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The utility of the self-pace submaximal run test for monitoring responses to training in endurance runners

This thesis is presented for the Degree of Doctor of Philosophy at the University of Kent.

by

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Declaration and statements

No part of this thesis has been submitted in support of an application for any degree or other qualification of the University of Kent, or any other university or institute of learning.

All research within this thesis was conducted according to the guidelines laid down by the Declaration of Helsinki (2008, including 2013 amendments), and all procedures were approved, in advance, by the University of Kent's ethics committee.

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General Abstract

The aim of this thesis was to explore the utility of the novel Self-Paced Submaximal Run Test (SRT_{RPE}); which monitors running velocity (v) and HR_{ex}, during 3, 3-min stages prescribed by Rating of Perceived Exertion (RPE) 10, 13 and 17 (Borg, 1985).

Study one (Chapter 3) assessed the construct validity and reliability of the SRT_{RPE}. Results showed large associations between v at each stage of the SRT_{RPE} and parameters of the graded exercise test including: maximal oxygen consumption (*r* range = 0.57 – 0.63) and v at 4 $mmol \cdot L^{-1}$ blood lactate (0.51 – 0.62), inferring the construct validity of the SRT_{RPE}. The v measured at each stage of the SRT_{RPE} showed low coefficients of variation (range = 2.5 – 5.6%) evidencing acceptable reliability. Study two (Chapter 4) examined longitudinal associations between repeated SRT_{RPE} trials and 12-min time trials (12minTT) conducted at 4-week intervals over a 16-week training period. Results showed vRPE 13 to be the most useful indicator of within-participant variance in v12minTT (*r* = 0.57). A meaningful change in v12minTT (0.6%) was associated with a 0.26, 0.14 and 0.18 $km \cdot h^{-1}$ change in vRPE 10, 13 and 17 respectively. Study three (Chapter 5) explored the sensitivity of the SRT_{RPE} to monitor over-reaching following an ultra-marathon race. Results demonstrated that performance at intensity RPE 17 was the most sensitive to prior competition load, with a meaningful decreased in vRPE 17 from 7-days pre-race to 48-hours post-race (-0.78 $km \cdot h^{-1}$), and meaningful increase between 48-hours post-race and 7-days post-race (+0.83 $km \cdot h^{-1}$). Study four (Chapter 6) utilised the SRT_{RPE} to monitor within-participant responses to a period of intensified training (+ 30% increase in duration each week for 3-weeks). vRPE 13 was most sensitive to increased training load, showing a meaningful decrease (5.37%) following 3-weeks over-load training. Within-individuals weekly training duration was moderately correlated with vRPE 13 and 17 (*r* range = -0.30 – -0.46).

In conclusion, this thesis provides evidence that the SRT_{RPE} is a reliable and valid tool for monitoring within-individual responses to training and competition in endurance runners. In particular, v monitored at RPE 13 and 17 is most sensitive to within-individual responses to acute and longitudinal training stress and can provide inference about endurance performance ability.

Covid-19 Mitigation Statement

Following UK Government guidance on 23rd March 2020 the University of Kent laboratory facilities were closed and face-to-face contact with individuals outside of your household was not permitted. As such, from the 23rd of March 2020 any further recruitment and data collection for this PhD was ceased.

The closure of facilities prevented further recruitment for the studies outlined in Chapter 5 and 6, resulting in smaller that required sample size. In addition, these circumstances prevented the recruitment of participants for the proposed 5th study of this thesis, which received ethical approval on 12th March 2020. Please refer to Appendix I to review the study proposal and Appendix V for the ethical approval letter.

Scientific Output

Publications

Sangan, H., Hopker, J., Davison, G., McLauren, S. (2021). The Self-Paced Submaximal Run Test: Associations with The Graded Exercise Test and Reliability. *International Journal of Sport Physiology and Performance.* In print

Conference Communications

Sangan, H. The utility of a self-paced submaximal running test to monitor fatigue in ultra-marathon runners. 24th Annual Congress of the European College of Sport Science, Prague. July 2019. Poster Presentation.

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Chapter 7: General Discussion

Abbreviations

ANOVA	Analysis of variance
ANS	Autonomic nervous system
ASRM	Athlete self-report measures
ATP	Adenosine triphosphate
B[La]	Blood lactate concentration
°C	Degrees centigrade
CI	Confidence interval
CL	Confidence limits
CO_2	Carbon dioxide
CV	Coefficient of variation
DALDA	Daily Analyses of Life Demands for Athletes
GPS	Global positioning system
GXT	Graded exercise test
HR_{ex}	Exercising heart Rate
HR_{max}	Maximal heart rate
HRR_{60}	Heart rate recovery over 60 seconds
HR-RS index	Heart Rate Running Speed index
ICC	Intraclass correlation coefficient
iTRIMP	Individualised Training Impulses
kg	Kilograms
km	Kilometres
$km \cdot h^{-1}$	Kilometres per hour
$L \cdot min^{-1}$	Litres per minute
LSCT	Lamberts Submaximal Cycle Test

LSRT	Lamberts Submaximal Run Test
LT1	First lactate threshold
LT2	Second lactate threshold
m	Meters
MET	Minimal effects test
min	Minutes
$mL\cdot kg^{-1}\cdot min^{-1}$	Millilitres of oxygen per kilogram of body weight per minute
$mmol\cdot L^{-1}$	Millimolar
mmHg	Millimetres per litre
O_2	Oxygen
OL	Overload
PO	Power output
PPO	Peak power output
r	Correlation coefficient
RE	Running economy
RHR	Resting heart rate
RPE	Rating of perceived exertion
rTSS	Training Stress Score
R^2	Coefficient of determination
s	Seconds
SD	Standard deviation
SEE	Standard error of the estimate
sRPE	Session rating of perceived exertion
SRT_{RPE}	Self-paced submaximal run test
SPXT	Self-paced exercise test
TT	Time trial

TTE	Time to exhaustion
v	Velocity
$\dot{V}$	Volume
$\dot{V}CO_2$	Volume of carbon dioxide
$\dot{V}O_2$	Volume of oxygen
$\dot{V}O_{2max}$	Maximal oxygen uptake
$v\dot{V}O_{2max}$	Velocity at maximal oxygen uptake
vpeak	Peak velocity
%	Percentage
>	Greater than
<	Less than

Chapter 1: Literature review

1.1 Overview

The aim of purposeful athletic training is to provide a stimulus that is effective in improving sport specific performance (Viru and Viru 2000). Through the considerate manipulation of the training variables; intensity, duration and frequency, adaptation to a plethora of structural and metabolic functions determining performance success may occur (Impellizzeri, Marcora and Coutts 2019). However, adaptation requires alternating periods of both training stress and recovery, with responses to each being highly individualised due to the influence of a variety of variables outside of training (Coutts, Kempton and Crowcroft 2018). Therefore, the frequent and reliable monitoring of an individual's dose-response relationship to training is important in providing an evidence-based approach to the individualisation of training stress and recovery (Kellmann 2010; Halson 2014; Sands et al. 2017).

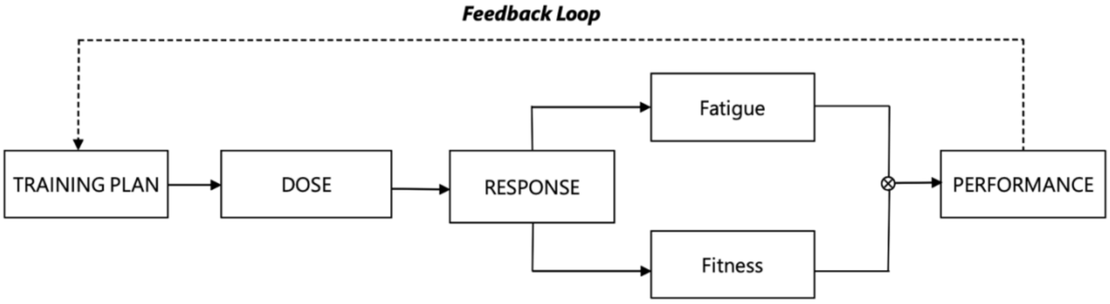


Figure 1. 1 Conceptual model for developing athlete monitoring systems. Taken from Coutts, Kempton and Crowcroft (2018)

A survey conducted with high performance staff, working within a range of sports including athletics, found the most important reasons for adopting athlete monitoring practices were; injury prevention (29%), monitoring the effectiveness of a training program (27%), maintaining performance (22%) and preventing overtraining (22%) (Taylor et al. 2012). Athlete monitoring systems involve the quantification of training load (dose) and an individual's ability to cope (response) to that training (figure 1.1) (Coutts, Kempton and Crowcroft 2018; Impellizzeri, Marcora and Coutts 2019). However, the selection of appropriate measures to assess this does-response relationship is inherently difficult due to the range of psychological, physiological and biochemical variables that are affected by training and recovery (Halson 2014). These measured variables can be categorised as internal or external (Impellizzeri et al., 2019) and subjective or objective (Borresen, 2008), and can be used in isolation, or together as part of a multifaceted approach to athlete monitoring (Le Meur, Hausswirth, et al. 2013; Heidari et al. 2019).

The selection of an appropriate protocol for monitoring within-individual responses to training can be guided by its validity, reliability and sensitivity (Currell and Jeukendrup 2008). Validity can be referred to as the degree in which the protocol resembles the performance that is being simulated (Hopkins 2000). Currell and Jeukendrup (2008) highlight three main approaches to validation of performance-based protocols: logical validity, criterion validity and construct validity. Logical validity merits the use of protocols which best simulate the sport specific competition demands, however this is difficult to truly quantify. Criterion validity uses correlation analysis between the new measure and a criterion measure to established either concurrent (correlated to) or predictive (able to replace) validity. As performance can be considered a construct as appose to a variable (Atkinson 2002), construct validity refers to the degree in which a protocol measures a hypothetical construct (i.e. aerobic fitness). This can be measured by comparing results between a cohort heterogenous in the given construct, or directly correlating athletes results in the test with other known determinants of the given fitness or performance construct (Currell and Jeukendrup 2008). Importantly, the validity is dependent upon the measure's reliability (Hopkins 2000). Reliability refers to the day-to-day variation in measured variables when no intervention is used (Hopkins 2002). Methods of measuring reliability include relative: intraclass correlation coefficients (ICC), and absolute: coefficient of variance (CV), standard error of measurement (SEM) and limits of agreement (LOA) (Atkinson and Nevill 1998; Hopkins 2000). Measures of absolute reliability allow for the sensitivity of the test to true changes in parameters to be estimated.

However, monitoring protocols shown to be valid and reliable within standardised research conditions can be unrealistic in an applied setting (Carling et al., 2018). Therefore, applied research should also focus on effective, feasible and sustainable monitoring protocols (Halson 2014; Saw and Kellmann 2016; Gabbett 2016). Practitioners/coaches and or athletes also need to consider how to make meaningful interpretations from results of large volumes of repeated measurements, and how to translate findings into actional recommendations on a day-to-day basis (Gabbett 2016). The following literature review aims to explore the determinants of endurance performance, to better understand the requirements of valid monitoring tools. In addition, it seeks to evaluate the current research to compare the parameters and protocols being used for within athlete monitoring in endurance runners and to review the benefits and limitations of each, with reference to their validity reliability, feasibility and sustainability.

1.2 Determinates of Endurance Performance.

The study of the physiological determinants of endurance performance (athletic events lasting more than approximately 5-min and requiring a substantial and sustained energy transfer from oxidative pathways) (Burnley and Jones 2007) has been a longstanding exploration spanning decades (Hill and Lupton 1923), from which our understanding has continuously improved as a result of technological, methodological and statistical advances. This knowledge is useful in guiding the selection and interpretation of valid methodologies to evaluate the effect of endurance training (Currell and Jeukendrup 2008)

The most common approach to determining endurance potential is through four physiological parameters, determined within a laboratory setting, which are proximal measures of the oxidative adaptations to endurance-exercise: Maximal oxygen uptake ($\dot{V}O_{2max}$), fractional utilization of $\dot{V}O_{2max}$, running economy (RE), and metabolic thresholds. These four variables form what is recognised as the 'classical-model' which centralises on oxidative metabolism as the limiting factor to performance velocity (figure 1.2).

