable Lactate Analyser (SensLab, GmbH, Leipzip, Germany).

Questionnaires

To monitor the psychophysiological recovery process between each physical training session, each subject was required to complete the Total Quality of Recovery (TQR) Questionnaire and a Well-Being Questionnaire prior to each exercise session. The TQR questionnaire was applied according to the recommendations of Kenttä and Hassmén (1998). The Well-Being Questionnaire required subjects to record subjective ratings of quality of sleep, fatigue, stress and muscle soreness on a likert scale of 1-7 from very, very low or good (1 point) to very, very high or bad (7 point) (Hooper et al. 1997). These questionnaires were implemented to ensure each subject had recovered from the previous training session. If a questionnaire revealed a subject was in a negatively recovered state, a further 24 h recovery was prescribed prior to undertaking the training session. Data not reported.

Training load quantification

A variety of methods were used to quantify the internal training load of the subjects during each exercise bout. For example, the HR-based TRIMP method proposed by Banister et al. (1991) (Banister's TRIMP) was used to quantify internal training load. This method was calculated using the following equation:

$$\text{TRIMP} = \text{D}(\Delta\text{HR ratio})e^{b(\Delta\text{HR ratio})} \qquad (2)$$

where: D = duration of training session, b = 1.67 for females and 1.92 for males and (ΔHR ratio) is determined using the following equation:

$$\Delta\text{HR ratio} = (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) / (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}) \qquad (3)$$

where HR_{rest} = the average heart rate during rest and HR_{ex} = the average HR during exercise (Banister 1991).

The HR-based method proposed by Lucia et al (2003) (Lucia's TRIMP) was also used to quantify internal training load in this study. This method involves multiplying the time spent in three HR zones (zone 1: below VT, zone 2: between VT and RCP; and zone 3: above RCP) by a coefficient relative to each intensity zone (k = 1 for zone 1, k = 2 for zone 2, and k = 3 for zone 3) and then summating the results. This method is summarised by the following equation:

$$\text{Lucia TRIMP} = (\text{duration in Zone 1} \times 1) + (\text{duration in Zone 2} \times 2) + (\text{duration in Zone 3} \times 3) \quad (4)$$

The sRPE method proposed by Foster et al. (1995) was also used as a method for quantifying internal training load. This method requires athletes to subjectively rate the intensity of the entire training session using a rating of perceived exertion (RPE) according to the category ratio scale (CR-10) of Borg et al. (1985).

The RPE value is then multiplied by the total duration (min) of the training session. To ensure the athletes report a RPE for the entire training session (global RPE) the measure of RPE is taken 30 min following the completion of the session. Standard instructions and anchoring procedures were explained during the familiarisation process (Noble and Robertson 1996). This method can be calculated using the following equation:

$$\text{Session-RPE} = D \times \text{RPE} \quad (5)$$

where D is the duration of the entire training session and RPE is the global RPE (Borg CR-10) (Foster et al. 1995).

Similarly, Session-$\text{RPE}_{(\text{worktime})}$ (sRPE_{wt}) was also used as a method to quantify internal training load. This method differs from sRPE in that the global RPE is only multiplied by the sum of duration actually spent performing physical training and not the duration of the entire training session. This method has previously been used to quantify training load in athletes undertaking resistance training (Day et al. 2004; Sweet et al. 2004). The total oxygen consumption (total $\dot{V}O_2$) was taken as the criterion measure of internal training load. This method was calculated as the mean relative $\dot{V}O_2$ for each exercise bout multiplied by the exercise duration. In addition to these methods for quantifying internal training load, the total work (kJ) performed during each training session was calculated and used as a measure of external training load.

Statistics

All data are mean ± standard deviation (SD) unless otherwise stated. A one-way analysis of variance (ANOVA) was used on each dependent variable to determine the session-to-session variability in HR, [BLa$^-$], $\dot{V}O_2$ and RPE. When a significant *F-value* was found the Scheffe post-hoc test was applied. Reproducibility of these responses is described using limits of agreement. Typical error as a coefficient of variation (CV) and interclass correlation coefficients (ICC) were calculated to establish the reliability of HR, [BLa$^-$], $\dot{V}O_2$ and RPE responses (Hopkins 2000). Pearson's product-moment correlations were used to examine the relationships of exercise intensity (expressed as a percentage of HR_{max}) and $\dot{V}O_{2max}$ with the corresponding standard deviation. The level of statistical significance was set at 0.05.

RESULTS

Maximal oxygen uptake ($\dot{V}O_{2max}$) for this group of subjects was not significantly different following the six week study (37.0 ± 4.3 $mL \cdot kg^{-1} \cdot min^{-1}$ vs. 40.3 ± 3.2 $mL \cdot kg^{-1} \cdot min^{-1}$) ($p<0.05$). Physiological and psychological data was recorded from a total of 180 training sessions. Individual correlations between total $\dot{V}O_2$ and commonly used methods for quantifying physical training load were determined from 18 individual training sessions are shown in Table 5.2 (over page).

Table 5.2: Individual correlations coefficients between total $\dot{V}O_2$ and common methods for quantifying physical training load.

Subjects	sRPE	$sRPE_{wt}$	Banister's TRIMP	Lucia's TRIMP	External Work
S1	0.72	0.74	0.83	0.88	0.94
S2	0.75	0.87	0.88	0.86	0.96
S3	0.81	0.87	0.85	0.80	0.92
S4	0.83	0.83	0.90	0.65	0.97
S5	0.84	0.83	0.88	0.92	0.93
S6	0.55	0.61	0.82	0.88	0.88
S7	0.71	0.74	0.82	0.88	0.92
S8	0.58	0.66	0.71	0.90	0.95
S9	0.89	0.86	0.90	0.75	0.96
S10	0.85	0.84	0.92	0.82	0.94
Mean ± SD	0.75 ± 0.11[a]	0.79 ± 0.09[a]	0.85 ± 0.06	0.83 ± 0.08	0.94 ± 0.03

[a] Significantly different to External Work, $P<0.05$.

One-way ANOVA revealed significant main effects between methods for quantifying physical training load. Scheffe post hoc analysis demonstrated significant differences between sRPE and external work ($p<0.001$) and $sRPE_{wt}$ and external work ($p<0.05$).

Individual correlations between $\%\dot{V}O_{2max}$ and each of the methods for quantifying training intensity were also determined from 18 individual training sessions. The individual correlation coefficients for methods to quantify training intensity can be seen in Table 5.3 (over page).

Table 5.3: Individual correlations coefficients between %VO_{2max} and common methods for quantifying training intensity.

Subjects	RPE (CR-10_{mean})	RPE (6-20_{mean})	%$[BLa^-]_{max}$	%HR_{max}	%W_{max}
S1	0.80	0.79	0.76	0.91	0.69
S2	0.75	0.69	0.79	0.95	0.67
S3	0.83	0.77	0.77	0.88	0.78
S4	0.81	0.82	0.74	0.92	0.70
S5	0.86	0.88	0.79	0.95	0.78
S6	0.73	0.72	0.78	0.90	0.68
S7	0.70	0.67	0.65	0.87	0.67
S8	0.83	0.80	0.85	0.90	0.79
S9	0.89	0.87	0.85	0.92	0.76
S10	0.82	0.78	0.78	0.95	0.79
Mean ± SD	0.80 ± 0.06	0.78 ± 0.07	0.78 ± 0.06	0.92 ± 0.03[a]	0.73 ± 0.05

[a] Significantly different to all other measures, $P<0.001$. %$[BLa^-]_{max}$ = Percentage of maximal blood lactate concentration, %HR_{max}= Percentage of maximum heart rate, %W_{max} = Percentage of maximum work.

The intra-rater reliability for each of the methods for quantifying training load and training intensity between trials 1–2 and 2–3 are shown in Table 5.4 and 5.5, respectively (over page). Using the %CV and %ICC from trials 2–3 each of the HR methods for quantifying training load showed a poor level of reliability (Banister's TRIMP [15.6% CV, 0.818 ICC] & Lucia's TRIMP [10.7% CV, 0.733 ICC]). A poor level of reliability was also shown for sRPE (28.1% CV, 0.763 ICC) and $sRPE_{wt}$ (28.1% CV, 0.735 ICC). A good level of reliability was shown for HR as a measure of exercise intensity (3.9% CV, 0.862 ICC). However, only a moderate level of reliability was shown for %$\dot{V}O_{2max}$ (6.1% CV, 0.835 ICC) and RPE 6-20 (8.5% CV, 0.765 ICC). A poor level of reliability was shown for the CR-10 scale (28.1% CV, 0.766 ICC).

Table 5.4: Measures of reliability (with 95% confidence intervals) of methods for evaluating training load and intensity from trial 1 to trial 2 on a cycle ergometer (n=10).

Training Load Variable	Change in Mean	CV	CV(%)	ICC	%ICC
sRPE	-6.55 (-11.39 to -1.71)	13.26 (11.243 to 16.17)	33.2 (27.5 to 41.9)	0.697 (0.539 to 0.808)	0.596 (0.404 to 0.739)
$sRPE_{wt}$	-6.15 (-10.31 to -2.00)	11.37 (9.64 to 13.87)	32.2 (27.5 to 41.9)	0.748 (0.610 to 0.842)	0.559 (0.356 to 0.712)
Banister's TRIMP	-2.37 (-4.45 to -1.01)	4.17 (3.99 to 5.75)	15.7 (13.1 to 19.4)	0.719 (0.568 to 0.823)	0.814 (0.706 to 0.885)
Lucia's TRIMP	-0.27 (-1.92 to 1.38)	4.51 (3.83 to 5.50)	14.4 (12.1 to 17.8)	0.62 (0.347 to 0.755)	0.593 (0.399 to 0.736)
% $\dot{V}O_{2max}$	-0.06 (-1.33 to 1.21)	3.47 (2.94 to 4.24)	6.8 (5.7 to 8.3)	0.822 (0.718 to 0.890)	0.796 (0.679 to 0.873)
Mean [BLa^-] ($mmol \cdot L^{-1}$)	-0.09 (-0.36 to 0.18)	0.73 (0.62 to 0.89)	17.3 (14.5 to 21.5)	0.85 (0.761 to 0.908)	0.857 (0.771 to 0.913)
CR-10	-0.34 (-0.59 to -0.09)	0.69 (0.59 to 0.84)	33.2 (27.5 to 41.9)	0.745 (0.606 to 0.840)	0.612 (0.424 to 0.749)
RPE 6-20	-0.23 (-0.56 to 0.11)	0.93 (0.79 to 1.13)	8.8 (7.4 to 10.8)	0.767 (0.637 to 0.854)	0.734 (0.589 to 0.832)
Heart Rate (mean)	-3.65 (-5.8 to -1.5)	5.89 (4.99 to 7.18)	4.1 (3.4 to 5.0)	0.835 (0.738 to 0.899)	0.857 (0.771 to 0.912)

CV = coefficient of variation; ICC = interclass correlation coefficient.