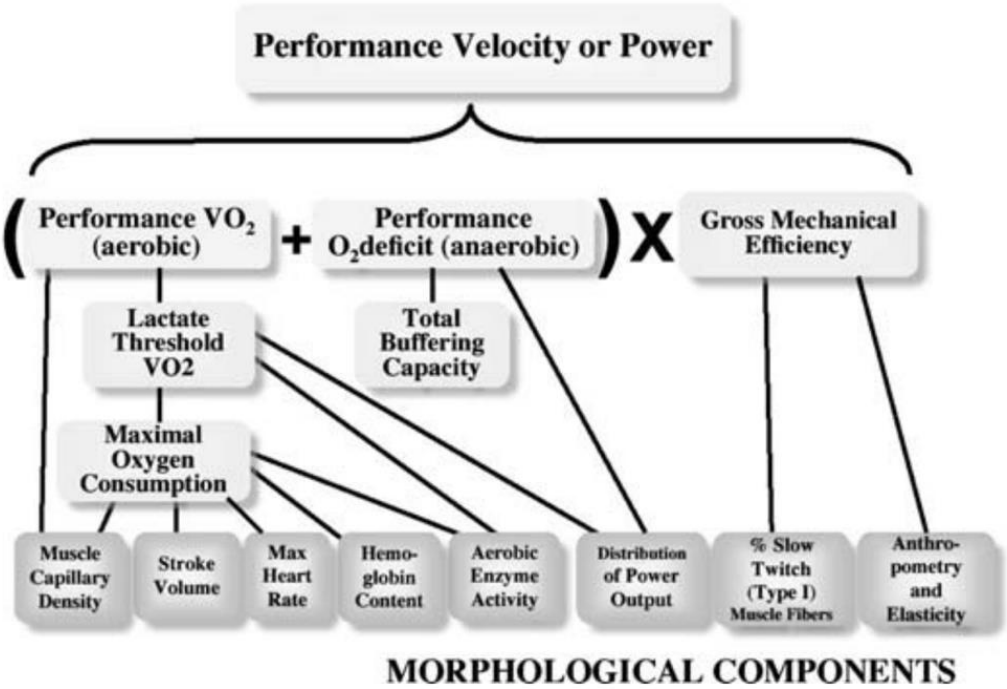


Figure 1. 2 Overall schematic of multiple physiological factors that interact as determinant of performance velocity. This figure serves as the conceptual framework for the idea discussed in Joyner and Coyle (2008)

1.2.1 Maximal Oxygen Uptake $\dot{V}O_{2max}$

$\dot{V}O_{2max}$ sets the upper limit of adenosine triphosphate (ATP) production from oxidative phosphorylation (Bassett and Howley 2000). Although debate exists, it is largely accepted that for running modalities, it is the ability of the cardiorespiratory system (i.e., heart, lungs, and blood) to transport oxygen (O_2) to the muscles and not the ability of muscle mitochondria to consume O_2, that limits $\dot{V}O_{2max}$ (Hill and Lupton 1923; Holloszy et al. 1977; Bassett and Howley 2000). In a cross-sectional investigation of 16 male distance runners ($\dot{V}O_{2max}$ range = 54.8 – 81.6 $mL \cdot kg^{-1} \cdot min^{-1}$), Costill et al (1973) showed an inverse relationship (r = -0.91) between $\dot{V}O_{2max}$ and time to complete a 10-mile run. Subsequent research has similarly shown that in male runners of varying marathon ability (time range = 2-hours 19-min – 4-hours 53-min) $\dot{V}O_{2max}$ was a strong determinant (r = 0.88) of marathon time (Maughan and Leiper 1983). Following 8-weeks endurance training (weekly distance range 180 – 155km) both male and female marathon runners have shown significant improvements in $\dot{V}O_{2max}$ (66.3 ± 9.2 to 69.9 ± 9.4 $mL \cdot kg^{-1} \cdot min^{-1}$), which was concurrent with increased time to exhaustion at velocities (v) equivalent to marathon and 10km personal best (Billat et al. 2002). In support of the use of $\dot{V}O_{2max}$ to monitor chronic adaptations to endurance-type training, through a 6-year longitudinal study, $\dot{V}O_{2max}$ was shown to be the best predictor of age-related changes in endurance exercise performance in 51 male and 23 female master's runners (Marcell et al. 2003), while RE and v at lactate threshold have shown to be weaker predictors of the age-related decline in endurance performance (Tanaka and Seals 2008).

However, studies analysing trained endurance athletes, homogenous in performance ability, have shown low associations between $\dot{V}O_{2max}$ and competitive endurance performance (Conley and Douglas, 1980). In a group of six males and six females aged 20 – 30 years with equivalent marathon performance times (~2-hours 40-mins) females were shown to have on average 10% lower $\dot{V}O_{2max}$. Where females have a lower $\dot{V}O_{2max}$, linked to lower cardiac output compared to males, achievement of equivalent running performance to their male counterparts is substituted by superior RE and fractional utilisation of $\dot{V}O_{2max}$ (Helgerud 1994). Furthermore, in contrast to the findings of Billat et al (2002), $\dot{V}O_{2max}$ has shown a low sensitivity to within-individual variance in endurance running performance with training (Arrese et al. 2005; Stratton et al. 2009). Therefore, although strong evidence of its importance in determining endurance performance ability, $\dot{V}O_{2max}$ is certainly not the only factor to consider monitoring within endurance athletes.

1.2.2 Fractional utilization of $\dot{V}O_{2max}$

Even though $\dot{V}O_{2max}$ sets the upper limit for ATP generation, it is evident that the intensities sustained during endurance-type exercise (greater than 5-min) are below 100% $\dot{V}O_{2max}$ (Costill, Thomason and Roberts 1973). Therefore, the fractional utilization of $\dot{V}O_{2max}$ (the percentage of $\dot{V}O_{2max}$ that can be maintained) has been shown to be an important determinant of endurance performance. A cross sectional analysis, showed that trained individuals could sustain exercise at 87% and 83% $\dot{V}O_{2max}$ for 1 and 2-hours respectively, compared with only 50% and 35% $\dot{V}O_{2max}$ for untrained participants (Åstrand and Rodahl 1970). In elite Kenyan runners, the fraction of the $\dot{V}O_{2max}$ sustained at the v corresponding to 10km race-pace can be as high as 93 – 98% $\dot{V}O_{2max}$ (Billat et al. 2003). Although the metabolic demands of the successful sub 2-hour marathon race are unknown, it was predicted from the marathon runners recruited by the 'Nike project' that running at the required 21.1 $km \cdot h^{-1}$ demanded a sustained intensity representing 94 ± 3% $\dot{V}O_{2peak}$ (Jones et al. 2021). This highlights the desirability and necessity to improve the fractional utilization of $\dot{V}O_{2max}$ to achieve endurance running success. With 8-weeks endurance training, the %$\dot{V}O_{2max}$ required to sustain marathon v for 10km has been shown to be significantly reduced (94.6 ± 6.2 to 90.6 ± 9.5% $\dot{V}O_{2peak}$) (Billat et al. 2002). The rightward shift in %$\dot{V}O_{2max}$ maintained was closely linked to a rightward shift in blood lactate accumulation, which support previous suggestions that %$\dot{V}O_{2max}$ is largely governed by the location of an individuals' lactate threshold (Helgerud 1994).

1.2.3 Metabolic Thresholds

Early studies recognised a critical work rate (a metabolic threshold) above which lactate accumulation occurs (Hill, Long and Lupton 1924; Owles 1930). Due to the difficulty in obtaining blood samples and analysis of bicarbonate within the blood, Wasserman and McIlroy (1964) identified this critical work rate through analysis of the rise in the respiratory exchange ratio (RER), during exercise in cardiac patients, terming this the 'anaerobic threshold'. However, the term anaerobic threshold is now largely condemned as this metabolic threshold point is now recognised as non-reliant on muscle anoxia as the term 'anaerobic' would suggest (Poole et al. 2021).

In the 1970's, research took advantage of the improvements in rapid responding gas analysers and computer processing to confirm the presence of the metabolic threshold previously termed the 'anaerobic threshold', through analysis of expired gasses during incremental exercise; determining this key threshold as the first increase in the ratio of expired ventilation to carbon dioxide (CO_2) output (VE/CO_2) (Wasserman et al. 1973). In their study, Wasserman et al (1973) also demonstrated that this ventilatory threshold occurred at the highest intensities in participants between the ages of 20 – 30 years (with their participant's ages ranging from 17 – 91 years) and that patients with cardiac disease had lower ventilatory thresholds than the least fit normal individuals; suggesting this metabolic threshold as an important determinant of physical health and fitness.

Following technological advances in the ability to sample and analyse capillary blood, research groups measured capillary blood lactate concentration (B[La]) to delineate two metabolic thresholds. The first lactate threshold (LT1) can be identified by a fixed criteria of 2 $mmol \cdot L^{-1}$ B[La] marking the 'aerobic threshold' while 4 $mmol \cdot L^{-1}$ marks the second lactate threshold (LT2) determining the 'anaerobic threshold' (Kindermann, Simon and Keul 1979; Heck et al. 1985). However, these fixed criteria were shown to be invalid representations, as they did not take into account the large individual variability in the trajectory of a person's lactate accumulation curve. As a result, individual lactate thresholds have been validly determined through the modelling of the inclination of the lactate curve (Keul et al. 1979) or inflection point (Machado et al. 2006) (see also section 1.6.1).

Previous research has shown the utility of monitoring these metabolic thresholds in determining endurance performance ability. In a group of eighteen, well trained endurance runners (mean = 70.4 ± 9.0 $mL \cdot kg^{-1} \cdot min^{-1}$), whom were assessed over a 2-year period, variance in endurance performance (average v during a 3km time trial) was most strongly related to variance in v at 4 $mmol \cdot L^{-1}$ B[La] (vLT2), when compared with the other parameters of the 'classical' model previously outlined (Bragada et al. 2010). These results are in agreement with those of earlier studies, which found a strong relationship (r range = 0.78 – 0.92) between endurance running performance (3km – marathon) and vLT2 (Farrell et al. 1993; Noakes, Myburgh and Schall 1990; Yoshida et al. 1993).

The physiological rationale for the rightwards shift in the metabolic thresholds with endurance training has been debated. The historic perspective is that lactate accumulation during exercise resulted from tissue hypoxia (Hill, Long and Lupton 1924; Wasserman et al. 1973). However, this has subsequently been disproved and it is now suggested that the lactate threshold reflects an imbalance between lactate appearance and removal (Brooks 2021). A study by Messonnier et al (2013) results showed that trained individuals had a significantly higher metabolic clearance rate (as tested through isotope tracers) than untrained individuals when participating in exercise at the same relative workload (67% $\dot{V}O_{2max}$) (Messonnier et al. 2013). A number of physiological adaptations could lead to improved lactate kinetics with evidence that endurance type training increases mitochondrial density and enzyme content, which would reduce lactate accumulation (Wagenmakers et al. 2006; Vollaard et al. 2009), as well as causing an increase in lactate transport proteins (MCT1), which would enhance lactate clearance (Bonen 1998).

1.2.4 Running Economy (RE)

RE can be defined as the oxygen cost (in $mL \cdot kg^{-1} \cdot min^{-1}$) of running at a given v, or the oxygen cost of running a certain distance (i.e., $mL \cdot kg^{-1} \cdot km^{-1}$). Studies as early as the 1930's identified disparity in the oxygen cost of running at the same submaximal v, commenting 'the least skilful participant using one-half more fuel than the most skilful' for the same work (20-min at 9.3 $km \cdot h^{-1}$) (Dill, Talbott and Edwards 1930). Later, Conley and Krahenbuhl (1980) showed that in a group of 10 elite distance runners (mean $\dot{V}O_{2max}$ = 71.7 $mL \cdot kg^{-1} \cdot min^{-1}$) RE accounted for 65.4% of the variance in 10km race performance. The influence of endurance-type training on adaptations in RE remain unclear. In a study by Scrimgeour et al (1986) participants who trained for greater than 100km distance per week, displayed superior (19.9%) RE than those who completed less than 100km per week, suggesting the importance of endurance-type training in stimulating adaptation to RE. However, due to the cross-sectional design of this study it cannot prove causality between RE and weekly training distance. In a longitudinal case study of a female marathon world record holder, it was shown that RE at 16 $km.h^{-1}$ decreased from 205 $mL \cdot kg^{-1} \cdot km^{-1}$, to 175 $mL \cdot kg^{-1} \cdot km^{-1}$ over 11 years of training (alongside performance improvements), suggesting RE is a factor influenced by endurance-type training. However, a range of mechanisms may be responsible for superior running economy; ranging from biomechanical parameters, cardiopulmonary function, and muscle fibre distribution (Saunders et al. 2004) making it difficult to determine how much of the improvement in RE can be influenced by endurance-type training, other training (strength and flexibility) or genetics (Balsalobre-Fernández, Santos-Concejero and Grivas 2016).

1.2.5 Peak Treadmill Velocity (vpeak)

The aforementioned, laboratory derived parameters encompass the classical model of determining endurance performance ability (Joyner and Coyle 2008). However, this model which focuses on oxidative metabolism as the central limiting factor to endurance-type exercise has been questioned.

Noakes and colleges (1990), have presented an alternative approach to the prediction of endurance performance, based around peak treadmill velocity (v_{peak}) as the main determining factor. They recruited 43 experienced male runners specialised in either marathon (68.1 ± 7.7 $mL·kg^{-1}·min^{-1}$) or ultra-marathon distance (64.5 ± 8.0 $mL·kg^{-1}·min^{-1}$). Participants completed an incremental exercise test to assess $\dot{V}O_{2max}$, lactate thresholds (vLT2), RE and v_{peak}; which was defined as the highest v ($km·h^{-1}$) maintained for a complete minute during the maximal test. Using participants recorded best times from each race distance (recorded within a 3-month period), Noakes et al (1990) reported v_{peak} to be the strongest predictor of performance at 10km, half marathon and marathon distance (*r* range = -0.91– 0.94), superior to the other parameters of the graded exercise test (GXT), except for vLT2 (lactate turnpoint, determined by visual inspection as the last B[La] concentration that immediately preceded the rapid and progressive increase in B[La] levels) which was a greater predictor of marathon performance in those marathon specialists. However, these results should be interpreted with caution as the use of participants personal best times within this analysis would not have been a valid interpretation of their current performance capacity.

The physiological determinants of a v_{peak} are not known, however, Noakes et al (1990) argue that if the absolute rate of oxygen consumption was the most important determinant of v_{peak} then $\dot{V}O_{2max}$ would have been a stronger predictor of running performance in their 1990 study. In the similar manner that Jones and Coyle (2008) explained the influence of each of the components of the classical model on performance VO_2, it is likely that v_{peak} acts as a single variable which encompasses each of the variables of the classical model.