Table 5.5: Measures of reliability (with 95% confidence intervals) of methods for evaluating training load and intensity from trial 2 to trial 3 on a cycle ergometer (n=10).

Training Load Variable	Change in Mean	CV	CV(%)	ICC	%ICC
sRPE	-4.2 (-8.50 to 0.09)	11.75 (9.96 to 14.33)	28.1 (23.3 to 35.2)	0.732 (0.588 to 0.832)	0.763 (0.631 to 0.852)
$sRPE_{wt}$	-3.6 (-7.21 to 0.01)	9.87 (8.37 to 12.04)	28.1 (23.3 to 35.2)	0.782 (0.660 to 0.865)	0.735 (0.592 to 0.834)
Banister's TRIMP	-0.05 (-1.46 to 1.36)	3.85 (3.26 to 4.70)	15.6 (13.0 to 19.3)	0.797 (0.680 to 0.874)	0.818 (0.711 to 0.887)
Lucia's TRIMP	0.52 (-0.93 to 1.96)	3.95 (3.35 to 4.81)	10.7 (9.0 to 13.2)	0.669 (0.500 to 0.789)	0.733 (0.589 to 0.832)
% $\dot{V}O_{2max}$	-0.49 (-1.60 to 0.63)	3.04 (2.58 to 3.71)	6.1 (5.2 to 7.5)	0.866 (0.785 to 0.918)	0.835 (0.737 to 0.898)
Mean [BLa^-] ($mmol \cdot L^{-1}$)	-0.28 (-0.55 to -0.02)	0.72 (0.61 to 0.88)	17.1 (14.3 to 21.2)	0.848 (0.757 to 0.907)	0.848 (0.757 to 0.907)
CR-10	-0.24 (-0.46 to -0.02)	0.61 (0.52 to 0.74)	28.1 (23.3 to 35.2)	0.777 (0.652 to 0.861)	0.766 (0.636 to 0.854)
RPE 6-20	-0.28 (-0.61 to 0.06)	0.91 (0.77 to 1.10)	8.5 (7.2 to 10.5)	0.773 (0.464 to 0.858)	0.765 (0.634 to 0.853)
Heart Rate (mean)	0 (-1.88 to 1.88)	5.16 (4.37 to 6.29)	3.9 (3.3 to 4.8)	0.864 (0.781 to 0.917)	0.862 (0.779 to 0.916)

CV = coefficient of variation; ICC = interclass correlation coefficient.

DISCUSSION

The purpose of this study was to evaluate the criterion validity and reliability of common methods for quantifying training load during endurance-based exercise. A number of previous studies have compared subjective (RPE-based) and objective (HR-based) methods for quantifying internal training load (Impellizzeri et al. 2004; Ozkan and Kin-Isler 2007; Foster 1998; Foster et al. 2001a). However, this is the first study to compare both internal and external methods for quantifying training load against measures of total $\dot{V}O_2$.

The present results reveal strong correlations between each method for quantifying training load (internal & external) and total $\dot{V}O_2$. The strongest correlation occurred between external work and total $\dot{V}O_2$. This result was expected considering the well-established strong positive relationship between these variables. The HR methods of Banister and Lucia also both produced strong positive correlations with total $\dot{V}O_2$. These results suggest that the HR methods may provide good alternative methods for quantifying training load where measures of external work are not easily defined (e.g. swimming and running). Interestingly, both the Banister and Lucia TRIMP produced significantly lower correlations with total $\dot{V}O_2$ than did measures of HR alone when compared with $\%\dot{V}O_{2max}$. This finding suggests that the calculation of a TRIMP score harbours increased potential for error associated with the strength of the weighting factors and / or the calculation of VT and RCP. These results agree with recent research suggesting that further refinement of these methods may improve the use of HR as a method for quantifying training load (Akubat and Abt 2011; Manzi et al. 2009).

In agreement with earlier research (Borresen and Lambert 2008b), moderate-to-strong correlations were also observed between sRPE and total $\dot{V}O_2$. Furthermore, a significant difference was also observed between sRPE and external work when compared with total $\dot{V}$

O_2. The reduced strength in the correlation between sRPE and $\dot{V}O_2$ compared to external work and the HR-based methods may be attributed to psychobiological nature of the CR-10 scale for monitoring exercise intensity. For example, the CR-10 scale was developed to reflect physiological (oxygen uptake, ventilation, HR, circulating glucose concentration, and glycogen depletion) and psychological responses to exercise. Therefore the reduced strength in the correlation between sRPE and total $\dot{V}O_2$ may suggest that factors other than $\dot{V}O_2$ effect global training load. For example, the muscle damage caused from a previous training bout may influence perception of effort (Marcora and Bosio 2007). However, no measures of muscle damage were examined in this study. The present investigation also showed the correlation between sRPE and total $\dot{V}O_2$ ($r = 0.75$) to improve with the calculation of $sRPE_{wt}$ ($r = 0.79$). Previous investigations have shown $sRPE_{wt}$ to be a valid method for quantifying internal training load in athletes undertaking resistance training (Day et al. 2004; Sweet et al. 2004). The present findings further support the use of $sRPE_{wt}$ as a valid method for quantifying internal training load in athletes undertaking endurance-based exercise.

Previous studies have suggested that RPE may provide a more valid method for quantifying training intensity when both aerobic and anaerobic systems are activated (e.g. intermittent exercise) (Bangsbo 1994; Impellizzeri et al. 2004). The present investigation revealed a significantly greater correlation between HR and % $\dot{V}O_{2max}$ compared with RPE and % $\dot{V}O_{2max}$ ($r = 0.92$ and $r = 0.80$, respectively). These results suggest that HR provides the most accurate field-based method for assessing exercise intensity when exercise is performed at an intensity $<\dot{V}O_{2max}$. However, since the obtainment of HR information requires expensive equipment and can be tedious to interpret, the present authors support the use of RPE as a valid and practical alternative for quantifying exercise intensity. Furthermore, previous studies have suggested RPE to be a valid method for quantifying exercise intensity during ultra high-intensity exercise (e.g. resistance training, plyometric training and intervals training at an intensity >$\dot{V}O_2max$) where HR measures may be inappropriate (Foster et al. 2001a; Day et al. 2004; Sweet et al. 2004). Collectively, these findings suggest RPE to be a versatile method for quantifying training intensity. Further studies are required investigating the validity of methods for quantifying training intensity in athletes performing supra-maximal exercise before this hypothesis can be confirmed.

The second purpose of this study was to determine the reliability of common methods for quantifying training load. The results show relatively poor levels of reliability for each of the HR-based methods (Banister's TRIMP [15.6% CV] & Lucia's TRIMP [10.7% CV]) for quantifying internal training load. Interestingly, the use of HR as a measure of exercise intensity showed good levels of reliability (3.9% CV). These results indicate that the weighting factors used to determine the TRIMP scores may also have reduced the reproducibility of these HR-based methods. Therefore a refinement in these weighting factors may increase the reliability of these methods (Manzi et al. 2009).

The present results also show poor levels of reliability for sRPE as a measure of internal training load (28.1% CV). These results may be attributed to the poor reliability of the CR-10 scale for quantifying small changes in training intensity (28.1% CV,). The present findings are in accordance with several previous investigations showing sRPE to have poor reliability (14.9% CV) when used to quantify internal training load in athletes undertaking resistance training (Day et al. 2004) and (31.9% CV) in small sided soccer games (Rampinini et al. 2007). The present authors do acknowledge that the use of %CV may be a poor method for determining the reliability of ordinal scales (e.g. CR-10 scales). However, to our knowledge, there is no method available to appropriately measure the reliability of these scales or allow comparisons with ratio scales (e.g. HR, RPE 6-20 scales). Furthermore, previous authors have also suggested an increased difficulty in determining the reliability of the CR-10 scale due to the multifactorial nature of the scale, which is mediated by both physiological and psychological factors (Borg et al. 1987; Morgan 1994).

Interestingly, the RPE 6-20 scale showed moderate levels of reliability (8.5% CV). The improvement in reliability in the RPE 6-20 scale may be attributed to the fact that the 6-20 scale is a ratio scale and / or is more sensitive than the CR-10 scale (e.g. 15 point scale compared to a 10 points scale). These results indicate that the reliability of sRPE may be improved if the measure of intensity was based on the RPE 6-20 scale. However, since the CR-10 scale has been suggested to be particularly useful for monitoring intensity during high-intensity, intermittent based activities (Impellizzeri et al. 2004), substituting the CR-10 scale for the RPE 6-20 scale may only benefit athletes undertaking endurance-based exercise at an intensity $<\dot{V}O_2max$.

In summary, the present study showed that measures of external work, HR-based methods and RPE-based methods each provided a valid method for quantifying training load in endurance-based exercise. However, of these methods, external work correlated best with total $\dot{V}O_2$. These results suggest that a measure of external work has the greatest aptitude for measuring training load in endurance athletes. A comparison between our internal training load methods showed the HR-based methods to correlate better with total $\dot{V}O_2$ when compared with the RPE-based methods. However, when interpreting these findings it is important to remember that factors other $\dot{V}O_2$ effect global training load. External work, HR and RPE were all valid methods for quantifying training intensity during endurance-based exercise at an intensity $<\dot{V}O_{2max}$. However, previous studies have suggested that RPE may be more appropriate for quantifying training intensity during supra-maximal exercise.

Poor levels of reliability were reported for each of the HR-based TRIMP methods for quantifying internal training load. Since HR alone was shown to have good reliability, the poor level of reliability in the TRIMP methods was attributed to inappropriate weighting factors or errors in determining VT and RCP. The sRPE was also shown to have poor reliability, most likely due to the poor reliability of the CR-10 scale for quantifying training intensity. Substituting the CR-10 scale with the 6-20 scale improves the reliability of the sRPE method.

Practical Applications

There are a variety of methods available to coaches for determining the individual stress placed on an athlete from an exercise bout. At present, measures of $\dot{V}O_2$ are thought to provide the most valid method for quantifying the internal training load in athletes undertaking endurance-based exercise. Unfortunately obtaining direct $\dot{V}O_2$ information in the field is mostly impractical. Of the alternative methods for quantifying training load, measures of external work still remain the most related to $\dot{V}O_2$ and therefore offers the best method for quantifying training load in athletes undertaking endurance-based exercise (e.g. road cycling). External work also provides athletes with instantaneous feedback regarding training intensity without the lag time associated with HR or the familiarisation required with RPE. However, if an athlete is undertaking endurance-based exercise where external work cannot be easily calculated (e.g. running, rowing and cross-country skiing) then HR-based methods provide the most valid alternative.

The RPE-based methods are the simplest and cheapest of all methods and may be the most valid methods for quantifying training load in athletes undertaking supra-maximal exercise. However, the RPE-based methods correlate least with $\dot{V}O_2$ during endurance-based exercise $<\dot{V}O_2max$, are subjective and require greater familiarisation. In conclusion, each of the methods for quantifying training load presented in this paper has both advantages and disadvantages in quantifying the training load placed on an athlete from an exercise bout. Weighing up the cost of the equipment, the level / goals of the athlete, and the intensity performed by the athlete, will determine which method is most appropriate for each individual.

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Chapter 6

A comparison of methods for quantifying training load: relationships between modelled and actual training responses

As per the peer-reviewed paper under review in *European Journal of Applied Physiology.*

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ABSTRACT

This study was designed to assess the validity of methods for quantifying training load, fitness and fatigue in endurance athletes using a mathematical model. Seven trained runners ($\dot{V}O_2max$: 51.7±4.5 $mL\cdot kg^{-1}\cdot min^{-1}$, age: 38.6±9.4 y, mean ± SD) completed 15 weeks of endurance running training. Training sessions were assessed using heart rate (HR), running pace and rating of perceived exertion (RPE). Training dose was calculated using the session-RPE method, Banisters TRIMP and the running Training Stress Score (rTSS). Weekly running performance (1500-m time trial), fitness (submaximal HR, resting HR) and fatigue (Profile of Mood States, Heart Rate Variability [HRV]) were measured. A mathematical model was applied to the training data from each runner to provide individual estimates of performance, fitness and fatigue. Correlations assessed the relationships between the modelled and actual weekly performance, fitness and fatigue measures within each runner. Training resulted in 5.4±2.6% improvement in 1500-m performance. Modelled performance was correlated with actual performance in each subject, with relationships being r=0.70±0.11, 0.60±0.10 and 0.65±0.13 for the rTSS, session-RPE and TRIMP input methods, respectively. There were moderate correlations between modelled and actual fitness (submaximal HR) for the session-RPE (-0.43±0.37) and TRIMP (-0.48±0.39) methods and moderate-to-large correlations between modelled and actual fatigue measured through HRV indices for both session-RPE (-0.48±0.39) and TRIMP (-0.59±0.31) methods. These findings showed that each of the training load methods investigated are appropriate for quantifying endurance training dose, and 2) that submaximal HR and HRV may be useful for monitoring fitness and fatigue, respectively.

Key words: training dose, fitness, fatigue, performance.

INTRODUCTION

Physical training load is the dose of training completed by an athlete during an exercise bout. There are a variety of different methods used to quantify training loads undertaken by athletes (Borresen and Lambert 2009). These methods can be described as either external (i.e. the training completed by the athlete (e.g. distance, power)) or internal (i.e. the athlete's response to external training load (e.g. heart rate (HR), perception of effort)) loads. Typically, measures of internal training load (i.e. the HR-based training impulse (TRIMP) and session-RPE (sRPE)) have been reported to be more appropriate for monitoring the training process as these methods incorporate the relative physiological stress imposed on the athlete (Viru and Viru 2000). However, recent technological developments (e.g. power meters, GPS devices, accelerometers etc.) and commercially available software (e.g. Training Peaks) have made external training load measures increasingly popular amongst athletes (Jobson et al. 2009). Indeed, the training stress score (TSS), which can be calculated from power meters, uses the concept of normalized power and an intensity factor based on an individual's lactate threshold of each training bout to provide a single estimate of the overall training load and physiological stress created by that training session. Whilst initially developed for cycling, the TSS concept has been modified for running using speed/distance measures and a unique algorithm based on the demands of running (Skiba 2006). These methods have recently attracted substantial interest from the coaching and athletic community; however, they are yet to receive critical scientific evaluation. Therefore, at present it is not known which method for quantifying training load is more appropriate for monitoring the training process or which relates best to the training outcomes (i.e. performance, fitness and fatigue).

Mathematical models can be used for describing and estimating the influence of physical training on athletic performance (Taha and Thomas 2003; Borresen and Lambert 2009). The first model proposed by Banister et al. (1975) considered the input dose effect that training has on the response elements of fitness and fatigue. The difference between these variables was suggested to reflect the performance of an athlete at a given time. This simplified model was shown as:

$$\text{Performance} = \text{Fitness} - \text{Fatigue}$$

This basic model has been shown to reflect the training responses of athletes undertaking swimming, running, cycling, triathlon and hammer throwing (For review see: Taha and Thomas 2003). The accuracy of such models have since been refined (Busso 2003), with the introduction of time invariant parameters to take into account the accumulative effects of fatigue. This model showed a significantly improved fit compared with previous models described in the literature (Busso et al. 1991; Banister et al. 1975; Calvert 1976).

Despite these refinements in modelling techniques, systems models have been unable to consistently predict performance on an individual basis in a real-world setting (Busso and Thomas 2006; Taha and Thomas 2003). This may be attributed to the lack of consensus as to the most appropriate method quantifying training load, performance, fitness and fatigue. At present, the most commonly used methods for quantifying fitness and fatigue parameters include HR information at rest and during exercise, as well as blood lactate, biochemical markers and subjective questionnaires (Hooper and Mackinnon 1995; Lambert and Borresen 2006). More recently, heart rate variability (HRV) has been shown to reflect changes in the autonomic nervous system and has been suggested as a useful tool for measuring training adaptation and fatigue (Aubert et al. 2003; Achten and Jeukendrup 2003; Buchheit et al. 2010). Although HRV has been shown to be useful in guiding training in recreational athletes

(Kiviniemi et al. 2009; Kiviniemi et al. 2007), the efficacy of HRV information for monitoring training in well trained adult athletes remains unclear.

Since the influence of different training load inputs into systems models is not well understood, the purpose of the present investigation was to compare currently used methods for quantifying internal (i.e. TRIMP, sRPE) and external (i.e. rTSS) training loads using the time invariant systems model previously described (Busso 2003). Furthermore, this investigation also compared the influence of a variety of fitness and fatigue markers on goodness-of-fit predictions within the model.

METHODS

Participants

Seven well-trained runners (mean ± SD, $\dot{V}O_2max$: 51.7 ± 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$, age: 35.8 ± 9.1 y) volunteered to participate in this study. Each athlete completed between 5-10 sessions per week prior to the commencement of the study. All athletes were fully informed of the potential risks and benefits associated with participation. Written informed consent was obtained by each athlete and ethical approval was granted by the University Human Research Ethics Committee for all procedures.

Experimental Design

A modelling post facto longitudinal research design was used to compare the performance, fitness and fatigue responses during a 15 week period. Individual training dose was measured via a Polar RS 800 HR monitor with a Polar s3 foot pod stride sensor^{TM} W.I.N.D (Polar Oy, Polar Electro, Kempele, Finland). Foot pods were calibrated at the commencement of the study and at the mid-way testing point according to the recommendations of the manufacturer. Running speed, distance and heart rate (HR) were recorded during each session. In addition, perception of effort was also measured following each training session using a rating of perceived exertion (RPE) according to the category ratio scale (CR-10 scale) of Borg et al. (1985).

Throughout the investigation period, selected performance, physiological and psychological tests were completed by the athletes. Specifically, a 1500 m running time-trial and a standardised submaximal HR test (HR_{submax}) were performed weekly. These tests were completed at the same time of day (16:00) following a standardised warm-up. Upon waking on the morning of these tests, each athlete completed a HRV test and recorded resting HR (HR_{rest}) values. Directly following the HRV test, each athlete was required to complete the POMS psychological questionnaire to assess psychological state (McNair et al. 1971).

Testing Procedures

Each athlete was tested at the same time of day following a full day of rest. Athletes were administered written guidelines on carbohydrate consumption prior to the study and were asked to standardise their diet for the 24 h prior to each testing session.

Physiological Measures

Maximal oxygen uptake ($\dot{V}O_2max$) was measured using an incremental treadmill running test to exhaustion on a motorised treadmill (Startrac Unisen Inc. USA). Following a five minute warm up at 8 $km{\cdot}h^{-1}$, the workload protocol commenced at a speed of 8.5 $km{\cdot}h^{-1}$. The workload was increased by 1.5 $km{\cdot}h^{-1}$ every four minutes until volitional fatigue. The athletes received a one minute rest period between workloads. Maximum oxygen uptake was measured using a gas analysis System (Physio-dyne® Fitness Instrument Technologies, Quogue, NY, USA) and was calibrated before and after each test with reference and calibration gases of known concentrations. The pneumotach was calibrated with ambient air using a 3 L syringe (Hans Rudolph Inc, Kansas City, USA). The reliability of $\dot{V}O_{2}max$ measures for this laboratory were acceptable (coefficient of variation (CV%, ± 90% confidence intervals (CI)) = 2.5 (1.8–4.3)).

Performance Measures

Each athlete completed a 1500 m time-trial once a week for the duration of the study. Maximal effort time trials have previously been suggested as ideal for evaluation of performance (Jeukendrup et al. 1996). Prior to the time-trial each athlete was required to complete a standardised warm up consisting of an 800 m jog, followed by the submaximal fitness test. Each athlete was then required to run 1500 m on a tartan track in the shortest time possible. To minimise the effects of pacing, the athletes began the time trial in a staggered start with 10 s between each participant. The athletes were not informed of their lap splits and given equal verbal encouragement. The test-retest reliability of the 1500 m time-trial was high (%CV (90%CI) = 2.7 (2.1–3.5)).