1.2.6 Oxygen Uptake Kinetics ($\dot{V}O_2$ kinetics)

Burnley and Jones (2007) put forth a case in favour of the use of $\dot{V}O_2$ kinetics as a determinant of endurance ability. Their 2007 review explains that the classical laboratory-derived parameters, are limited in that each do not present an evidentially based ‘why’ for their association with endurance performance. Alternatively, it is their view that each of these parameters works to determine the character of the $\dot{V}O_2$ kinetics, as such ‘only by appreciating how the classical parameters of physiological function interact with the kinetics of $\dot{V}O_2$, can the physiological determinants of athletic performance be truly understood’.

At the onset of exercise (regardless of exercise domain) there is an abrupt increase in pulmonary $\dot{V}O_2$ (Phase I) which results from increased venous return and elevated pulmonary blood flow (not muscular extraction of O_2). This is then followed by Phase II, the primary phase in which pulmonary $\dot{V}O_2$ reflects the muscle $\dot{V}O_2$ with estimated 10% error (Barstow, Lamarra and Whipp 1990). The behaviour of the $\dot{V}O_2$ kinetics proceeding Phase II can be used to determine if exercise is within the heavy domain (below anaerobic threshold) or severe domain (above anaerobic threshold) (Whipp and Wasserman 1972). If exercise is in the heavy domain, pulmonary $\dot{V}O_2$ progressively rises (named the slow component of $\dot{V}O_2$) before reaching a steady state between 10 – 20-mins; if in the severe intensity domain, the slow component of $\dot{V}O_2$ will not stabilise and will continue to rise until reaching a maximum (fatigue) (Whipp and Wasserman 1972; Wasserman et al. 1973). As detailed in section 1.2.3 endurance training can stimulate a rightward shift in the placement of the metabolic thresholds. This shift in the workload which determines the heavy domain, extends the range of workloads that can be sustained without the presence of the $\dot{V}O_2$ slow component. Cross sectionally, studies have shown that patients with pulmonary cardiovascular diseases have slower $\dot{V}O_2$ kinetics than elite endurance athletes. In addition, the time taken to reach steady state ($\dot{V}O_2$ time constant) has shown to be decreased in recreationally trained athletes following 6-weeks of endurance training (Berger et al. 2006; Carter et al. 2000). There is therefore a case to consider $\dot{V}O_2$ kinetics as a useful determinant of endurance performance, hypothesised to be an informative outcome measure for the myriad of physiological adaptations that occur with endurance training.

1.2.7 The Role of Rating of Perceived Exertion (RPE)

RPE is used to subjectively quantity an individual’s perception of the physical demands of the task, more precisely ‘the feeling of how heavy and strenuous a physical task is’ (Borg 1982) . An individual’s RPE reflects the integration of various information inputs, including a variety of signals sent from peripheral working muscles and joints, the central cardiovascular and respiratory functions, and from the central nervous system (Borg 1982; Hardy and Rejeski 1989; Rejeski and Ribisl 1980). The most widely used measurement scale used to quantify RPE is the 15 point Borg scale, described as a psychological category scale in which participants rate their RPE between 6 (no exertion at all) to 20 (maximal exertion) (Borg 1982). Subsequent scales used for measuring RPE have been shown to be reliable including category ration scale (CR-10) (Chen, Fan and Moe 2002)(Chen, Fan and Moe 2002)and the OMNI-RPE (Robertson et al 2004)

The RPE scale can be used in two methods. Firstly, RPE is most widely used throughout literature as a response measure (passive estimation) in which participants accredit a given exercise intensity with a RPE rating. The passive estimation of RPE was originally described as having a linear relationship with heart rate and work-load (Borg 1970) and has since shown to share a close relationship with other physiological markers of exercise intensity including blood lactate (Pandolf et al. 1972; Borg et al. 1987) and oxygen uptake (Chen et al. 2002).

Secondly, and to a lesser extent throughout literature, the RPE scale can be used in production trials (active production), in which intensity is anchored by a given RPE value. The active production of intensity through use of the RPE scale has shown to be reliable and valid for treadmill running (Dunbar et al. 1992; Eston et al. 1988; Glass et al. 1992; Smutok et al. 1980) and cycling ergometry (Buckley et al. 2000; Dunbar et al. 1992; Eston and Williams 1988) (see section 1.6.4).

1.2.7.1 The Role of RPE in the Regulation of Pace

The sport of endurance running follows a ‘closed-loop’ design, in which athletes are required to cover a pre-specified distance in the shortest amount of time. In order to out-compete other athletes, competitors must regulate their work rate to ensure an optimal expenditure of energy throughout the race without premature exhaustion. The chosen distribution of work rate during an endurance performance is termed ‘pacing’ (Foster et al. 2005; Abbiss and Laursen 2008). It is proposed that the regulation of work-rate during self-paced exercise occurs as a consequence of anticipatory forecasting and afferent feedback to the brain.

The anticipatory model suggests that feedforward control of pace is regulated by ‘teloanticipatory’ mechanisms (Ulmer 1996), whereby the knowledge of the end-point of the task, integrated with prior experience, is used to anticipate the work rate required to complete the task without catastrophe of physical systems (Tucker 2009). In addition, the model states that motivation and physiological inputs before exercise are taken into account during the composition of an RPE template for the given race distance/duration. However, if this feedforward mechanism was the sole regulator of pace, it would be expected that pace remain unchanged throughout a given distance. However, it is evident from race data that variable pacing strategies are employed (Díaz, Fernández-Ozcorta and Santos-Concejero 2018). This evidences the additional role of a feedback mechanism.

The alterations of power/velocity during an endurance task, likely influenced by feedback mechanisms informed by metaboreceptors, thermoreceptors, cardiovascular pressure and mechanoreceptors, are thought to offer a protection against catastrophic failure before the known endpoint. In the anticipatory model, it is proposed that pace is continuously manipulated during exercise, by an unconscious comparison of the actual perceived exertion compared with the RPE template (Tucker 2009). In contrast, the psychobiological model theorises that pace is regulated based on a conscious RPE, which is compare, in a conscious manner within the brain (central governor), with an anticipated RPE template (Pageaux 2014; Marcora 2010).

Whether consciously or unconsciously referenced, there is strong evidence for the use of an RPE template to terminate exercise during fixed intensity trials. In their evaluation (Noakes 2004) of Baldwin et al (2003) study, Noakes highlights the use of an RPE template to regulate exercise intensity toward volatile exhaustion. Baldwin and colleagues (2003) required participants to cycle at 70 % of $\dot{V}O_{2max}$, until volatile exhaustion, either in the presence of low or high intramuscular glycogen. The authors reported that the starting and final RPE values were similar between conditions, however the rate of increase in RPE in the low glycogen state was faster than in the high. Noakes (2004) evaluation of this study highlights that when expressed at relative time-points (% of total time), RPE values are the same for both conditions, and follow the same linear upward trajectory. Firstly, this provides evidence that RPE increases as a linear function of the percentage of race completed or distance remaining, in a recognisable template during fixed intensity exercise trials. Secondly, that feedback from metaboreceptors has an important contribution to athletes' RPE.

During self-paced trials, the RPE template has shown to be robust in its response to varying environmental conditions. Tucker et al (2007) showed that in the presence of hyperoxia (Fraction of inspired oxygen 40%), cyclists completing a 20km TT recorded significantly higher (+ 5%) power output, when compared with normoxic conditions. However, exercising heart rate, B[La] concentration and RPE values obtained every 2km were not significantly different between trials. This shows that the RPE template was used to regulate pace and control the 'limiting' factors such as B[La] accumulation as a direct consequence.

In a study by Schallig et al (2016) researchers attempted to manipulate the RPE template by providing incorrect information of the total distance of time trial efforts. 10 trained male cyclists performed 3 separate cycling TT’s: 10km, 15km, and a manipulated 15km during which participants started the TT believing that they were performing a 10km TT, however, at 7.5km they were told the actual distance was 15km. Results showed that at the same absolute time points, RPE values in the 15km TT were significantly lower than that during the 10km TT and the manipulated TT. In the manipulated TT, after 7.5km, participants corrected pace and their RPE values shift down to meet the same linear RPE trajectory of the 15km TT. This shows the importance of knowledge of the distance and thus endpoint of race in setting the RPE template. It also shows the robustness of this template and the ability to re-adjust pace to suit a new template when misinformation of distance is provided. Interestingly, participants performed better in the 15km TT that was manipulated when compared with the straight 15km TT, suggesting a conservative pacing strategy in the known 15km TT. The authors accredited this to the inexperience of the participants, but this also provides some evidence (in novice athletes) of the role of the brain in conserving energy expenditure to avoided catastrophe before the end point of the race.

This supporting literature provides evidence of the important role that an athlete’s perception of effort plays in the selection of pace during a race and determination of performance. Section 1.6.4 explains how measures of perception of effort can be used to assess training responses and readiness to compete.

1.3 Principles of the Training Process

Exercise stress is considered the most potent, controllable factor leading to improvement in the determinants of endurance performance outlined in section 1.2 (Banister et al. 1975; Impellizzeri et al. 2005). Manipulation of the mode, duration and intensity of exercise results in a highly specific and individualised acute response (Hildebrandt et al. 2003; Coffey et al. 2006; Egan and Zierath 2013). It is the repeated activation of these responses through structured and purposeful training that leads to chronic adaptation (Egan and Zierath 2013; Cunanan et al. 2018). An optimal training process requires the navigation of the delicate balance between training stress and recovery to ensure that after the dissipation of fatigue, a supercompensation in performance remains at the time of competition (Bompa and Haff 2009; Bellinger 2020). In addition, the longevity of chronic adaptations requires careful consideration of the concepts of progression, overload and reversibility (Mujika and Padilla 2000).

A number of models have been proposed to conceptualise the training process, and act as frameworks for monitoring athletes’ responses. The original work of Bansiter (1975) uses mathematical modelling which considers the internal training load as the input and the effect of training is described by two antagonistic functions: A positive response leading to ‘fitness’ and a negative response presenting as ‘fatigue’. In its simplest form, Banister’s model has been reduced to the following equation:

$$Performance = fitness- fatigue$$

Banister’s (1975) model accounts for the delay in the appearance of positive adaptations following training, which was longer in duration than the time required for the dissipation of training induced fatigue (Banister et al. 1975). This relationship between fitness and fatigue has been used to model and explain the consequences of training interventions such as taper periods and over-training (Mujika et al. 1996). Extensions of the original model demonstrated the reduction in the negative influence of training (fatigue) when progressively reduced over a period of 3 to 4-weeks (taper period) resulting in ~3% increase in performance (fitness) in elite swimmers (Mujika et al. 1996). Banister’s original model has been criticised for not accounting for the instance that over time, an increase in training frequency will stimulate a progressive increase in the magnitude and duration of the fatigue induced by a same training bout (Busso 2003; Hellard et al. 2006). Modifications that account for the change in the dose-response relationship over time have been used to depict the inverted U relationship to describe performance gain against training frequency (Busso 2003; Hellard et al. 2006).

Research has highlighted the requirement to individualise the quantification of an athlete's internal training loads to improve the accuracy of banisters original model (Hellard et al. 2006; Manzi et al. 2009) Furthermore, in most models, the parameters used are measured in laboratory conditions (cycle ergometer) and use maximal performance tests each session, which is not logistically viable, or responsible in an applied setting (Busso 2003). Banister's mathematical model has subsequently been used to create a more user-friendly framework from which monitoring systems can be developed in an applied practice (Impellizzeri et al. 2005, 2019; Coutts et al. 2018). The most refined framework by Impellizzeri et al. (2019) highlights internal load as the primary input leading to variability in response to a given external exercise load (figure 1.3).

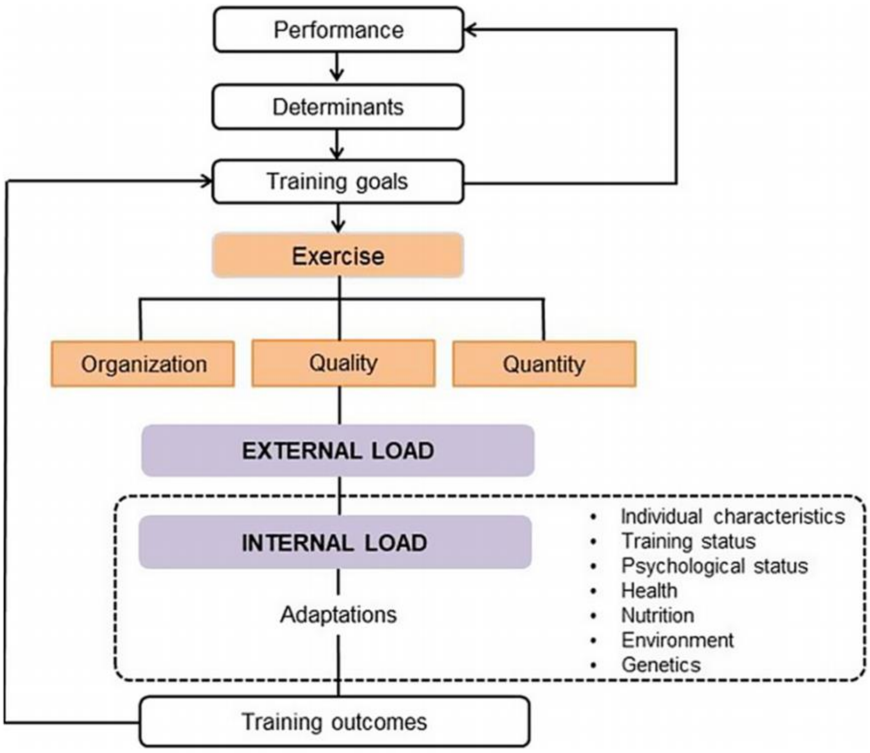


Figure 1. 3 Theoretical framework of the training process (Impellizzeri, Marcora and Coutts 2019)

Impellizzeri et al. (2019) suggest the use of de-coupling between the internal and external load, as a possible tool to monitoring fitness and fatigue state. Their most recent model incorporates a feedback loop which highlights the requirement to modify future input if an alternative training outcome is required. In addition, it details further the external variables (e.g., nutrition, environment, genetics.) that cause within and between-participant variances in response to a given external load.

These theoretical frameworks highlight the importance of the accurate analysis of three key components for insightful athlete monitoring in endurance-type sports: training load, fitness and fatigue. However, it is evident, as a result of the varied approaches used within the current literature, that there is no gold standard quantification of training load with the units of measurement used by coach's dependent mainly on their finances and experience. In addition, coaches must also decide the most relevant tool to monitor sport specific fitness and fatigue, which similarly are constrained by logistics, time and finances (Coutts et al. 2018).

1.4 Monitoring Training Load

As explained in section 1.3, training load is the input variable within the training process and quantifies the ‘stress’ imposed upon the body (Banister 1975; Impellizzeri, Marcora and Coutts 2019). The magnitude of training load can be manipulated by duration, intensity, frequency and modality. Dependent upon the phase of training (overload, maintenance, taper) training load must be accurately managed to control the desired outcome. Therefore, the accurate quantification of training load, and the ability to repeatedly monitor such input variables is an essential component of any athlete monitoring process (Halson 2014).

1.4.1 External Training Load Variables

External training load is often referred to as a the ‘work done’ and measured independently of the athlete’s internal characteristics (Halson 2014). Within endurance running, the primary measures of external load would be distance, duration, and running v, while more recent developments in technology have allowed for the analysis of running kinematics, gait and power (Anderson and Neilson 2017). A benefit of monitoring external load is its accessibility, this is particularly important when including completion loads within the training process.

The reliability of global positioning systems (GPS) for monitoring speed in intermittent team sports has been profoundly researched, and has shown good reliability in assessing acceleration, deceleration, and straight-line sprint speed (Crang et al. 2020). However, the reliability of wearable GPS units to quantify distance and speed within continuous endurance running is less explored. Research has shown that over an ultra-marathon race of varied terrain, a variety of branded wrist worn GPS devices recorded distance within 0.6 ± 0.3% to 1.9 ± 1.5% (Johansson et al. 2020). In addition the Polar s3 foot pod stride sensor™ for measuring distance when running has shown to be as low as CV = 2.6, 90% CI; 2.1–3.5 (Wallace, Slattery and Coutts 2014). Provided that a CV <10% is considered acceptable (Hopkins 2000), this evidence suggests GPS devices to be reliable indicators of external load variables for runners. However, to the best of our knowledge, there is no literature regarding the decay of reliability of these GPS units over time or between brands.

When analysing v sustained for a given duration or distance, it is important that v is considered relative to the athletes maximal capacity or v at important physiological thresholds as discussed in section 1.2.3 to more accurately estimate the load imposed and predicted training effect (Midgley, McNaughton and Wilkinson 2006). The training stress score (TSS), which can be calculated from GPS data, uses the concept of normalised power and an intensity factor based on an individual's metabolic thresholds for each training bout, quantifying a single estimate of the relative physiological stress. Although initially developed for cycling the TSS has subsequently been modified for running (rTSS) using velocity/distance measured and v at LT2 (Skiba 2006). Wallace, Slattery and Coutts (2014), used the rTSS within a time-invariant systems model (Busso 2003) which was previously discussed in section 1.3, to retrospectively model 1500m time trial performance over a 15-week observation period. The modelled time trial performance using the rTSS showed large associations with actual weekly 1500m time trial performance ($r = 0.70$). However, there has been (to the best of our knowledge) no subsequent attempts to validate the use of the rTSS for the quantification of training load in runners.

1.4.2 Internal Load Measures

The internal load is the relative physiological and psychophysiological stress imposed by exercise. As exercise affects a number of physiological and psychological systems, there is a range of variables that can be used to quantify internal load (Halson 2014; Nuuttila et al. 2020).

1.4.2.1 Blood Lactate Concentration (B[La])

B[La] is sensitive to changes in exercise intensity (Nuuttila et al. 2020) and duration and is reflective of the metabolic demand of the exercise bout (Costill 1970). The concentration of B[La] recorded during an exercise bout is dependent upon: 1) the rate of formation of lactate within the muscles, 2) the cellular utilization of lactate, 3) the rate of diffusion of lactate into the blood (Strom 1949). As discussed in section 1.2.3 monitoring the concentration of B[La] after exercise can provide important information regarding work done around the they metabolic thresholds. However, collecting B[La] samples for the regular quantification of training load is limited. Wallace et al (2004) showed that over three repeated trials of running at v equating to 90% of 10km personal best pace, B[La] showed a CV (defined at the standard deviations, relative to the mean) of 38.1%. This large test-retest variability is constant across literature, and thought to be related to the sensitivity of this measure to a plethora of confounding variables including; temperature, hydration status, glycogen content, previous training, nutrition and sampling procedures (time and site) (Borresen and Lambert 2008; Halson 2014). In addition, the collection of B[La] samples within the field requires expensive equipment and test expertise; as such, it is not favourable as a recurring measure of training load.

1.4.2.2 Heart rate response to exercise (HR_{ex})

Monitoring heart rate during exercise (HR_{ex}) serves as a rapid, convenient, and easy-to-implement method of quantifying internal load. HR_{ex} reflects an indirect measure of aerobic metabolism, validated by the linear relationship between HR_{ex} and O_2 consumption during steady state exercise (Mann, Lamberts and Lambert 2013). The reliability of submaximal HR_{ex} to monitor intensity has been debated due to its sensitivity to stimuli outside of training stress (i.e. environmental condition, glycogen stores and dehydration) (Achten and Jeukendrup 2003). Lamberts et al (2004) monitored the HR_{ex} response of 44 'physically active' male and female participants, at 8.4, 9.6, 10.8 and 12.0 $km\cdot h^{-1}$ throughout a 20m indoor shuttle run test, on five consecutive days. Results showed HR_{ex} response to have a CV = 2.3%, 2.1%, 1.7% and 1.3% respectively (Lamberts et al. 2004). This research shows that when other factors potentially affecting HR_{ex} are controlled (e.g., time of day, temperature and caffeine intake) this parameter can serve as a reliable measure of intensity and thus overall session load. Bagger, Petersen and Pedersen (2003) assessed the variability in HR_{ex} response to treadmill running in a cohort of 15 moderately trained male runners. The runners completed 10-min treadmill-based running at 90% of their 10km personal best pace, on 3 occasions, separated by 3 – 4-weeks; HR_{ex} was analysed at 8-min into the exercise trial. In the same 3 visits, following a 2-hour recovery, runners completed a 10km TT on a track, during which HR_{ex} was monitored throughout. Results showed for HR_{ex} during the treadmill-based running CV was 6.5 ± 6.0%, for the track-based 10km TT, CV was 4.6 ± 4.4% (Bagger, Petersen and Pedersen 2003). This research, which uses greater periods between repeated trials (3 – 4-weeks) than Lamberts et al (2004) (1-day), shows that for the same external load (either constant v/power or constant duration) the physiological strain (metabolic demand) quantified through HR_{ex}, varies over time as a result of training induced adaptations. It is therefore important to considerer HR_{ex} response in combination with external load measures, to build a better estimate of the total stress imposed by a given session.

1.4.2.3 Training impulses (TRIMP)

TRIMP was developed by Banister (1991), as a unit of physical effort that is calculated by combining both external load measures (training duration) and internal parameters through use of maximal, resting, and average HR_{ex} recorded from a given session. Adaptions have sought to improve the validity of the original model (Banister, Macdougall and Wenger 1991) by grouping HR_{ex} data into either five zones defined by % HR_{max} (Edward TRIMP)

(Edwards 1993) or three zones based upon the individuals HR_{ex} below, at, or above the LT2/VT2 (anaerobic threshold) (Lucias TRIMP). In each, the weighting factors applied the HR_{ex} data is either consistent for all based upon a population standard, or gender-dependent coefficients. However, in an attempt to increase the sensitivity of calculations the individualised TRIMP (iTRIMP) utilises a weighted factor applied to HR_{ex} data, which is based upon the individual's profile of a typical B[La] response curve to increasing exercise intensity (Manzi et al. 2009). Manzi et al (2009), compared the used of Banister's (1991) TRIMP (in which the weighting factor was consistent), with the iTRIMP model to track training load in a group of runners participating in 8-weeks endurance type-training. Their results showed that iTRIMP was positively correlated with improved v at 2 $mmol \cdot L^{-1}$ ($r = 0.87$) and 4 $mmol \cdot L^{-1}$ ($r = 0.74$) over the 8-weeks training, which was greater in association than that of Banister's TRIMP ($r = 0.61$, $r = 0.59$ respectively). This provides good evidence for the utility of the iTRIMP model to quantify the dose -response relationship in runners. Importantly, their research support for the use of individual physiological characteristics (B[La] profiles) rather than average exercise values when modelling internal training load.

1.4.2.4 Session Rating of Perceived exertion (sRPE)

Although shown to be valid and reliable, the use of HR_{ex} data as part of an integrated model (i.e., training impulses) is not always a viable methodology for quantifying training load, due to the expense of the technology and time requirement to process the data. An alternate methodology uses RPE to quantify the psychophysiological strain of a session. Foster (2001) developed the sRPE method for quantifying training load, which required athletes to subjectively and retrospectively rate their exertion from the session using the RPE on a 1 – 10 scale (CR-10 scale), which is then multiplied by the duration of the exercise (min). Wallace et al (2014b), compared the quantification of training load for HR_{ex} based (Banister and Lucias TRIMP) and RPE based (sRPE) with VO_2 measured during three repeated trials of both a steady state and interval training session on a cycle ergometer. Their results showed that Banister TRIMP had the strongest associations with measured VO_2 during the sessions ($r = 0.85 \pm 0.06$) while sRPE shared a weaker association ($r = 0.75 \pm 0.11$). Furthermore, sRPE was shown to have a poor level of reliability (CV= 28%) when compared with Banisters TRIMP (CV = 15.6%). In a study by the same research group (see section 1.4.1), sRPE was used to model 1500m performance over a 6-week training period. Modelled performance showed a large association with actual performance ($r = 0.60$), however this was weaker than that modelled by rTSS and

Banisters TRIMP (Wallace et al. 2014). The authors suggested that the use of sRPE is limited by its high measurement error, as well as being restricted by the confined 1–10 values of the CR-10 scale (Foster et al. 2001), which reduces the accuracy, particularly showing athletes inability to delineate between moderate-to-high intensities using the scale.

1.5 Parameters used to Monitor responses to Training in Endurance Athletes

As discussed in section 1.3 the quantification of training load offers the input variable to modelling the training process. However, the dose-response relationship is highly individualised, meaning that the same ‘input’ can stimulate very differing ‘output’ both between and within-individuals. Therefore, there remains a requirement to additionally provide valid and reliable data pertaining to the sport-specific responses (fitness and fatigue) of the athletes to training, in order to direct an evidence-based approach to the programming of training content for each individual.

1.5.1 Athlete Self Report Measures (ASRM)

ASRM offer an appealing method to assess training effect because of their affordability, minimal requirement for tester expertise, and low impact on athlete time. The breadth of ASRM available allows practitioners to report upon a range of factors which can be negatively affected by training stressors including: Psychological stress, perceived muscular fatigue and social well-being. The selection and refinement of ASRM items must go through several phases: Firstly, the relevance of the evaluation of a particular item (e.g. stress or recovery) must be based upon sound theory, secondly ‘exploratory factor analysis’ is used to refine and reduce the number of items, lastly ‘confirmatory factor analysis’ is subsequently used to test the hypothesized relationship of scales and dimensions (Kellmann and Kallus 2001; Saw et al. 2017). Caution should be given to customised ASRM which have not been subject to the aforementioned validity process. The Recovery-Stress Questionnaire for Athletes (RESTQ- Sport) (Kellmann and Kallus 2001), which uses a Likert scale from 0 (never) to 6 (always) to rate feelings of stress and recovery specific to athletes, has previously been shown to display high test-retest reliability (r = 0.79), when repeatedly measured over a short-term (3-day) period. The internal consistency of ASRM is suggested to increase as athletes become more familiar with a measure (Saw et al. 2017)

The Rest-Q Sport and The Daily Analyses of Life Demands for Athletes (DALDA) (Rushall 1990), which are athlete specific, have shown to be sensitive to periods of intensified training (Halson et al. 2002; Achten et al. 2004; Coutts, Wallace and Slattery 2007; Capostagno, Lambert and Lamberts 2014) and recovery phases (Coutts, Wallace and Slattery 2007) within endurance-type training. In some cases, research reports superiority of ASRM in detecting states of fatigue prior to significant variation in biochemical and performance measures (Verde, Thomas and Shephard 1992; Coutts, Wallace and Slattery 2007). Coutts et al. (2007a, 2007b) showed an increase in the stress scores in a group of athletes who completed ~290% higher training load than those prescribed to normal training, which was concomitant with a 3.7% reduction in the groups 3km TT running performance. However, the study did not explicitly assess the within-individual relationship between variance in REST-Q Sport, DALDA and running performance, meaning only a suggestion pertaining to their relationship can be made. The limited evidence for a quantifiable relationship between ASRM and sport-specific performance limits the ability to set thresholds for meaningful changes. Alternatively, the assessment of an individual threshold relies on the collection of multiple data points over-time, to determine a 'normal-sate' (Rushall 1990). However, this monitoring period is often neglected within research due to time constraints. Caution should be exercised when using ASRM measures due to their subjective nature, which exposes them to reporting bias.