Submaximal Fitness Test

The HR_{submax} required athletes to complete a 1500 m circuit at a standardised pace of 210 $m \cdot min^{-1}$. This test was completed on a weekly basis prior to the 1500-m time-trial. Pacing was achieved using instantaneous feedback from the Polar s3 stride sensor^{TM} W.I.N.D and RS 800 running computer (Polar Oy, Polar Electro, Kempele, Finland). Heart rate information was collected during the entire exercise bout. Submaximal HR response was taken as the mean HR during the final 30 s of the exercise bout. A measure of RPE (6-20 scale) was also collected at the completion of the test (Borg 1973).

Training Load Quantification

TRIMPS

A variety of methods were used to quantify the training load of the athletes during each exercise bout. The methods selected utilise a variety of training responses including HR-based information, perception of effort as well as external load measures. The TRIMP method proposed by Banister et al. (1991) was used to quantify internal training load. This method was calculated using the following equation:

$$\text{TRIMP} = D(\Delta\text{HR ratio})e^{b(\Delta\text{HR ratio})} \tag{1}$$

where: D = duration of training session, b = 1.67 for females and 1.92 for males and (ΔHR ratio) is determined using the following equation:

$$\Delta\text{HR ratio} = (\text{HR}_{ex} - \text{HR}_{rest}) / (\text{HR}_{max} - \text{HR}_{rest}) \tag{2}$$

where HR_{rest} = the average heart rate during rest and HR_{ex} = the average HR during exercise (Morton et al. 1990).

Session-RPE

The sRPE method proposed by Foster et al. (1995) was also used to quantifying internal training load. This method requires athletes to subjectively rate the intensity of the entire training session using a RPE according to the category ratio scale (CR-10) of Borg et al. (1985). The RPE value was then multiplied by the total duration (min) of the training session. To ensure the athletes reported a RPE for the entire training session, RPE measures were taken 30 min following the completion of the session. Standard instructions and anchoring procedures were explained during the familiarisation process (Noble and Robertson 1996).

Training Stress Score

Daily training load was also quantified from velocity data recorded with a Polar RS 800 running computer and a calibrated Polar s3 foot pod stride sensor^{TM} W.I.N.D. (Polar Oy, Polar Electro, Kempele, Finland) and expressed as a rTSS. The rTSS is calculated using the Gravity Ordered Velocity Stress Score (GOVSS) algorithm according to previously described methods (Skiba 2006). In general, this measure is a TRIMP measure derived from external load data and is calculated similar to other training impulse measures that combine exercise duration and intensity (Allen and Coggan 2006; McGregor et al. 2009). McGregor et al (2009) have previously described this method for running using training data collected from training logs. The test-retest reliability of the foot pod units for measuring distance was determined in pilot testing was high (%CV (90%CI) = 2.6 (2.1–3.5).

Fitness

A variety of methods were used to measure fitness or adaptation to training. HR_{rest} was collected upon waking, each morning of the performance tests. The measurement was recorded as the minimum HR obtained during 5 min of lying in a supine position. Additionally HR_{submax} and submaximal RPE (RPE_{submax}, 6-20) taken during the standardised submaximal warm-up were also used as a measure of fitness.

Fatigue

Several methods were used to assess the fatigue of the athletes in the study. Prior to the each weekly performance test, each athlete completed mood states (POMS) questionnaire (McNair et al. 1971). This is a 65-item inventory of six subscales: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia and confusion-bewilderment. The athlete used a 5-point scale (0-'not at all' to 4-'extremely') to respond to each term according to the question; ‘‘How have you been feeling for the past week including today?’’. A specific sub-analysis of the POMS data using only the responses to the fatigue-inertia subset were completed and reported as a score out of 20.

Heart rate variability was recorded upon waking on each morning prior to the performance test. Polar RS 800 HR monitors (Polar Oy, Polar Electro, Kempele, Finland) were used to record R-R intervals at a timing accuracy of 2 ms. The measurement started with 5 min of lying supine followed by 5 min of standing (Kiviniemi et al. 2007). The R-R interval data were downloaded to a personal computer using Polar ProTrainer5 software (version 5.40.171, Finland) and analysed using Kubios HRV software (version 2.0, Biosignal Analysis and Medical Imaging Group, Finland). Occasional ectopic beats were automatically replaced with interpolated adjacent R–R interval values. Power spectral analysis was performed on the data using a traditional Fast Fourier Transform algorithm and a parametric method based on autoregressive time series modelling to establish power (ms^2) in distinct frequency bands, the high frequency (HF) range (HF = 0.15–0.40 Hz) and the low frequency (LF) range (LF = 0.04–0.15 Hz). The HRV ratio was determined as the HF/LF. In addition, the standard deviation of instantaneous beat-to-beat R-R interval variability measured from Poincaré plots (SD1) (Huikuri et al. 1996) was calculated during the last 3 min of the 5-min standing period as a vagal-related HRV index (Tulppo et al. 1996). Due to technical difficulty, only data were collected from six participants.

Fitting the Model

The time invariant systems model used in this study has been previously described (Busso 2003). This model assumes that the gain term of the fatigue effect is mathematically related to the training dose using a first-order filter. Performance output can be described as:

$$\hat{p}^n = p^* + k_1 \sum_{i=1}^{n-1} w^i \mathrm{e}^{-(\mathrm{n-i})/\tau 1} - \sum_{i=1}^{n-1} \mathrm{k}_2^{\mathrm{i}}\, w^i \mathrm{e}^{-(\mathrm{n-i})/\tau 2}$$

in which the value of k_2 at day i is estimated by mathematical recursion using a first-order filter with a gain terms k_3 and a time constant τ^3:

$$k_2^i = k_3 \sum_{j=1}^{i} w^j e^{-(i-j)/\tau 3}$$

The parameters for the model were determined by fitting the model performances with actual performances using the least squares method using the Solver function in Microsoft Excel (Microsoft, Redmond, USA). The set of model parameters was determined by minimizing the residual sum of squares between modelled performance and actual performances (RSS):

$$RSS = \sum_{n=1}^{N} [p^n - \hat{p}^n]^2$$

where n takes the N value corresponding to the days of measurement of the actual performance. Successive minimization of the RSS with a grid of values for each time constant gave the total set of model parameters.

Statistical Analyses

Models were developed for each athlete and the goodness of fit values were used to determine the best fitting model from either the rTSS, HR- or RPE-based training load measures. The coefficient of determination (r^2), giving the variation explained by the model, was calculated to establish the goodness of fit for the model. Within-individual correlations between the various actual and predicted measures of performance, fitness and fatigue were analysed using the Pearson's correlation coefficient. The following criteria were adopted to interpret the magnitude of the correlation (r) between test measures: <0.1 trivial, 0.1–0.3 small, 0.3–0.5 moderate, 0.5–0.7 large, 0.7–0.9 very large, and 0.9–1.0 almost perfect. Differences between the mean within-individual correlations between each of the methods were assessed using a one-way ANOVA with Tukey HSD post hoc to locate differences. Statistical significance was set at $P<0.05$. All data are presented as mean ± SD unless otherwise stated.

RESULTS

Five hundred and forty two individual training sessions were analysed during the investigation period. Individuals completed an average of 77 ± 20 individual training sessions with the weekly training duration of 389 ± 168 min and weekly training distance of 68 ± 36 km. This training resulted in a 5.4 ± 2.6% improvement in 1500-m time-trial performance. Modelled performance significantly correlated with actual performance in each athlete, with average correlations being 0.70 ± 0.11 (Table 6.1), 0.60 ± 0.10 (Table 6.2) and 0.65 ± 0.13 (Table 6.3) for the rTSS, sRPE and TRIMP input methods, respectively. The within-individual correlations between each of these methods were not significantly different between methods ($p=0.33$).

Fitness

Maximum oxygen uptake was not significantly changed (51.7 ± 4.5 $\mathrm{mL \cdot kg^{-1} \cdot min^{-1}}$ vs. 51.3 ± 6.1 $\mathrm{mL \cdot kg^{-1} \cdot min^{-1}}$, $p>0.05$). Fitness measured by HR_{submax} decreased non-significantly from 77.9 ± 5.1 to 74.8 ± 5.5% during the study ($p>0.05$, Figure 6.1A). Tables 2 and 3 show that there were moderate correlations between modelled and actual fitness measures (HR_{submax}) for the sRPE (-0.43 ± 0.37) and TRIMP (-0.48 ± 0.39) methods, respectively. Additionally, RPE_{submax} did not significantly change (11.7 ± 1.0 to 11.3 ± 1.4, from week 1 to week 15) during the test period and small correlations with modelled fitness using each of the training load input methods ($p>0.05$, Figure 6.1A). Finally, there were no significant group changes in HR_{rest} during the study. There were only trivial correlations between HR_{rest} and modelled fitness outcomes using any of the different training load measures (Tables 6.1B).