1.5.2 Monitoring the Autonomic Nervous System

The autonomic nervous system (ANS) is a component of the peripheral nervous system which is responsible for the modulation of cardiovascular function, blood pressure and respiratory function, which as described in section 1.2 are integral components of aerobic performance. Measures of the ANS at rest, during exercising and over post-exercise recovery offer a window into training induced cardiovascular morphology and oscillations between sympathetic and parasympathetic control (Buchheit 2014).

1.5.2.1 Resting Heart Rate (RHR)

Clinical examinations, and in-vivo studies have provided strong evidence of structural remodelling of both the left and right ventricles (Pluim et al. 2000; Prior and La Gerche 2012) and sinus node re-modelling (downregulation of HCN4 protein) (D'Souza et al. 2014) in endurance trained athletes. These training induced adaptations lead to a reduction in RHR (bradycardia) (Da Silva et al. 2014; Plews, Laursen, Kilding, et al. 2013), which can therefore be used as an accessible, non-invasive surrogate measure (Pluim et al. 2000; Prior and La Gerche 2012). The concurrent validity of RHR was shown by Plews, Laursen and Stanley et al (2013) who found a strong correlation between the average weekly RHR and change in 10km TT performance (r = 0.73) in runners completing a 9-week training intervention. Importantly, the study found that RHR taken on a single day (every Tuesday) as opposed to the 7-day average RHR, shared a weaker correlation with 10km time trial performance (*r* = 0.21). The authors demonstrate that the CV in 7-day average RHR (CV = 12.2%) was comparable to that for RHR on each Tuesday data point (CV = 13%), which would not explain the large difference in its association with performance. However, the methodology for calculation of CV in RHR indices is not detailed in the current (Plews, Laursen, Stanley, et al. 2013) or its sister paper (Buchheit et al. 2010), therefore may not reflect the likely disparity in the longitudinal variation if RHR on each Tuesday compared with 7-day average RHR measured over the 9-week intervention.

In a unique study by Pla et al 2021, RHR was monitored in a group of 20 elite swimmers during normal training (mean duration 24.1 ± 3.2-hours) and following 4-weeks of de-training (mean duration 10.4 ± 3.6-hours) and social-isolation as a consequence of the COVID-19 pandemic. Their results showed that anatomical position during measurement significantly affected the results; showing that standing RHR (4-min measurement time) was increased significantly over 4-weeks detraining (103.3 ± 13.2 at de-training compared with 88.4 ± 9.4 beats·min^{-1} normal training, $P < 0.001$), while RHR in a supine position displayed less of a variance (58.8 ± 8.2 vs. 56.5 ± 7.4 beats·min^{-1}, $P < 0.05$). Interestingly, increases in RHR were greater in those who showed a significant decrease in well-being and those who were middle-distance (more aerobically trained) compared with sprinters. The results of both Plews et al (2013) and Pla et al (2021) highlight the methodological considerations for both data collection (anatomical position) and data processing (averaging of data) that should be considered when monitoring RHR. In addition, the relationship between self-reported well-ness and RHR found within socially isolated athletes (Pla et al. 2021), highlights that factors outside of training-stress should also be considered as effectors on RHR.

There is evidence of ambiguity in the measurement of RHR, which increases as a result of insufficient training stimulus (de-training) and as a result of acute phases of over-load training. For example, previous research has reported acutely increased RHR (60-min – 24-hours post-race) in response to participation in an ultra-marathon (Burr et al. 2012; Fazackerley, Fell and Kitic 2019). Therefore, RHR should be interpreted alongside training load data to inform decision making regarding the appropriate strategy to resume homeostasis. The high day-to-day variability in RHR which is suggested as CV ~10% (Plews et al. 2013; Buchheit et al. 2014), reduces confidence in the measures ability to detect meaningful change. In order to limit the measurement error, considerable attention needs to be given to standardising confounding variable such as; environmental conditions (e.g. noise, temperature), life-style (e.g. caffeine, sleep, psychological stress), anatomical position (supine or standing) and respiratory rate (Buchheit 2014), which can be seen as a limitation for its use outside of a research environment.

1.5.2.3 Heart Rate Variability (HRV)

HRV is a measure of the fluctuations in the intervals between consecutive heart beats (R to R intervals) and provides a direct measure of the parasympathetic contributions (vagal tone) to RHR. There is a range of parameters to assess resting HRV, though the root-mean-square difference of successive normal *R–R* intervals (RMSSD) in the time domain and analysis of the high frequency power (HFP) in the power spectral domain, are amongst the most widely used resting measures within athlete monitoring. A review of the literature performed by Bellenger et al (2016) reports a small increase in RMSSD and HFP, following endurance-type training leading to improved performance. However, in cases of decreased performance following intensified training, the results showed no definitive directional change in these HRV indices (Bellenger et al. 2016). Research has shown the utility of daily monitoring of HRV to guide the individual prescription of training in endurance runners (Bahenský and Grosicki 2021) and cyclists (Javaloyes et al. 2020). In a study by Vesterinen, Nummela, Heikura et al (2016) a group of 40 recreational runners were divided into either a HRV guided group or normal training group, with all completing 8-weeks of interval training. The HRV guided group would either complete the assigned interval session or rest, depending on whether their morning HRV was within or outside of the smallest worthwhile change. At the end of the 8-weeks a small group difference between HRV guided and normal training groups was found for v 3km (HRV Guided = 2.1 ± 2.0% versus Normal = 1.1 ± 2.7%; Effect size = 0.42), while there was no difference for change in $\dot{V}O_{2max}$ (HRV Guided 3.7 ± 4.6%, versus normal = 5.0 ± 5.2%, Effect Size = 0.26). However, the HRV guided group participated in considerably less high intensity interval training sessions (1.8 vs 2.8 sessions per week) compared to the normal group, suggesting HRV-guided training may allow for more efficient training programming (Vesterinen, Nummela, Heikura, et al. 2016).

As a relatively new measurement, the literature regarding HRV can be difficult to compare due to large variability in methods of collection between studies; including variation in the anatomical position of participants, duration of measurement, timing of measurement (rolling averages versus single-day values) and equipment used. In addition, HRV is highly sensitivity to the environmental and lifestyle variables which similarly affect RHR (see section 1.5.2.1), which increasing noise in the measurement. Research has shown short duration recordings (5-min) of RMSSD to have a reliability of CV= 12%, while HFP has a far greater day-to-day variability CV = 82% (Al Haddad et al. 2011). However, this will vary depending of the equipment used for analysis (ECG, Heart rate monitors, mobile apps) (Buchheit 2014; Guzik et al. 2018). The high measurement error in HRV and reliance on highly standardised conditions means that caution should be taken in translating findings outside of a research context (Buchheit 2014).

1.5.2.4 Heart Rate (HR_{ex}) during Submaximal Exercise

During short-bouts of submaximal steady-state exercise, there is a linear relationship between HR_{ex} and VO_2, making HR_{ex} a valid measure of the metabolic demand (intensity) of a given standardised exercise (Arts and Kuipers 1994). Research has shown high reliability of HR_{ex} measures, suggesting a standard error of measurement of submaximal HR_{ex} as 1.1 – 1.4% at intensities ranging from 60 – 90% HR_{max} (Lamberts et al. 2004), which makes this a popular measure in an applied settings.

A decrease in submaximal HR_{ex} is characteristic of an increase in aerobic fitness following training (Jones and Carter 2000). This is the results of a number of physiological and metabolic adaptations leading to an increase in the oxygen carry capacity of the blood (greater concentration of haemoglobin), an improved arterio-venous difference at the sight of the muscle, and increase in stoke volume (due to cardiac remodelling) (Jones and Carter 2000). However, similarly to RHR (see section 1.5.2.1) there is ambiguity in the measurement of HR_{ex} with acute periods of training induced fatigue similarly resulting in a decrease in HR_{ex}. In a systematic review, Bosquet (2008) reports a small overall effect of short periods of over-load training on submaximal HR_{ex} (overall effect: -2.6 beats·min^{-1}, >2 training weeks: -3.6 beats·min^{-1}). A recent study explored the difference in HR_{ex} during 5-min submaximal running at fixed v, between the recovered (Weekend recovery period) and strained (participation in Monday-Friday training) states over 12-weeks of training (Schneider et al. 2020). The results showed that there was an overall meaningful linear reduction in submaximal HR_{ex} of -1.4% (-3.0% to 0.3%) over the 12-week training period. Results also showed that HR_{ex} was -1.5% (-2.2% to -0.9%) lower in the strained compared to recovered state (Schneider et al. 2020). These results highlight the necessity to interpret HR_{ex} result alongside ASRM and training data to provide appropriate context (acutely strained or improved fitness).

Following short term periods of exercise cessation (14-days) research has shown an increase in the submaximal HR_{ex} (~6%) of runners during exercise at 75% and 90% VO_{2max} (Houmard et al. 1992). A review by Mujika et al (2000) suggests this short-term increase in HR_{ex} can be explained by a decrease in plasma volume in detrained athletes. Throughout a greater period of physical deconditioning (up to 12-weeks) in runners, submaximal HR_{ex} is shown to rise progressively, and is thought to result from the reduction in left-ventricular hypertrophy (Martin et al. 1986).

Although there is a plethora of literature which uses HR_{ex} to monitor athletes' fitness and fatigue, it is often difficult to compare results due to large variability in the duration and intensity of submaximal exercise used within studies. There is some suggestion that an intensity > 80% HR_{max} is required when aiming to monitor fatigue status in endurance runners (Vesterinen, Nummela, Äyrämö, et al. 2016; Siegl et al. 2017a), however more research is required to fully elucidate the most appropriate way to standardised intensity and the optimal duration of exercise for monitoring HR_{ex} responses to exercise.

1.5.2.5 Heart Rate Recovery (HRR)

Postexercise HRR, usually monitored for the 60 – 300-s following cessation of standardised exercise, characterises the parasympathetic reactivation and sympathetic withdrawal following exercise cessation (Daanen et al. 2012). A faster HRR has shown to be indicative of a positive adaptation to endurance-type training. Dixon et al (1992) reported that HRR (5-min following 15-min at 50% peak v) recovered faster in 10 highly trained male long-distance runners (average 58 beats in 5-min) than in 14 sedentary male control participants (average 35 beats in 5-min). However, a faster HRR has also been shown in over-reached athletes, and in the days following participation in ultra-marathon racing (Mann et al. 2015; Siegl et al. 2017b).

Following submaximal exercise (10-min at 80% of v_{peak}), HRR showed a stable magnitude of reliability from measurement at 1-min – 5-min (ICC = 0.80 at 1-min versus ICC = 0.79 after 5-min), with the standard error of the measurement averaging 8% (Bosquet, Gamelin and Berthoin 2008). A number of variables will affect HRR including the intensity and duration of the preceding exercise which must be standardised over repeated tests. In addition to this; age, postprandial status, temperature, noise and mood state have shown to affect results and should be considered during within-athlete monitoring (Daanen et al. 2012).

1.6 Exercise Tests for Monitoring Responses to Training in Endurance Athletes

1.6.1 The Graded Exercise test (GXT)

GXTs are used to assess the relationship between external workload (v) and pulmonary (VO_2), cardiovascular (HR_{ex}), and metabolic (B[La]) responses, in a controlled environment. As detailed in section 1.2, GXT's can be used to measure the determinants of endurance performance including: $\dot{V}O_{2max}$, v_{peak}, vLT2 and RE. GXT's can be conducted using either a RAMP (external workload increases in a progressive, linear fashion) or STEP protocol (periodic increases in external workload through time-fixed stages). In runners the STEP protocol is most applicable due to the technological restrictions on conducting RAMP on a treadmill or track. Pollock et al (1976) conducted a comparison of a range of treadmill-based STEP protocols: Balke (Balke and Ware 1959), Bruce (Bruce et al. 1963), Ellestad (Ellestad et al. 1969), and modified Astrand (Dey, Samanta and Saha 2004), which vary in both duration of step and modality of workload increases (v or gradient increase). Their results showed that there was no significant difference in the $\dot{V}O_{2max}$ measured by each protocol, which has been confirmed in subsequent investigations (Miller et al. 2007). However, there was a significant difference between protocols for the amount of participants who displayed a $\dot{V}O_{2max}$ plateaux (Pollock et al. 1976). Subsequent research has argued that the attainment of a $\dot{V}O_{2max}$ plateaux (considered a criterion for measurement of maximal capacity) is more likely affected by the gas sampling frequency than duration of testing; showing chances of detecting a plateaux to be greater when using; 15-s sampling (91 % of participants), 30-s (89 %), breath-by-breath (81 %) and 60-second intervals (59 %) (Astorino 2009).

As described in section 1.2 3. The analysis of metabolic thresholds is also a key outcome of the GXT. Both ventilatory (VT1, VT2) and lactate thresholds (LT1, LT2) can be analysed during the GXT, with the v at each shown to share a close relationship (ICC range 0.82-0.90), dependent on the methods of determination, in runners (Cerezuela-Espejo et al. 2018). In cyclists, VT1 and VT2 have shown to be validity assessed using short STEP protocols with Beaver, Wasserman and colleagues using 1-min exercise increments in their pioneering investigations (Wasserman et al. 1973; Beaver, Wasserman and Whipp 1986).These findings have more recently been validated in runners (Cerezuela-Espejo et al. 2018). For the determination of LT1, LT2 it is recommended that STEP stages exceeding 3-min should be used to increase the validity in measurements however, the optimal duration of stages is shown to be dependent on age and training status of participants as this affects the diffusion rate of lactate into the blood (Bentley, Newell and Bishop 2007; Faude, Kindermann and Meyer 2009). Using a GXT with intensity increasing by 1 km·h^{-1} each 1-min and criteria detailed in Cerezuela-Espejo et al (2018) the treadmill v at VT1 and VT2 measured using 5-s average of breath-by-breath data MetaLyzer 3B- R3, Cortex Biophysik GmbH, Leipzig, Germany) displayed a CV = 2.08% and 1.92% respectively. In the same study, for treadmill v at LT1 and LT2 determined by capillary B[La] measured each 2-min the CV = 1.99% and 3.08% respectively. Each therefore show an acceptable reliability for repeated measurements. When monitoring individuals responses to training using the GXT it is therefore important to standardise both testing protocol and treatment of data (Bentley, Newell and Bishop 2007; Faude, Kindermann and Meyer 2009).

The GXT has been criticised for the following methodological limitations explained by Noakes 2008: 1) Participants do not know the expected duration of the exercise bout when it begins, 2) The intensity of the exercise increases progressively, sometimes rapidly from low to “maximal” work rates, 3) The participants cannot regulate the exercise intensity except by choosing when to stop. Each of these limitations removes the GXT protocol from the requirements placed on athletes participating in endurance competition to self-regulate paced based upon those feedforward and feedback mechanism described in section 1.2.7 (Noakes 2010). As such its ability to truly capture an athlete’s endurance performance ability is questioned.

1.6.2 Time Trials (TT) and Time-to-exhaustion Tests (TTE)

Two forms of performance-based exercise tests are most prominent throughout literature; that is duration or distance specific time trials (TT) and time-to-exhaustion (TTE) protocols, each with varying advantages to monitoring individuals. TT’s can be used to closely monitor an athletes’ potential to perform in competition due to their high ecological validity to competition performance, provided the distance, modality and environment of the test replicates (as close as possible) the demands of the athlete’s competition. In direct comparison, TTE would be considered a less valid measure of competitive endurance performance due to the unknown end-point of the task, which does not directly replicate the psychobiological demands of competitive endurance performance (self-paced exercise) (Noakes, Gibson and Lambert 2005, Tukeer et al 2009).

However, TTE presents a different benefit for monitoring purposes, in its ability to directly evaluate the effects of training on the physiological and psychological responses (tolerance) to a given workload. In contrast, this is not possible during TT as results would be confounded by the varying workload throughout the test. In order to assess individual's variation in responses during TTE over-time, data can be treated with either the 'individual isotope method' in which absolute time points are selected for analysis based upon the shortest TTE, or the 'relative isotope method' in which response at the same relative time point (i.e. 50% of total time) is compared (Nicolò et al. 2019).

The main criticism against the use of TTE is the well reported low within-participant reliability in the end-point of the test. Laursen et al (2007) compared reliability of TT and TTE in male distance runners $\dot{V}O_{2max}$ (61 ± 8 $mL \cdot kg^{-1} \cdot min^{-1}$). Participants completed two treadmill-based 5000m and two 1500m TT's, as well as four TTE trials: two at the equivalent mean v 5000m and two at the equivalent mean v 1500m, all on a treadmill. Results demonstrated a coefficient of variation (CV) for the 5000m TT and 1500m TT (CV [mean ± SD] = 1.7 ± 1.2% and CV = 2.6 ± 1.8%, respectively), which was considerably lower than the CV for the TTE at v 5000m and v 1500m (CV = 11.2 ± 7.4, and CV = 10.2 ± 10.1%, respectively). Additional research has shown an even greater within-subject variability in the end-point of the task, for longer duration (30-min) TTE in runners (CV = 25.3%) (Nicolò et al. 2019). Hopkins et al (2001) reports the variability in competitive performance in events from 5000m – marathon distance in the fastest half of finishers as CV range = 1.1 – 3.8% and in the slowest half of runners as CV range = 2.4 – 4.2%. This implies that the TTE would be unsuitable for monitoring the marginal changes in performance which can lead to meaningful variation in competitive standing. This large within-individual variability in the outcome of a TTE test likely occurs because participants do not have prior knowledge of the end-point of the task, which is a key component in the construction of the RPE template, which is used to appropriately regulate pace during and endurance task (Tucker et al 2009).

The variability in performance of a TTE may also be better controlled when the intensities are fixed relative to an individual's metabolic thresholds. For example studies utilising TTE at fixed intensity of ~10% of work rate at LT2 or 85% of maximal aerobic speed on a cycle ergometer or treadmill have been sensitive in reporting reductions in performance ranging from 14 to 27% following short periods of over-load training; proposing the value of TTE in assessing non-functional overreaching (Urhausen, Gabriel and Kindermann 1998; Bosquet, Léger and Legros 2001). However, the within-individual error in these measurement was not reported or considered within analysis. As such when monitoring response or non-response using TTE tests, it is important to consider the appropriate statistics to control for the unavoidable within-participant random variation between the baseline and follow-up time points. (Atkinson, Williamson and Batterham 2019).

The test-retest reliability of TT's relies upon both familiarisation and time between measurements (Stevens and Dascombe 2015). For example, in cyclists 30km TT's were performed with a 6-week period between; the CVs were reported to be 5.5% without initial familiarisation, 2.4% following familiarisation and 5.3% following the 6-week hiatus. This systematic bias is important to consider when assessing meaningful variance in within-individual performance overtime.

Monitoring performance with sport specific TT's is stated as the only established verification method for diagnosis of training-induced fatigue along the continuum from acutely fatigued, functional-over-reaching, non-functional over-reaching and overtraining syndrome; depending upon the time taken for TT performance to return to normal (Meeusen et al. 2013). However, this relies upon retrospective analysis of performance tests to ascertain the time-taken to return to 'normal' performance, by which time it may be too late to reverse the negative impact. In addition, this requires multiple completion of exhaustive TT's or TTE tests which would not be suitable for an over-trained athlete.

Although exhaustive performance tests, in particular TT's, have shown high ecological validity and reliability, their use within athlete monitoring is not without its limitations. The requirement for standardised conditions and trial familiarisation to acquire accurate baseline and repeated measurements is time-consuming and difficult to apply outside of a laboratory setting. Most prominently, the exhaustive nature of these tests makes them too demanding to be performed regularly, as a way of monitoring the acute fluctuations in fitness and fatigue required to navigate the delicate balance between training stress and recovery.

1.6.3 Submaximal Exercise Tests.

The Lamberts Submaximal Cycle Test (LSCT) was developed to provide a less demanding testing protocol when compared with exhaustive performance tests (e.g. 40km TT in cyclists) and has been successfully integrated into athlete's training programmes to routinely monitor fitness and fatigue (Lamberts et al. 2011). The LSCT comprises of three submaximal stages (6-min 60%HR_{max}, 6-min 80%HR_{max}, and 3-min 90% HR_{max}) during which rating of perceived exertion (RPE), power output (PO) or v are measured. Additionally, HRR in the 60-s after stage 3 is recorded (HRR_{60}). The test is designed on the premise that a change in measured internal load in response to a fixed external load, can indicate adaptation or maladaptation to training (Halson 2014). The test has since been adapted for use in runners (Vesterinen, Nummela, Äyrämö, et al. 2016) and rowing (Otter et al. 2015) modalities.

Lamberts et al. (2011) reported that cycling power output (Watts) at 80% and 90% HR_{max} had a strong association with 40km TT performance (time s, $r = 0.84$ and 0.92, respectively). In an adaptation for runners (LSRT), Vesterinen et al. (2016) demonstrated large to very large correlations between v at the three stages of the protocol, recorded on an outdoor track, prescribed by intensity 60%, 80% and 90% HR_{max}, treadmill-based measured of $\dot{V}O_{2max}$ ($r = 0.60$, 0.75 and 0.85, respectively) and vLT2 ($r = 0.83$, 0.89, 0.78, respectively). This suggests construct validity between the track-based LSRT and parameters of the treadmill-based GXT, demonstrating that both tests measure an analogous construct of fitness (Currell and Jeukendrup 2008).This is important in understanding how variance in the LSRT might indicate changes in the ability to perform in endurance events. The LSCT (Vesterinen et al 2016) has shown excellent intraclass correlation coefficients for all variables (ICC = 0.81– 0.98), measured over three repeated tests. The PO at each stage has shown small test error measurements for each stage (0.8% to 4.4%), with variability decreasing as intensity increases throughout each stage (Rodríguez-Marroyo et al. 2017; Lamberts et al. 2011). However, the test-re-test reliability for the running and rowing modality have not been published.

The LSCT has shown sensitivity to acute increases in training load (Lamberts et al. 2010; Hammes et al. 2016; Siegl et al. 2017a; Decroix, Lamberts and Meeusen 2018; Capostagno, Lambert and Lamberts 2019). In a group of eight professional female cyclist's ($\dot{V}O_{2max}$ 59.5 ± 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$) the LSCT was performed on day 1, 5 and 8 of an intensive training camp (Decroix, Lamberts and Meeusen 2018). Results showed that PO measured over the last 5-min of stage 2 (80% HR_{max}) tended to increase by day 5 (6.35 ± 3.01, $P = 0.09$) and significantly increased by day 8 (14.58 ± 3.52 % $P = 0.009$) compared to day 1. Similarly, PO measured in the final 2-min of stage 3 (90% HR_{max}) was significantly increased at day 8 (5.0 ± 2.4%, $P = 0.09$). This appears less of a variance than at stage 2, which may result from cyclist's inability to reach the target 90% HR_{max} at this stage on days 8 (actual intensity reached 88% HR_{max}). The requirement for greater external work rate was accompanied by significantly greater RPE reported at the final 30-s of stage 2 (+2 ± 0.21units ;$P < 0.001$) and stage 3 (+2 ± 1.2 units $P < 0.001$) at day 8 compared to day 1. HRR_{60} did not show a significant ($P > 0.05$) difference, however as cyclist did not reach the 90% HR_{max} of the final exercise stage at day 8, the comparison of HRR_{60} from day 1 – 8 would be invalid. This research supports similar findings in male cyclists (Hammes et al. 2016) in which PO increased at stage 2 and 3 following 6-days intensified training. However, in both studies, the training-induced responses are assessed in an overall group (mean ± SD) pre-post manner, with no analysis of the within-individual responses to the LSCT over time. As individuals responses were depicted to be highly variable over the training camp (Decroix, Lamberts and Meeusen 2018), it would be interesting to assess the relationship between individual training load imposed (iTRIMP) and individual response to LSCT to better assess the sensitivity of the LSCT to within-individual responses to training.

In a recently published study, the ability of the LSCT to detect adaptors and non-adapters to a 2-week high intensity interval training (HIT) was assessed (Capostagno, Lambert and Lamberts 2021). Within the study cyclists were categorised as ‘adaptors’ if they improved 40km TT above the typical error of this test (27-s), and non-adaptors if TT performance remained unchanged or fell below this threshold. The LSCT was performed as a warm before each 40km TT and peak power output (PPO) tests completed before and after the 2-week HIT training intervention, and as a warm-up prior to each of the 4 HIT sessions. The results showed that HHR_{60} following the LSCT showed the strongest association with improved 40kmTT ($r = 0.56$), with adapters displaying a significantly faster HRR_{60} from per-post intervention ($P = 0.023$) while non-adapters displayed a significantly slower HRR ($P = 0.01$) pre-post intervention. Ambiguously, faster HRR_{60} has also been evidenced as a negative consequence of acute fatigue following participation in ultra-marathon running (Mann et al. 2015; Siegl et al. 2017). This highlights the utility of LSCT in providing a simple protocol for the multivariate analysis of fitness and fatigue, in which performance and RPE responses in the 3 prior exercise stages can be used to add context to the HRR_{60} data.

The study by Capostagno, Lambert and Lamberts (2021) revealed that mean PO during stage 2 of the LSCT tended to be different between the “adapters” and “non-adapters” and could be particularly insightful for athlete monitoring. This agrees with the work of Decroix, Lamberts and Meeusen 2018, who similarly showed greater variance in PO at stage 2 following 8-days intensified training, compared to stage 3. In runners, v at 80% HR_{max} (Stage 2 of the LSCT adapted for runners) showed the strongest association with $\dot{V}O_{2max}$, v_{peak} and vLT2, when compared with v at 70% HR_{max} (Stage 1) and 90% HR_{max} (Stage 3). Taken together, this suggests that monitoring performance at stage 2 of the LSCT may be most informative in assessing responses to endurance training. The mechanisms responsible for the superior sensitivity of stage 2 to fitness and fatigue is not understood, however it is likely that’s positioning around the key metabolic threshold (LT2/VT2) influences its sensitivity. It could also be hypothesised that participants in the study of Capostagno Lambert and Lamberts (2021) still carried some residual fatigue from the training sessions into post-testing sessions, which may have dampened their performance and responses at stage 3 in particular as this is the most intensive stage. As such performance enhancements at stage 3 may have been under-estimated, augmenting stage 2 as a superior monitoring stage. However, RPE was not rated significantly differently at either stage 2 or 3 from pre-post testing and participants were provided with 4-days recovery between training and post-testing which may discredit this hypothesis. Where previous research has only assessed group changes pre-post intervention, further research regarding the within-participant responses to the LSCT/LSRT following training intervention could make a useful contribution in exploring the sensitivity of stage 2 to individual fitness and fatigue.