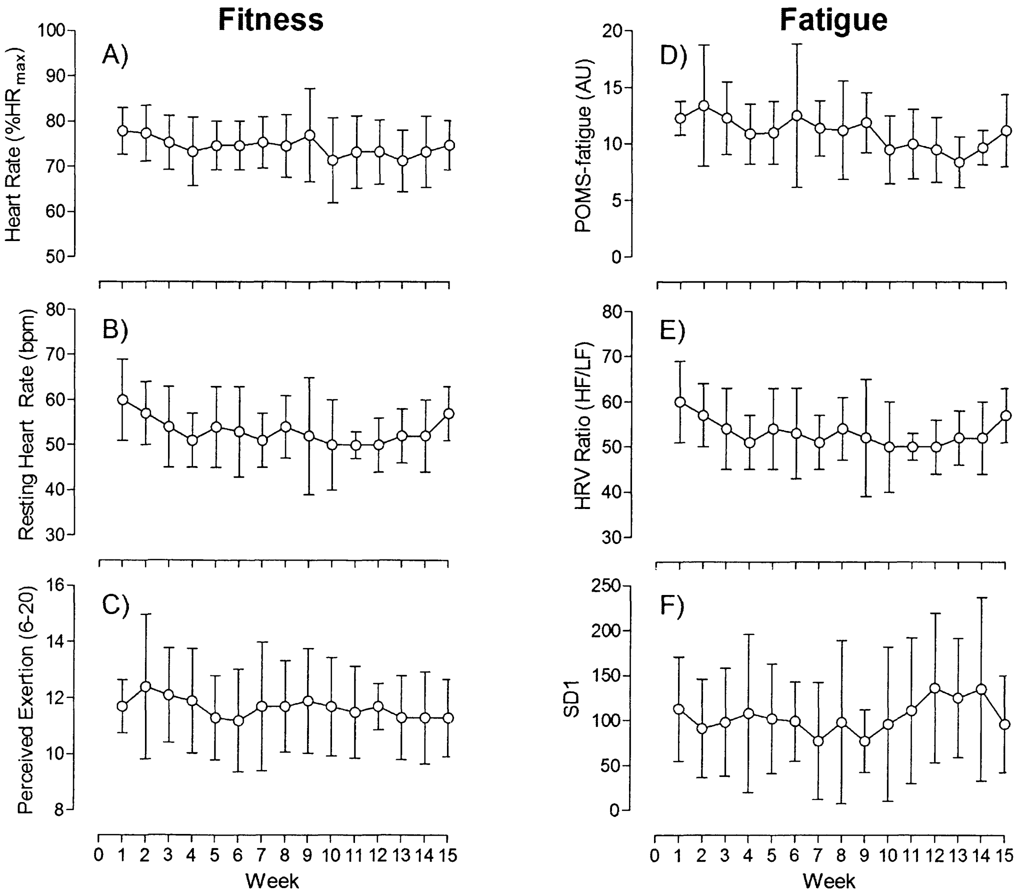

Figure 6.1: Mean (±SD) Fitness [A) HR_{submax}, B) HR_{rest} and C) RPE_{submax}] and Fatigue [D) POMS-fatigue, E) HRV ratio and F) SD1] measures during the 15 week study.

Fatigue

Using the fatigue subset of the POMS questionnaire, the athletes reported substantial fluctuations in fatigue status across the 15-week training period (range: 7–20). However, there were no group changes in the POMS fatigue scores during the study period (Figure 6.1D). Notably however, these measures showed trivial correlations with modelled fatigue using each of the various training load input methods. Similarly, the HRV ratio also revealed was unrelated to the modelled fatigue in this study (Figure 6.1E). In contrast, there were moderate-to-large correlations between modelled and actual fatigue measures using SD1 when both sRPE (-0.48 ± 0.39, Table 6.2) and TRIMP (-0.59 ± 0.31, Table 6.3) methods were used as the input methods. There were no significant group changes in SD1 during the study (Figure 6.1F).

DISCUSSION

The purpose of this study was to compare the validity of three common methods for quantifying training load (i.e. rTSS, sRPE & TRIMP) using a systems model approach. This study also examined the influence of the various training load inputs on actual training outcomes (i.e. performance, fitness & fatigue) compared to those predicted by the model. The main results demonstrated large correlations between each of the different methods for quantifying training loads and modelled running performance. Notably, the relationships between rTSS and performance were slightly larger than both methods for quantifying internal training load (i.e. sRPE and TRIMP). These results contrast to common training theory which suggests that it is the internal stimulus that determines training adaptation (Booth and Thomasson 1991; Viru and Viru 2000; Impellizzeri et al. 2005). A possible explanation for the reduced relationship between the internal training load methods and performance may be attributed to the relatively poor measurement reliability of the CR-10 Borg scale for estimating exercise intensity and/or the inability of the generic HR methods to adjust for individual fitness/performance characteristics.

Table 6.1: Individual and mean (±SD) correlations (r) between modelled and actual performance, fitness and fatigue using rTSS as the training load input method.

		Relationships with Modelled Fitness			Relationships with Modelled Fatigue			
Subject	**Performance**	**HR$_{submax}$**	**HR$_{rest}$**	**RPE$_{submax}$**	**POMS**	**Fatigue**	**HRV Ratio**	**SD1**
1	0.75	-0.14	-0.33	0.36	-0.10	0.06	0.06	0.02
2	0.55	0.02	-0.48	0.20	0.16	0.41	0.75	-0.59
3	0.60	-0.57	0.06	-0.57	-0.16	-0.33	0.13	-0.75
4	0.82	-0.41	0.13	-0.01	-0.02	0.16	-0.03	-0.67
5	0.63	0.29	-0.44	-0.62	-0.27	-0.27	0.00	-0.01
6	0.69	-0.74	0.99	-0.76	-0.19	-0.43	-	-
7	0.84	-0.72	-0.35	-0.23	0.65	0.43	0.44	-0.40
Mean (±SD)	0.70±0.11	-0.32±0.39	-0.06±0.52	-0.23±0.43	0.01±0.31	0.00±0.35	0.23±0.31	-0.40±0.33

Table 6.2: Individual and mean (±SD) correlations (r) between modelled and actual performance, fitness and fatigue using sRPE as the training load input method.

		Relationships with Modelled Fitness			Relationships with Modelled Fatigue			
Subject	**Performance**	**HR$_{submax}$**	**HR$_{rest}$**	**RPE$_{submax}$**	**POMS**	**Fatigue**	**HRV Ratio**	**SD1**
1	0.52	-0.02	-0.39	0.26	-0.20	-0.32	-0.05	0.20
2	0.62	0.10	-0.29	0.25	0.20	0.24	0.71	-0.76
3	0.69	-0.52	0.16	-0.53	0.09	0.05	0.07	-0.69
4	0.53	-0.34	0.14	-0.11	-0.07	0.15	-0.08	-0.64
5	0.53	-0.95	-0.15	-0.41	-0.01	0.42	0.16	-0.08
6	0.57	-0.69	0.94	-0.67	-0.19	-0.37	-	-
7	0.77	-0.58	-0.25	-0.21	-0.74	0.02	-0.74	-0.83
Mean (±SD)	0.60±0.10	-0.43±0.37	0.02±0.46	-0.20±0.36	-0.13±0.30	0.03±0.29	0.01±0.47	-0.47±0.42

Table 6.3: Individual and mean (±SD) correlations (r) between modelled and actual performance, fitness and fatigue using Banister's TRIMP as the training load input method.

		Relationships with Modelled Fitness			Relationships with Modelled Fatigue			
Subject	**Performance**	**HR_{submax}**	**HR_{rest}**	**RPE_{submax}**	**POMS**	**Fatigue**	**HRV Ratio**	**SD1**
1	0.78	-0.14	-0.37	0.29	-0.17	-0.02	0.09	-0.05
2	0.55	0.04	-0.47	0.17	0.18	0.48	0.76	-0.72
3	0.66	-0.56	0.09	-0.57	-0.11	-0.29	0.00	-0.65
4	0.67	-0.27	0.18	-0.17	0.21	0.35	0.08	-0.65
5	0.54	-0.95	-0.12	-0.40	0.05	-0.39	0.30	-0.29
6	0.51	-0.72	0.95	-0.76	-0.36	-0.28	-	-
7	0.86	-0.73	-0.38	-0.21	-0.67	-0.07	-0.68	-0.90
Mean (±SD)	0.65±0.13	-0.48±0.36	-0.02±0.49	-0.24±0.38	-0.12±0.31	-0.03±0.33	0.09±0.47	-0.54±0.31

We have recently reported high measurement error of the session-RPE using the CR-10 scale (CV: 28.1%) compared to HR (CV: 3.9%) during endurance cycling (Wallace et al. 2011). In particular, we observed a poor sensitivity to small changes in intensity during moderate-to-hard exercise with this scale (Wallace et al. 2011). In the present study, 63% of all training sessions were rated as 'moderate-to-hard', which may have influenced the fit of the between modelled and actual performance. Therefore, the combination of the higher measurement error of the CR-10 RPE scale coupled with the scales reduced sensitivity at moderate-to-high intensities may explain the reduced relationship between sRPE and predicted running performance.

Relatively poor levels of test-retest reliability for the Banisters' generic HR TRIMP (15.6% CV) have also been reported in healthy individuals undertaking steady-state cycle training in a laboratory setting (Wallace et al. 2011). Notably however, the reliability of the HR TRIMP method improved when adjusted to account for individual differences in ventilatory thresholds (i.e. Banister's TRIMP [15.6% CV] vs. Lucia's TRIMP [10.7% CV]) (Wallace et al. 2011). Moreover, it has also been shown that training loads calculated from individual HR-lactate relationships (i.e. the individual HR-based TRIMP) rather than the Bannisters' TRIMP were related to both changes in fitness (running speed and 2 and 4 $\text{mmol} \cdot \text{L}^{-1}$ blood lactate) and running performance (5000 m and 10000 m time trials) in eight long distance runners during a 9 week training period (Manzi et al. 2009). Taken collectively with these previous observations, the present findings suggest that the relationship between HR TRIMP methods and training outcomes may be improved if the TRIMP calculation is modified to account for individual physiological thresholds. The absence of this individualised process in Banisters TRIMP may explain the reduced relationship between this method and endurance running performance.

Running speed was also collected which was then expressed as an arbitrary measure of external training load using the rTSS. Similar to the individualised TRIMP methods, the rTSS calculates training dose by multiplying training duration with training intensity. However, unlike TRIMP and sRPE, the rTSS calculates training intensity using an intensity factor calculated from a percentage of an individuals' 'threshold' running pace. The rTSS is based on the TSS, where exercise intensity is calculated from normalised power measures (Allen and Coggan 2006). The TSS was originally adapted from Banisters' TRIMP, and has been reported to be appropriate for monitoring individual training (Allen and Coggan 2006). Whilst the present study is the first to examine the relationship between rTSS and running performance, previous studies have successfully used the TSS to quantify training load in cycling (Garvican et al. 2010) and running (McGregor et al. 2009). In this study, the relationship between rTSS and modelled performance was the strongest of each of the training load methods. The improved associations between the rTSS compared to the sRPE and HR TRIMP methods are likely explained by the ability of the rTSS to adjust for differences in individual performance characteristics and the improved measurement reliability of the foot pods compared with the other training load quantification methods.

Whilst internal training load methods appear to be theoretically robust for quantifying training load (Impellizzeri et al. 2005; Viru and Viru 2000), more work is required to determine appropriate weighting factors for HR methods and to increase measurement reliability when using perceptual measures to assess exercise intensity. It is possible that the substitution of the CR-10 scale with the CR100 or 6-20 RPE scales may, in part, address this issue. Indeed, whilst the present study shows that the rTSS relates best to predicted performance, further research is required to assess the efficacy of this tool in a different cohort of athletes with varying training goals.

The second purpose of this investigation was to examine the relationships between actual and predicted measures of fitness and fatigue using a systems modelling approach for assessing training responses. Moderate correlations were observed between HR_{submax} and predicted fitness when TRIMP and sRPE were used as training inputs. It is widely recognised that HR_{submax} decreases with endurance training in adult populations with these changes being largely attributed to decreases in sympathetic activity of the heart (Carter et al. 2003), and increased plasma volume (Covertino 1991). Despite this, several previous studies have only shown small to moderate changes in HR_{submax} in trained endurance athletes following intensive training periods (Buchheit et al. 2010; Uusitalo et al. 1998; Swaine et al. 1994). It was suggested that training elicits differing effects on indices of fitness which limit the efficacy of HR_{submax} as a marker of cardiovascular fitness. These previous findings may explain the moderate relationship between HR_{submax} and predicted fitness using HR and sRPE load input methods in the present study. Collectively, the current findings support the use of HR_{submax} as a valid simple fitness test for assessing fitness changes in endurance runners; however the moderate strength of the correlations indicate that other measures may be required to accurately monitor how an athlete is responding to training.

Many studies have shown HR_{rest} to decrease slightly following endurance training (Uusitalo et al. 1998; Buchheit et al. 2010; Wilmore et al. 2001). This phenomenon has been attributed to decreases in intrinsic rhythmicity of the heart and an increase in the predominance of parasympathetic control (Smith et al. 1989). Despite this, no relationships were observed between actual HR_{rest} and modelled fitness in the runners in the present study. These findings are in accordance with previous research showing no decreases in HR_{rest} following periods of intensified training (Melanson and Freedson 2001; Fry et al. 1992a; Zavorsky 2000). The lack of agreement in the findings between these studies may be due to the differences in training undertaken by the participants and/or the inter-individual differences of the training status of the athletes. Furthermore since HR_{rest} can also be influenced by factors such as age, hydration and environmental conditions, the present study does not support the use of HR_{rest} as an idiosyncratic marker of cardiovascular fitness.

Heart rate variability represents the beat-to-beat variation in R-R intervals and is widely used as a non-invasive measurement of autonomic nervous system activity (Achten and Jeukendrup 2003). Recent research has focussed on the effectiveness of HRV for assessing training adaptation at the level of the individual athletes (Hautala et al. 2010; Buchheit et al. 2011; Buchheit et al. 2010) and guiding training on an individual basis (Kiviniemi et al. 2009; Kiviniemi et al. 2007). The majority of longitudinal monitoring studies have reported that vagal-related indices increase after aerobic training (Melanson and Freedson 2001; Tulppo et al. 2003; Borresen and Lambert 2008a; Sandercock et al. 2005) and recent research has also shown that changes in these indices are related to endurance running (Buchheit et al. 2010) and cycling performance (Lamberts et al. 2009; Lamberts et al. 2010). Moreover, a recent meta-analysis has shown that HRV is a potential marker of short term training fatigue (Bosquet et al. 2008). In part agreement with this suggestion, we observed moderate-to-large correlations between instantaneous beat-to-beat variability (SD1) and predicted fatigue when sRPE and TRIMP were used as training load inputs. However, in contrast, there were no significant relationships between predicted fatigue and other HRV indices (i.e. HF, LF, rMSSD, SD2, data not reported) within time and frequency domains. The lack of associations between these measures with modelled fatigue may be due to the level of accumulated fatigue which may not have been sufficient to alter changes in cardiac autonomic function, or alternatively, that these indices better reflect fitness adaptations. However, we also failed to observe relationships with any of the HRV indices and modelled fitness. Regardless, these

SD1 results indicate that this measure may provide a simple, non-invasive and objective method for assessing short-term fatigue in endurance athletes.

Psychological tools such as the Profile of Mood State (POMS) questionnaire have been used to assess mood states in athletic populations (Martin et al. 2000; Hooper et al. 1997). From these investigations several links have been made between changes in POMS fatigue scores in athletes undertaking intensified training periods (Martin et al. 2000; Liederbach et al. 1992) or exhibiting symptoms of overtraining or staleness (Hooper et al. 1997). However, in the present study, a poor relationship was observed between the fatigue subset of POMS and predicted fatigue. These results are similar to an earlier study examining the relationship between the fatigue subset of POMS and predictions of fatigue using a modelling approach (Wood et al. 2005). The previous authors reported a moderate correlation between the fatigue subset of POMS and predicted fatigue, but only provided data from a single runner where 10 fatigue (POMS) measures were taken over a 12 week training period. The reduced strength in this correlation was attributed to the inability of the fatigue subset to detect the source of fatigue (i.e. global fatigue vs. training induced fatigue). The poorer correlation in the present study compared to Wood et al. (2005) may be explained by the increased number of POMS measures taken from the runners in this study (10 v 15). Importantly, some individuals in this study did exhibit large-to-moderate correlations between predicted fatigue for the POMS-subset with each of the training load inputs. Collectively, however, the lack of relationship between the POMS fatigue subsets and predicted fatigue suggests that these measures are insensitive to small changes in cumulative fatigue in trained athletes. It may be that other psychometric tools that assess sport-related fatigue, rather than mood states, such as the RESTQ-Sport (Kellmann and Kallus 1993), the Daly Analysis for Life Demands of Athletes

(DALDA) (Rushall 1990) or the training distress questionnaire (Main and Grove 2009) are more appropriate for assessing training related fatigue in endurance athletes.

There are some limitations of this study that must be acknowledged. First, the efficacy of the mathematical model itself consists of several limitations that may reduce its adequacy. It is generally reported that a large number of performance tests are required to gain a stable fit in the model. Indeed, it has been suggested that between 20–200 performance tests are required within a short time to obtain a robust model (Taha and Thomas 2003). Whilst we measured performance 15 times, which is high in comparison to most other modelling studies, the stability of the model may be inadequate to truly describe the relationships reliably. Since it would be practically unrealistic to substantially increase the number of maximal performance tests with athletes in a normal training environment, this approach may only be limited to laboratory studies. Secondly, although reasonable attempts were made to control the performance test environment, not all factors could be controlled. It is possible that factors such as the climate (e.g. temperature, wind etc.) and athlete motivation may have affected 1500 m time-trial performance independent of the other factors assessed in this study and therefore also influences the relationships between the modelled and actual performance. Finally, the athletes in this study were endurance athletes who do not regularly compete in relatively short events such as 1500 m time-trial or train for these events. It is therefore possible that the lack of specificity in the performance test may have reduced the strength of the training impulse-performance outcome for these athletes.

Summary

The main findings of this study are that there were large relationships between each of the different methods for quantifying training loads and modelled running performance. However, notably, the relationships between rTSS and modelled 1500 m time-trial performance were slightly larger than both methods for quantifying internal training load (i.e. sRPE and TRIMP). From a practical point of view, these results suggest that it is important to select a reliable measure of training load and that methods for quantifying load should be adjusted to account for individual athlete characteristics. However, other factors such as practical usefulness need to be considered when monitoring athletes (particularly large groups). Therefore, the HR and in particular, the session-RPE method may be suitable practical choices for monitoring load in a training environment. The moderate relationships between some of the fitness (i.e. $\%HR_{max}$) and fatigue (i.e. SD1) variables indicate that these markers may be useful for monitoring athletes to better understand their response to the training process. Taken together, these results suggest that each of the methods used in this study are appropriate for monitoring training dose in endurance athletes. However, coaches and scientists should be aware that ideally, the training load measures should be reliable and account for differences in individual physiological/performance characteristics of athletes.

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Chapter 7

Thesis Summary and Conclusions

SUMMARY

This thesis presented four papers that examined the validity and reliability of methods for quantifying physical training loads in endurance exercise (see Figure 7.1). The first study was designed to examine the ecological validity of the session-RPE method for quantifying training loads in competitive swimmers. In this study, session-RPE was compared with previously used criterion measures of assessing training load in swimming (i.e. HR methods and distance). Furthermore, this study also examined the correspondence between athlete and coach perceptions of internal training load using the session-RPE method. The findings from this study further confirmed the ecological validity of the session-RPE method. A second manuscript was then presented outlining the practical efficacy of the session-RPE method for monitoring the training process in swimming.

The second study was designed to establish the criterion validity and reliability of common methods of quantifying training load in endurance exercise. Specifically, this study examined the relationship between both internal (e.g. HR-, RPE-based) and external (e.g. work) measures of quantifying training load using oxygen consumption ($\dot{V}O_2$) as the criterion measure. The study revealed strong relationships between each of the training load methods and $\dot{V}O_2$. However, a poor level of reliability was observed for the session-RPE and HR methods. The third study applied each method for quantifying training load to a mathematical model in an attempt to assess the accumulated effects of training. Construct validity was established for each training load input with strong relationships between actual performance and modelled performance predicted by the model. Stronger relationships between training inputs and performance were observed with improvements in reliability in methods for assessing exercise intensity. The third study also examined the validity of commonly used methods for assessing fitness and fatigue. This was achieved by comparing actual measures of fitness and fatigue with those predicted by the model.