The LSCT prescribes exercise intensity by a relative intensity (either $\%HR_{max}$ or $\% v_{peak}$) in an attempt to stimulate an approximately equivalent exercise stress at each stage, between individuals with different absolute exercise capacities. However, this way of standardising stage intensities may be limited as it does not necessarily place individuals at an equivalate intensity based upon the varying position of individuals metabolic thresholds within their spectrum of exercise capacity from rest to maximal. For example, in an early study by Katch et al (1978), 31 males participated in a GXT on a cycle ergometer with external load increasing every 3-mins until exhaustion. The V-Slope method (Wasserman et al. 1973) was used to assess VT1 and VT2. Results showed that when exercising at 80% HR_{max} 17 participants were exercising at an intensity belowVT2 , while 14 were above. Similar variability in responses was later confirmed by Meyer, Gabriel and Kindermann (1999) in a group of trained cyclists and triathletes ($\dot{V}O_{2max}$ 62.2 ± 5.0 $mL \cdot kg^{-1} \cdot min^{-1}$), for whom cycling at 85% HR_{max} translated to a range of 87 – 116% of work rate at anaerobic threshold. This provides evidence that within the LSCT individuals across each stage may be exercising at differing intensity domains at each stage, which effects the $\dot{V}O_2$ kinetics during exercise (see section 1.2.6) (Burnley and Jones 2007). As highlighted in section 1.2, the rightward shift in the placement of these key metabolic thresholds, and subsequent change in $\dot{V}O_2$ kinetics at a given v, is an important outcome of endurance training and determines performance ability therefore, it may be more insightful to standardise the intensity of the 3 stages around each individuals metabolic thresholds.

Moreover, as described in section 1.2.7, athletes' perception of effort plays an important role in the control of pace during an endurance task. Within the LSCT previously described, athlete rating of perceived exertion is collected as a response measure through passive estimation, in which participants provide an appraisal of their effort during test stages. However, the passive estimation of RPE is subject to participant bias, and testers cannot be certain that the value provided accurately reflects the athlete's perception of effort. In addition, the use of fixed external intensities takes away the demand to regulate pace based upon those feedforwards and feedback mechanisms previously described, thus the LSCT protocol as it stands removes much of the psychobiological demand of endurance performance which is an important factor in the determination of competitive endurance performance (Noakes 2008).

Lastly, the requirement on athletes to continually check their actual HR_{ex} against their target HR_{ex} while exercising could be seen as cumbersome. This may become a particular burden in translating the protocol to runners in an outdoor setting, in which they would be required to check their watch-face at regular intervals to accurately adjust their pace to meet the target HR_{ex} required. This is effortful for the participant and relies on both their experience in adjusting pace and their motivation to meet the target set to them. In a group setting, where a coach may have multiple athletes to instruct, this would also require them to know each individuals target HR_{ex}. Furthermore, during analysis coaches/practitioners would need to make an informed decision as to whether each athlete met that target HR_{ex} within the necessary range, before results can be interpreted. As such the use of fixed external intensities may not be the most practical way to control submaximal intensity during testing in runners.

1.6.4 Self-Paced Exercise Tests

A key limiting factor of both the GXT and other submaximal exercise tests previously described (Lamberts et al 2011, Vesterinen et al 2016, Siegl et al 2017) is their use of fixed external intensities, which removes an athlete's requirement to control their pacing and reliance on the passive estimation of RPE which is subject to bias. Alternatively, RPE production trials, in which exercise intensity is anchored by RPE, addresses these limitations, and may serve to better reflect endurance performance ability by facilitating the active use of the feedforward and feedback mechanisms thought to control pace during competitive endurance races (see section 1.2.7).

Eston and Thompson (1997) first investigated the validly of what they termed the RPE production test, for use in clinical populations. The authors compared participant responses between a submaximal exercise test in which intensity of stages were fixed by power output (a STEP GXT protocol) and a production test in with participants were required to regulate their intensity based upon the RPE scale (RPE 9, 13, 15, 17) (Eston and Thompson 1997). Results showed individual correlations from linear regression analysis for work rate, HR_{ex} and RPE responses to both protocols ranged from $r = 0.96$ to 0.99. In clinical populations the use of RPE to prescribe exercise intensity during both testing and training is considered beneficial in comparison to fixed external loads, as RPE has been shown to be a more pleasing a way to prescribe intensity and will naturally move with the adaptation in cardio-respiratory fitness (Parfitt, Evans and Eston 2012). Furthermore, it is thought to be superior to the use of target HR_{ex} as this variable can be altered by a number of medical conditions, making its day-to-day variances too inaccurate for exercise prescription. For athletic populations the use of RPE to prescribe intensity during GXT's could be beneficial as it addresses the limitation proposed by Noakes (2008).

Mauger and Sculthorpe (2012) compared a SPXT protocol for use in trained individuals, in which participants complete 5x 2-min stages at RPE 11,13,15,17 and 20, with a traditional GXT on a cycle ergometer. Their result showed a significantly greater $\dot{V}O_{2max}$ (40 ± 10 versus 37 ± 8 $mL \cdot kg^{-1} \cdot min^{-1}$) and peak power output (273 ± 58 versus 238 ± 55 Watts) in the SPXT compared to GXT, despite non-significant differences in HR_{max}, RER_{max}, VE_{max}. Subsequent studies comparing the physiological response of a treadmill-based SPXT with the traditional GXT have similarly shown either higher $\dot{V}O_{2max}$ production from SPXT or no significant difference in $\dot{V}O_{2max}$ between protocols (Chidnok et al. 2013; Faulkner et al. 2015; Straub et al. 2014). It is hypothesised that the ability of athletes to self-regulate workload, acts favourably in some manner; potentially by allowing variation in muscle force and duration of contractions, to enhanced blood flow and thus rates of muscle oxygen extraction to achieve higher work rates (Jenkins et al. 2017).This theory stems from the finding that HR_{max} and ventilation (VE) was not found to be significantly different between SPXT and GXT, disproving that greater oxygen delivery could be the driving factor, suggesting extraction at the sight of the muscles may be reason for achievement of higher work rates (Mauger and Sculthorpe 2012; Mauger et al. 2013). However, Astorino and colleagues (2015) and Jenkins et al (2017) provide evidence against this theory by demonstrating that cardiac output during SPXT protocol was comparatively greater than in GXT; potentially as a result of better pacing strategy and efficient activation of Type II and Type I fibres. This would alternatively suggest a greater delivery of oxygen to be the driving factor of greater $\dot{V}O_{2max}$ in SPXT. Although the mechanisms for the achievement of greater work-rates in SPXT remain to be fully elucidated, this collection of literature provides a strong case for the beneficial use of SPXT in allowing participants to reach higher work rates at exhaustion. This may better reflect an athletes v_{peak} which has been previously shows by Noakes et al (1990) to be a strong predictor of competitive endurance performance ability. However, SPXT may be limited by their use of ‘zonal placing’ on the treadmill to adjust v, which is open to tester interpretation.

To resolve these potential limitations of modulating pace on a treadmill, Lim et al (2016) assessed the concurrent validity of a track-based SPXT (5x 2-min at RPE 11, 13, 15, 17 and 20) completed on an outdoor synthetic 400m athletics track with ventilatory data collected via a portable K4-b-TX Cosmed gas analyser (Cosmed K4-b-TX, Rome, Italy). Lim et al (2016) found participants to record a greater $\dot{V}O_{2max}$ on the track in comparison to a duration matched treadmill-based GXT (range +3.0% – 4.8% higher), with participants reaching a higher v_{peak} in the field-based SPXT. In addition, Lim et al (2016) assessed the test-retest reliability of the field-based SPXT, showing that for $\dot{V}O_{2max}$, there was a mean difference of 0.05 $mL \cdot kg^{-1} \cdot min^{-1}$ (0.2%) and 1.3 $mL \cdot kg^{-1} \cdot min^{-1}$ (1.8%) between trial 1–2 and trial 2–3 respectively, and large ICC $\dot{V}O_{2max}$ (ICC = 0.80), HR_{max} (ICC = 0.94) and v_{peak} (ICC = 0.81). This provides some evidence of the validity and reliability of the field-based SPXT, however further research is required to confirm the results of Lim et al (2016).

There is limited evidence for the sensitivity of the SPXT in monitoring fitness and fatigue in endurance runners. Hogg et al (2018), conducted a study to compare the ability of a treadmill-based SPXT and traditional GXT to monitor adaptations following 6-weeks of endurance-type training; in which intensity was either prescribed by the SPXT or the GXT. Those participants whom completed training based on the SPXT displayed significant improvement in $\dot{V}O_{2max}$ (51.7 ± 5.3 versus 54.8 ± 5.7 $mL \cdot kg^{-1 \cdot} min^{-1}$) and v at RPE20 (14.2 ± 1.9 versus 15.7 ± 1.9 km h^{-1}) in the SPXT test. This was validated by a concurrent improvement in track-based critical speed in the group. In addition, there was no significant difference in results compared to the group assigned to training prescribed by GXT and monitored using the GXT (54 ± 5.0 versus 56.3 ± 6.2 $mL \cdot kg^{-1 \cdot} min^{-1}$). Although this provides some evidence of the sensitivity of the SPXT in monitoring adaptations to endurance-type training, further investigation in warranted to fully elucidate the use of SPXT in asses both fitness and fatigue in endurance athletes.

Whether measured by SPXT or GXT, as discussed in section 1.2.1, the use of $\dot{V}O_{2max}$ for monitoring endurance-athletes has limitations; specifically in homogenous cohorts (elite athletes) $\dot{V}O_{2max}$ has shown a low association with competitive performance (Conley, Douglas L. 1980; Costill 1967), and low sensitivity to within-subject variation in performance over a season (Stratton et al. 2009). Comparatively, work rate (v) at LT2, has shown greater associations with seasonal changes in endurance performance (3km-marathon) (Yoshida et al. 1993; Sjodin and Svedenhag 1985). However, the analysis of key metabolic thresholds through a SPXT has gone largely unstudied.

Giovanelli (2019) sought to investigate the validity of measured metabolic thresholds through a novel four-stage SPXT named the RABIT test. This test comprises of 10-min free warm-up pace, 5-min at RPE 13 3-min at RPE = 15, 10-min at RPE 11, separated by 1-min standing recovery. The $\dot{V}O_2$ and v measures during 5-min at RPE 13 were not shown to be significantly different from the corresponding parameters measures at VT2, determined by the V-slope methods (Beaver, Wasserman and Whipp 1986) during a track based GXT: $\dot{V}O_2$ = 2.6 ± 8.3% difference from RABIT versus GXT and v = -2.9 ±3.8% difference. However, although shown on a group level to have a non-significant difference between responses at RPE 13 and VT2 measured during the track based GXT, the large standard deviations in these results show that there may be large inter-individual discrepancies.

At RPE 11 there was a non-significant difference in $\dot{V}O_2$ compared with that measured at aerobic threshold in the GXT (3.2 ± 11.2%) however, there was a significant difference in v (-6.8 ± 5.6%), and large standard deviations within the group results still apply. The results showed that the RABIT was able to predict v VT2 with 71% certainty however only 21% certainty for v aerobic thresholds (Giovanelli et al. 2019). This provides some evidence of the utility of SPXT to assess these key metabolic thresholds, however there may be is large inter-individual differences in its validity.

Importantly, there is currently no research which assesses the utility of the SPXT to monitoring within-individual responses to endurance-type training.

1.7 Rational for the Self-paced, submaximal run test (SRT_{RPE})

As described in section 1.2, endurance performance is determined by the level of aerobic metabolism that can be maintained during a race (performance $\dot{V}O_2$) (Bassett and Howley 2000; Joyner and Coyle 2008b). Performance $\dot{V}O_2$ is influenced by $\dot{V}O_{2max}$ and fraction of $\dot{V}O_{2max}$ that can be sustained, work rate at the metabolic threshold determine by LT2/VT2 and RE (Bassett and Howley 2000). Although these parameters are often analysed using a treadmill-based GXT to assess the construct of aerobic fitness in runners (Carter, Jones and Doust 1999; Bassett and Howley 2000; Stratton et al. 2009), the analysis of these parameters for the purpose of monitoring acute within-participant responses to training has limitations. Specifically, in homogenous cohorts of runners, $\dot{V}O_{2max}$ has shown a low association with competitive performance (Conley, Douglas L. 1980; Alvero-Cruz et al. 2019) and low sensitivity to within-participant variation in performance following training (Stratton et al. 2009). Comparatively, v at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and v at 4 mmol·L^{-1} B[La] (vLT2), have shown greater associations to within-individual changes in endurance running performance (Stratton et al. 2009). However, the traditional analysis of $v\dot{V}O_{2max}$ and vLT2 by the GXT requires expensive equipment, invasive procedures (blood sampling) and tester expertise, making this protocol inappropriate for regular monitoring and largely inaccessible to recreational athletes and coaches.

Outside of a laboratory setting, aerobic fitness can be indirectly assessed through distance (Stratton et al. 2009) and time (Alvero-Cruz et al. 2019) fixed TT's and TTE. However, although more accessible, these protocols require athletes to perform maximally to exhaustion, making them inadequate for the regular monitoring of an athlete's responses alongside training.

The LSCT (Lamberts et al. 2011), is a practical exercise test which can be routinely integrated into training as a warm-up. In an adaptation for runners, the v monitored while running on an outdoor track at 60%, 80% and 90% HR_{max} has been shown to be positively associated with aerobic fitness parameters; $\dot{V}O_{2max}$ (*r* range 0.58 – 0.75) (Vesterinen, Nummela, Äyrämö, et al. 2016) and vLT2 (*r* range 0.79 – 0.89), suggesting that submaximal performance within this field-based test offers good construct validity in relation to aerobic fitness. However, the reliability of the LSRT has not been published.

The current protocol for the LSCT (Lamberts et al. 2011) and LSRT (Vesterinen, Nummela, Äyrämö, et al. 2016) may be limited by monitoring individual's responses to fixed intensities prescribed by a %HR_{max}. Firstly, this does not completely relinquish the requirement for athletes to complete a separate maximal exercise test. Standardising the intensity of each stage by %HR_{max}, likely leads to large inter-individual differences in metabolic, perceptual and performance responses (e.g. b B[La] and RPE), due to the inter-individual variations in the location of metabolic thresholds (anaerobic threshold) between the stage intensities of 60% – 90% HR_{max} (Katch et al. 1978; Meyer, Gabriel and Kindermann 1999). In addition, the reliance on the passive estimation of RPE at the end of each stage, leaves this measure open to subject bias. Importantly, the use of fixed external intensities takes away the need for the athlete to regulate their own pace based upon feedforward and feedback mechanisms (Tucker 2009) removing much of the psychobiological demand of endurance performance which is an important factor in the determination of competitive endurance performance (Noakes 2008).

In response to these limitation, the current thesis aims to explore the utility of a self-paced submaximal run test (SRT_{RPE}) which monitors v, HR_{ex} and B[La])responses to 3, 3-min stages prescribed by RPE 10, 13 and 17 (Borg 1985).

The prescription of intensity by RPE may serve to better reflect endurance performance ability by facilitating the active use of the feedforward and feedback mechanism thought to control pace during competitive endurance races. It may also serve as a more practical, user-friendly and time efficient alternative. This is because it removes the reliance on athletes completing a separate GXT to accuracy prescribed intensities. In addition, while completing the test, runners will not be required to frequently check their watch to correct their pace, which is both cumbersome and reliant on their experience and motivations to meet a target HR_{ex}. Lastly, for a coach/practitioner which have a large training group, the use of RPE to prescribe exercise intensities reduces the strain on them to know each individuals target intensity and spend additional time retrospectively assessing if their athlete has accuracy met their target intensity within a set range of values.

The intensities of RPE 10, 13 and 17 have been chosen as they are hypothesised to reflect intensities below, approximately at, and above vLT2. This is based upon previous literature which shows that the vLT2 has consistently been appraised by RPE values 12 – 14, regardless of gender or competitive level and despite large inter-individual differences in the %$\dot{V}O_{2max}$ or %HR_{max} at this threshold (Demello et al. 1987; Seip et al. 1991). In addition, Siegl et al (2017) reports that in their adaptation of the LSCT, runners completing 6-min at 60% peak treadmill run speed (PTRS), 6-min at 70% PTRS and 3-min at 85% PTRS, valued their RPE at 10±1, 14±1 and 17±1 respectively. As such the values selected for the SRT_{RPE} also represent those of Siegl et al (2017).

Lastly, the use of 3-min stages is thought to allow adequate time for participants to used feedback mechanism to adjust their v to meet the RPE value prescribed (Carter et al. 2002; Lim et al. 2016), whilst minimising the time required for testing compared to similar submaximal protocols (i.e. ~6-mins less versus LSCT).

Chapter 2: General Methods

This Chapter describes the calibration procedures and methodologies used in two or more chapters within the thesis. Details of other methods used in only one chapter will be found within the methods section of the specific chapters.

2.1 Two Phase Graded Exercise Test.

The following two-phase progressive treadmill test (GXT) was used for the assessment of individual B[La] concentration profiles (see 2.1.3) in Chapter 3, ventilatory thresholds (see section 2.1.3) in Chapter 6 and $\dot{V}O_{2max}$ (see section 2.1.3) in Chapter 3, 4, 5 and 6.

2.1.1 Calibration of equipment.

The scales used to measure participants' body mass are tested on a yearly basis by the Medway Council Trading Standards team in order to ensure that they are within the manufacturer's accuracy tolerances.

Throughout all GXT's expired gases were measured with the use of an online breath-by-breath analysis system (Cortex Metalyzer II, Cortex, NL). Immediately prior to each test the gas analyser was calibrated in accordance with the manufacturer's guidelines, using a calibration gas and 3-litre syringe. A two-point gas calibration was completed using a measurement of ambient air and a measurement of standard compressed gas of 17% O_2 and 5% CO_2. The 3-litre syringe (Hans Rudolph Inc. Kansas, USA) was used to calibrate the flow sensor and turbine.

Capillary B[La] concentration was analysed using a laboratory analyser (Biosen C-line, EKF diagnostic, Barleben, Germany) which was calibrated using the manufacturer's recommended 12 $mmol \cdot L^{-1}$ standard (EKF diagnostic, Barleben, Germany). This calibration process was then repeated automatically every 60-min.

The motorised H/P/Cosmos Saturn treadmill (H/P/Cosmos, Nussdorf-Traunstein, Germany) was serviced and calibrated twice a year by HaB International Ltd. This company is the main UK distributor for HP Cosmos treadmills and the servicing and calibration is conducted in line with the manufacturers' recommendations and guidelines. When the calibrations are being conducted the polar heart rate monitors output (Polar T31 Instruments, Kempele, Finland) from the treadmill is also checked and calibrated.

2.1.2 Procedures.

Participants undertook a two-phase treadmill based (H/P/Cosmos, Nussdorf-Traunstein, Germany) GXT for the assessment of vLT1 and vLT2 (Phase-one) and to determine $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$ and HR_{max} (Phase-two). Before initiation of the test, all participants read the standardised instructions for reporting the RPE (6-20) scale (Borg 1998). Participants completed a 5-min warm up at an intensity representing the v at which walking transitioned to running (range 7 – 9 km·h^{-1}). Phase-one comprised of 5 – 7 submaximal intervals with v increasing by 1 km·h^{-1} every 4-min, initiated at the v completed during warm-up. In the 1-min recovery between intervals, RPE (6–20) (Borg 1998) was reported and a 5µL fingertip capillary blood sample was taken to assess B[La] (Biosen C-Line, EKF Diagnostics, Penarth, UK). Phase-one was terminated when B[La] exceeded 4 mmol·L^{-1}. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase-one, increasing v by 0.5 km·h^{-1} every 1-min until volitional exhaustion. Maximal effort was accepted by attainment of at least two of the following criteria: HR_{ex} within 10 beats·min^{-1} of age-predicted maximum; RER ≥ 1.10; RPE ≥ 17; and B[La] ≥ 8 mmol·L^{-1}. $\dot{V}O_{2max}$ was determined as the highest 30-s average oxygen uptake (ACSM 2014) and v at this point ($\dot{V}O_{2max}$) was considered the $v\dot{V}O_{2max}$. HR_{ex} was recorded at a second by second frequency; Heart rate maximum (HR_{max}) was considered the highest 5-s average recorded HR_{ex} (Polar T31 Instruments, Kempele, Finland). The first and second lactate threshold (vLT1, vLT2) was calculated as the v at which B[La] reached 2 mmol·L^{-1} and 4mmol·L^{-1} respectively (Biosen C-line, EKF diagnostic, Barleben, Germany).

2.1.3 Physiological measures.

The first and second lactate thresholds (LT1, LT2)

LT1 and LT2 were calculated as the point at which B[La] reached 2mmol·L^{-1} and 4mmol·L^{-1}, respectively (Biosen C-line, EKF diagnostic, Barleben, Germany). The v at each threshold (vLT1, vLT2) were recorded for use in Chapter 3.

The first and second ventilatory threshold (VT1, VT2)

VT1 and VT2 were identified by visual inspection of plots for each relevant respiratory variable (according to 5-s time-averaging). The criteria for VT1 were an increase in VE/$\dot{V}O_2$ with no concurrent increase in VE/$\dot{V}CO_2$ and departure from the linearity of VE by time plot. The criteria for VT2 were a simultaneous increase in both VE/$\dot{V}O2$ and VE/$\dot{V}CO_2$. The average 5-s HR_{ex} corresponding to VT1 and VT2 were recorded for use in Chapter 6. (Wasserman et al. 1973)

Maximal oxygen consumption ($\dot{V}O_{2max}$)

$\dot{V}O_{2max}$ was determined as the highest 30-s average oxygen uptake (ACSM 2014) attained in the test to exhaustion. All tests were accepted as maximal following the attainment of at least two of the following criteria: heart rate within 10 beats·min^{-1} of age-predicted maximum; RER ≥ 1.10; RPE ≥ 17; and B[La] concentration ≥ 8 mmol·L^{-1}. HR_{max} was considered the highest recorded heart rate.

Velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$)

$v\dot{V}O_{2max}$ was determined as the v stage at which $\dot{V}O_{2max}$ was determined.

2.2 The Self-paced Submaximal Run Test (SRT$_{RPE}$)

2.2.1 Calibration of equipment and standardisation of environment.

The blood lactate analyser (Biosen C-line, EKF diagnostic, Barleben, Germany) was calibrated as detailed in Chapter 2.1.1

The SRT$_{RPE}$ took place on an outdoor synthetic running track. Where possible testing was restricted to ensure that environmental conditions did not negatively affect performance. This was ice on the track (temperature below 0º), significant surface water and winds grater that were 29 km/h (5 on the Beaufort scale). For each test temperature and wind speed were recorded. Information was provided by the met office readings https://www.metoffice.gov.uk/

2.2.2 Procedures.

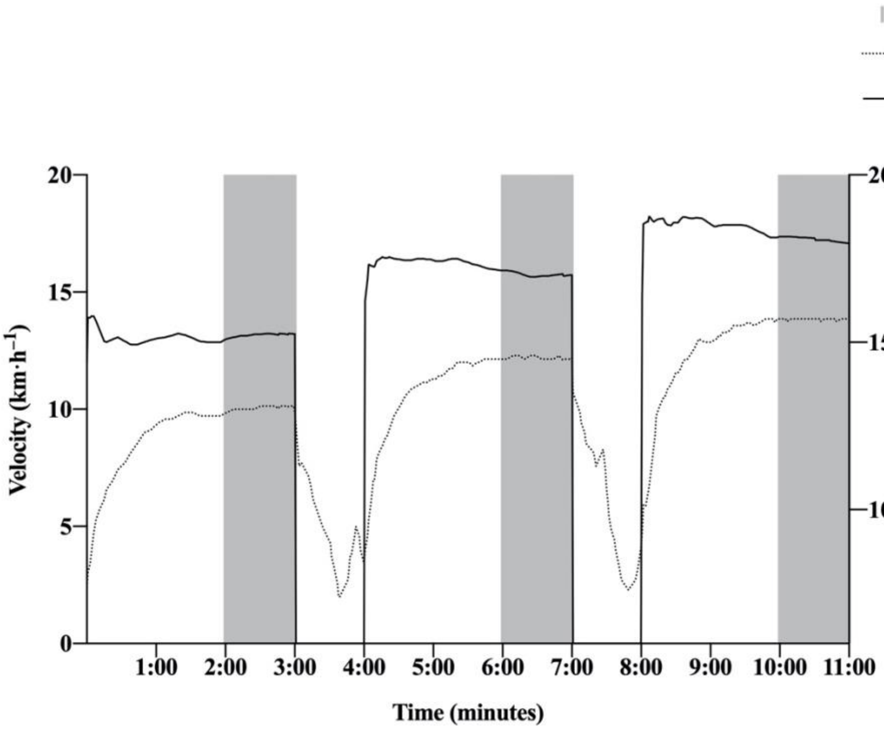


Figure 2. 1 Schematic of the Self-paced submaximal run test (SRT$_{RPE}$)

The SRT$_{RPE}$ comprised of three, 3-min stages interspersed by 1-min recovery, performed on an outdoor, synthetic, 400m running track. Intensity was prescribed by RPE 10, 13 and 17(Borg 1998). Participants were instructed to control their pace based upon a set of standardised instructions, which were re-read to them prior to each SRT$_{RPE}$(Borg 1998).

Participants were directed to select their pace based on the effort being a total of 3-min so that they were holding an RPE 10, 13 and 17 for a duration of 3-min as appose to reaching RPE 10, 13 and 17 at the end of the 3-min.

During each 3-min stage, participants v (km·h^{-1}) and HR$_{ex}$ (beats·min^{-1}) were recorded using a GPS monitor (1Hz sampling rate; Polar V800 or Garmin Forerunner 235 as specified within the chapters) and HR$_{ex}$ monitor (1Hz sampling rate; Polar H7). The watch-face was covered during testing using a sleeve or sweat-band. A whistle was blown to signify the end of each 3-min stage.

2.2.3 Analysis of the SRT$_{RPE}$

Data from the GPS watch and Bluetooth heart rate strap was uploaded and exported to a comma separated values (CSV) file. This provided v and HR$_{ex}$ data in 1-s intervals.

Velocity (v) and Exercise Heart rate (HRex)

The first 2-min (120-s) of v and HR$_{ex}$ data are excluded from analysis of each 3-min stage as it is hypothesised that participants will require this time to compare actual effort with the anticipated RPE template (Carter et al. 2002; Achten and Jeukendrup 2003), and will subsequently reach and sustain their target pace (in knowing the endpoint at 3-min in duration) reflecting the given RPE value by 2-min's

Capillary blood lactate concentration (B[La]).

Whole fresh blood, collected from the fingertip is analysed for blood lactate concentration (Biosen C-line, EKF diagnostic, Barleben, Germany).

Heart rate run speed (HR-RS) index

The basis of HR-RS index in the linear relationship between HR_{ex} and v. As such HR-RS index represents the absolute difference in the theoretical and actual v for a given HR_{ex}. Calculated