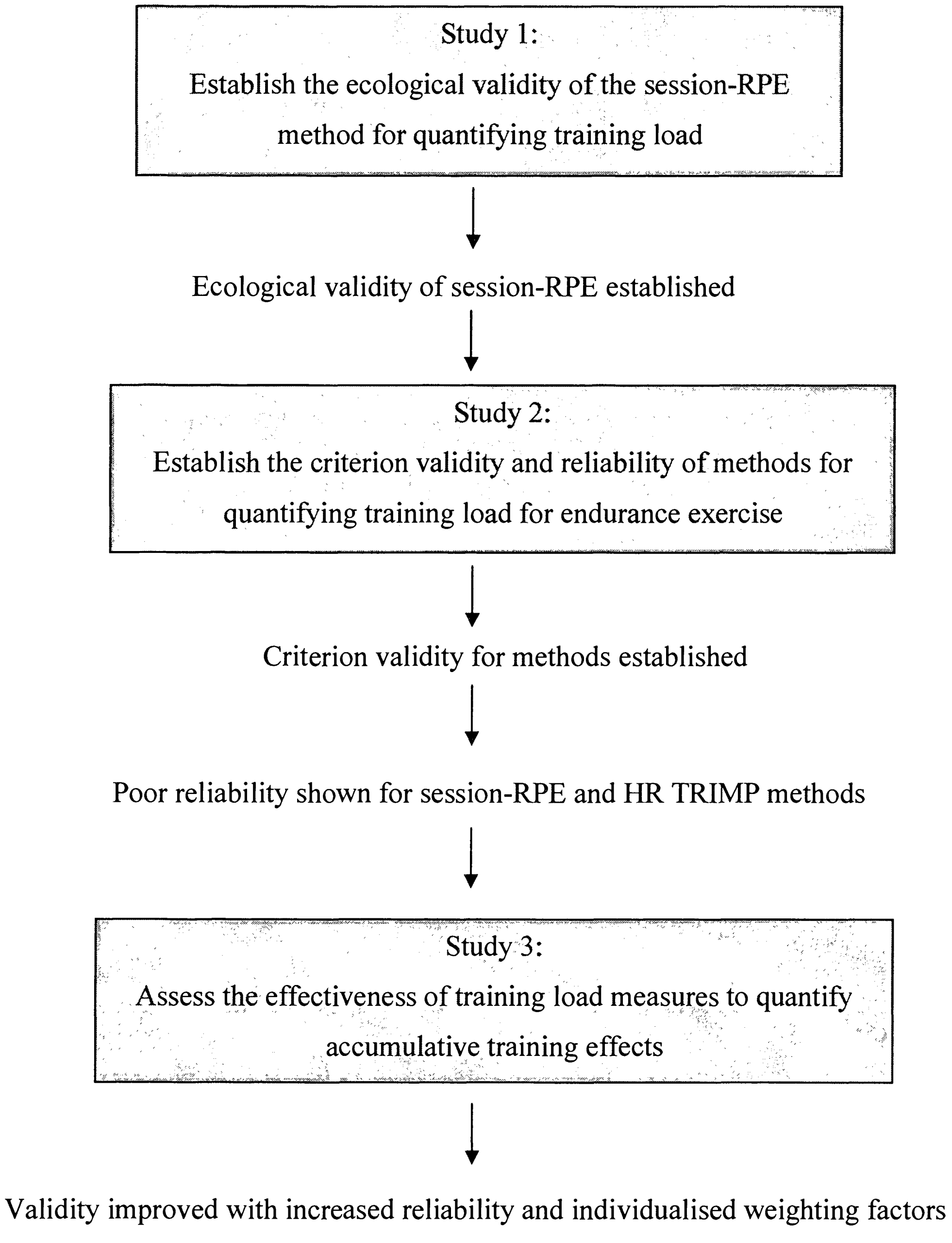

Figure 7.1: Outline of the research progress linking the three major studies undertaken in this thesis.

Study 1

Objective 1

The purpose of this investigation was to establish the ecological validity of the session-RPE method for quantifying training loads in competitive swimmers. This was established through comparisons with HR methods and distance as criterion measures. The findings of this study were in agreement with other previous investigations (Foster et al. 2001a; Impellizzeri et al. 2004; Alexiou and Coutts 2008; Coutts et al. 2009), that suggest that the RPE method may be more sensitive than HR or distance measures for describing the response to training during high-intensity or intermittent exercise. Therefore, given the importance of high-intensity exercise in swimming and the difficulties associated with collecting HR information in an aquatic environment, the session-RPE method may provide a more valid approach to monitoring internal training load in competitive swimmers.

Objective 2

The second purpose of this study was to examine the correspondence between athlete and coach perceptions of internal training load using the session-RPE method. To achieve this, both coach intension and athlete perception were evaluated using the session-RPE method. The results of this study are in agreement with previous research (Foster et al. 2001b), suggesting a tendency for athletes to report higher training intensities compared with coaches during sessions designed to be easy, and lower training intensities compared with coaches during sessions designed to be difficult. These findings are consistent with previous investigations showing a mismatch between athlete and coach perceptions of training intensity at low and high intensities (Foster et al. 2001b). Taken collectively, the present findings support the use of session-RPE as a valid and practical tool for monitoring training loads in swimming.

Study 2

The purpose of this investigation was to compare the criterion validity and test-retest reliability of common methods for quantifying training load in endurance exercise. This study was the first to compare both internal (i.e. HR and RPE) and external (work) methods for quantifying training load against measures of $\dot{V}O_2$ in a laboratory setting. The findings showed that measures of external work, HR methods and RPE methods each provided a valid method for quantifying training load in endurance exercise. However, of these methods, external work correlated best with $\dot{V}O_2$. These results suggest that measures of external work may be more valid than internal measures for quantifying training dose in endurance exercise. A comparison between internal training load methods showed the HR methods to correlate better with total $\dot{V}O_2$ when compared with the RPE methods. However, caution should be taken when interpreting these results as factors other than $\dot{V}O_2$ have been shown to affect global training load.

Poor levels of reliability were reported for each of the HR TRIMP methods for quantifying internal training load. Since HR alone was shown to have good reliability, the poor level of reliability in the TRIMP methods was attributed to inappropriate weighting factors or errors in determining the physiological / performance thresholds that are applied to the calculation of these methods. The session-RPE method was also shown to have poor reliability. These findings were attributed to the poor reliability of the CR-10 scale for quantifying training intensity, particularly at intensities around lactate threshold. Taken collectively, these findings suggest that measures of external work provide the most valid method for quantifying training load in endurance exercise. Furthermore external work also provides athletes with instantaneous feedback regarding training intensity without the lag time associated with HR or the familiarisation required with RPE. However, if an athlete is undertaking endurance exercise where external work cannot be easily calculated (e.g. running, rowing and cross-country skiing), then HR methods provide the most reliable alternative. The present results support the use of RPE methods as simple and cheap methods for quantifying training load in athletes undertaking supra-maximal exercise or exercise involving a variety of training modalities.

Study 3

Objective 1

The purpose of this study was to establish the construct validity of common methods for quantifying training load. This was achieved by applying each of the training inputs to a mathematical model to examine the accumulated effects of training. The findings revealed strong relationships between actual and predicted running performance using each of the training inputs. Notably, the relationships were slightly larger between rTSS and modelled performance compared with both internal training load methods (i.e. session-RPE and TRIMP). These results were attributed to the increased reliability of the devices used to measure rTSS and the application of individual performance thresholds in the calculation of this method. Figure 7.2 shows a representation of the factors that contribute to the validity of the methods examined. However, other factors such as practical usefulness need to be considered when selecting a method for monitoring athletes (particularly large groups). Therefore, HR and in particular, the session-RPE methods may be suitable practical choices for monitoring load in a training environment.

Objective 2

The second purpose of this investigation was to examine the validity of commonly used methods for assessing fitness and fatigue using a mathematical model. The findings revealed moderate correlations between modelled and actual fitness (HR_{submax}) for the session-RPE and TRIMP methods and moderate-to-large correlations between modelled and actual fatigue measured through HRV indices for both session-RPE and TRIMP methods. These findings showed that HR_{submax} and HRV may be useful for monitoring fitness and fatigue, respectively.

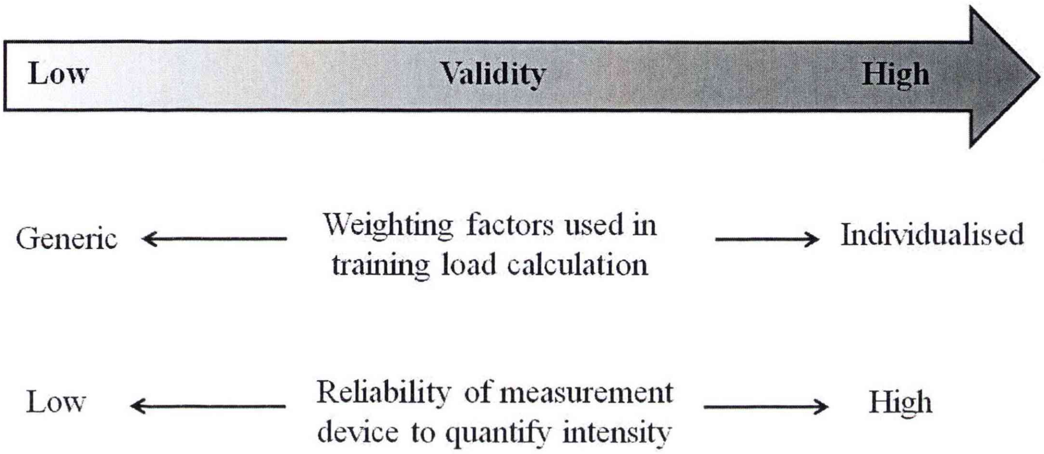

Figure 7.2: The continuum of validity for methods for quantifying training load.

CONCLUSION

In conclusion, this thesis attempted to establish the validity of commonly used methods for quantifying training loads in endurance exercise. The aim of this thesis was addressed by conducting three separate studies. Through these studies, different modes of endurance exercise and levels of athlete conditioning were examined in laboratory and practical settings. Collectively, the findings of this thesis show that each of the methods examined provided valid methods for quantifying training loads in endurance exercise. However the results did show that both the level of reliability of the training intensity measure and the weighting factors used to account for individual performance / physiological characteristics can influence the efficacy of each method for quantifying training load. The findings from these studies provide important implications for sports scientists, coaches and athletes when selecting methods for monitoring the training process.

RECOMMENDATIONS

A previous limitation for competitive swimmers has been the inability to accurately quantify the dose of each exercise bout. This limitation is exacerbated by the numerous training modalities that swimmers routinely undertake (e.g. swimming and dry land workouts) and the inability to compare these modalities on a common scale. The findings from Study 1 show session-RPE to be a valid method for quantifying training dose in swimming. These findings are in agreement with other previous studies that have shown session-RPE to compare favourably with more complicated methods of quantifying training load in endurance (Foster et al. 2001a), team sport (Impellizzeri et al. 2004) and resistance trained athletes (Day et al. 2004). Based on these collective findings, session-RPE is recommended as a useful tool for quantifying internal training load in competitive swimmers. The second manuscript demonstrates how session-RPE can be used to provide coaches and athletes with instant feedback regarding the internal training stress imposed on an athlete from each exercise bout. This information can then be used to improve periodisation strategies, improve session execution and ultimately improve swimming performance. Furthermore, the use of RPE scales is recommended in swimming as it presents a cost efficient, non-invasive and reliable method for quantifying training intensity.

Study 2 examined the validity and reliability of internal and external methods for quantifying training load in endurance exercise. The findings showed that measures of external work, session-RPE and HR TRIMP methods are all appropriate for quantifying training load in endurance exercise. However, of the methods used, measures of external work related best with measures of oxygen consumption. Therefore the recommendations of this study are that where possible measures of external work should be used to calculate the training dose undertaken during endurance exercise. Furthermore, measures of external work may also provide athletes with instantaneous feedback regarding training intensity without the lag time associated with HR or the familiarisation required with RPE. However, if an athlete is undertaking endurance exercise where external work cannot be easily calculated (e.g. running, rowing and cross-country skiing) then HR methods provide the most valid alternative.

Study 3 examined the construct validity of methods for quantifying the accumulated effect of training in well trained runners. These findings showed that each of the training load methods investigated are appropriate for quantifying endurance training dose. However, of the methods examined, rTSS related best to performance when compared to internal (i.e. session-RPE, HR TRIMP) measures. Therefore the use of rTSS for quantifying the training dose of endurance runners is recommended. Furthermore, the foot pods used in this study to calculate pace and distance showed the smallest measurement error when compared to HR and RPE measures of exercise intensity. These results suggest that external measures (e.g. speed, power etc.) may also provide the most appropriate methods for measuring exercise intensity in endurance exercise. These findings are in accordance with Study 2 which demonstrates improvements in measurement error increase the validity of the measure for quantifying training dose. This study also examined the validity of commonly used methods for assessing fitness and fatigue. Based on the findings of this study, the use of submaximal HR tests and measures of HRV for assessing the fitness and fatigue, respectively, in athletes undertaking endurance exercise is recommended.

DIRECTIONS FOR FUTURE RESEARCH

The outcomes of the present series of studies suggest that future research should:

1. Examine the influence of substituting the CR-10 scale with the CR100 or 6-20 scale in the calculation of the session-RPE method.
2. Investigate the usefulness of the session-RPE method for monitoring the accumulated effects of training during a prolonged training period.
3. Investigate the most valid method for determining HR TRIMP methods.
4. Explore the rTSS in more detail.
5. Compare the validity of external and internal methods for quantifying training load during intermittent sports

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Chapter 8

Appendices

APPENDIX A

INFORMED CONSENT FORMS

UNIVERSITY OF
TECHNOLOGY SYDNEY

UNIVERSITY OF TECHNOLOGY, SYDNEY
INFORMED CONSENT FORM

I ______________________ *(participant's name)* agree to participate in the research project "The ecological validity and application of the session-RPE method for quantifying training loads in swimming" being conducted by Lee Wallace at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney. I am aware that my participation in this research may involve up to 18 h of my time over a 12 week period. I also understand that there are possible risks in participating in this study. These possible risks are:

1. **Fatigue from testing:** The exercise protocols in the present study may be demanding. It is anticipated that you may feel general fatigue from physical testing completed in this study. However, this fatigue will be no greater than you normally endure during competition.

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

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

I am aware that I can contact Lee Wallace (phone: 9514 5851 or [redacted]) or his supervisor Dr Aaron Coutts (ph: 9514 5188) if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish and without giving a reason. I agree that Lee Wallace has answered all my questions fully and clearly. I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

______________________________ ____/____/____
Signed by

______________________________ ____/____/____
Witnessed by

NOTE: This study has been approved by the University of Technology, Sydney Human Research Ethics Committee (HREC_2004-140P). If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer, Ms Susanna Davis (ph: 02 - 9514 1279, Susanna.Davis@uts.edu.au). Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

UNIVERSITY OF
TECHNOLOGY SYDNEY

UNIVERSITY OF TECHNOLOGY, SYDNEY

INFORMED CONSENT FORM

I ______________________________ *(participant's name)* agree to participate in the research project "Using a systems approach to validate common methods for quantifying training load in endurance athletes" being conducted by Lee Wallace at the School of Leisure, Sport and Tourism, Faculty of Business, University of Technology, Sydney. I am aware that my participation in this research may involve up to 18 h of my time over a 12 week period. I also understand that there are possible risks in participating in this study. These possible risks are:

1. **Risk of infection during blood sample collection:** There is a very small risk of infection when blood samples are withdrawn during venipuncture or pinprick. However, this risk will be minimal. All venipuncture will be performed by a trained phlebotomist in a sterile environment in accordance with the occupational health and safety guidelines. All capillarised blood sampling from pinprick will be undertaken by trained personal under sterile conditions using standard procedures.

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

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

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APPENDIX B

PSYCHOLOGICAL QUESTIONNAIRES

Name: **Date:** **Session Number:**

Wellbeing Questionnaire

Circle the most appropriate number for each category and summate the total score in the box provided

	Very, very low / good			**Normal**			**Very, very high / bad**
How was your sleep?	1	2	3	4	5	6	7
How is your fatigue level?	1	2	3	4	5	6	7
How is your stress level?	1	2	3	4	5	6	7
How is your muscle soreness?	1	2	3	4	5	6	7

Total Quality Recovery

Please circle the number which best describes your recovery in the last 24 h

6	no recovery at all
7	extremely poor recovery
8	
9	very poor recovery
10	
11	poor recovery
12	
13	reasonable recovery
14	
15	good recovery
16	
17	very good recovery
18	
19	extremely good recovery
20	maximal recovery

PROFILE OF MOOD STATES

Below is a list of words that describe feelings people have. Please read each one carefully. Then tick the answer which best describes HOW YOU FEEL RIGHT NOW. Make sure you answer every question.

	Not at all	**A little**	**Moderately**	**Quite a bit**	**Extremely**
1. Panicky	0	1	2	3	4
2. Lively	0	1	2	3	4
3. Confused	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Depressed	0	1	2	3	4
6. Downhearted	0	1	2	3	4
7. Annoyed	0	1	2	3	4
8. Exhausted	0	1	2	3	4
9. Mixed- up	0	1	2	3	4
10. Sleepy	0	1	2	3	4
11. Bitter	0	1	2	3	4
12. Unhappy	0	1	2	3	4
13. Anxious	0	1	2	3	4
14. Worried	0	1	2	3	4
15. Energetic	0	1	2	3	4
16. Miserable	0	1	2	3	4
17. Muddled	0	1	2	3	4
18. Nervous	0	1	2	3	4
19. Angry	0	1	2	3	4
20. Active	0	1	2	3	4
21. Tired	0	1	2	3	4
22. Bad tempered	0	1	2	3	4
23. Alert	0	1	2	3	4
24. Uncertain	0	1	2	3	4

RECOVERY-STRESS QUESTIONAIRE

NAME: ____________________________

Please take 10 minutes to carefully read and answer the following questions.

IN THE PAST (3) DAYS / NIGHTS

1. … I watched TV

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

2. … I did not get enough sleep

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

3. … I finished important tasks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

4. … I was unable to concentrate well

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

5. … everything bothered me

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

6. … I laughed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

7. … I felt physically bad

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

8. … I was in a bad mood

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

9. … I felt physically relaxed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

10. … I was in good spirits

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

11. … I has difficulties concentrating

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

12. … I was worried about unresolved problems

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

13. … I felt at ease

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

14. … I had a good time with friends

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

15. … I had a headache

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

16. … I was tired from work

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

17. … I was successful in what I did

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

18. … I couldn’t switch my mind off

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

19. … I fell asleep satisfied and relaxed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

20. … I felt uncomfortable

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

21. … I was annoyed by others

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

22. … I felt down

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

23. … I visited some close friends

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

24. … I felt depressed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

25. … I was dead tired after work

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

26. … Other people got on my nerves

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

27. … I had a satisfying sleep

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

28. … I felt anxious or inhibited

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

29. … I felt physically fit

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

30. … I was fed up with everything

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

31. … I was lethargic

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

32. … I felt I had to perform well in front of others

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

33. … I had fun

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

34. … I was in a good mood

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

35. … I was overtired

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

36. … I slept restlessly

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

37. … I was annoyed

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

38. … I felt as if I could get everything done

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

39. … I was upset

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

40. … I put off making decisions

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

41. … I made important decisions

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

42. … I felt physically exhausted

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

43. … I felt happy

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

44. … I felt under pressure

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

45. … Everything was too much for me

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

46. … My sleep was easily interrupted

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

47. … I felt content

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

48. … I was angry with someone

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

49. … I had some good ideas

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

50. … Parts of my body were aching

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

51. … I could not get rest during the breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

52. … I was convinced I could achieve my set goals during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

53. … I recovered well physically

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

54. … I felt burned out by my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

55. … I accomplished many worthwhile things in my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

56. … I prepared myself mentally for performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

57. … My muscles felt stiff or tense during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

58. … I had the impression there were too few breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

59. … I was convinced that I could achieve my performance at any time

0	1	2	3	4	5	6
never	Seldom	sometimes	often	more often	very often	always

60. … I dealt effectively with my team mates’ problems

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

61. … I was in good condition physically

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

62. … I pushed myself during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

63. … I felt emotionally drained from performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

64. … I had muscle pain after performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

65. … I was convinced that I performed well

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

66. … Too much was demanded of me during breaks

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

67. … I psyched myself up before performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

68. … I felt that I wanted to quit my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

69. … I felt very energetic

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

70. … I easily understood how my team mates felt about things

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

71. ... I was convinced that I trained well

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

72. ... The breaks were not at the right times

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

73. ... I felt vulnerable to injuries

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

74. ... I set definite goals for myself during performance

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

75. ... My body felt strong

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

76. ... I felt frustrated by my sport

0	1	2	3	4	5	6
never	seldom	sometimes	often	more often	very often	always

77. ... I dealt with emotional problems in my sport very calmly

0	1	2	3	4	5	6
never	seldom	sometimes	often	More often	very often	always

THANK YOU!

Appendix C

Rating of Perceived Exertion Scales

BORG's 0-10 RATING OF PERCIEVED EXERTION SCALE

0	Nothing at all
1	Very Easy
2	Easy
2.5	
3	Moderate
4	
5	Hard
6	
7	Very hard
8	
9	
10	**Maximum**
11	
↯	
•	Absolute maximum

BORG's 6-20 RATING OF PERCIEVED EXERTION SCALE

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion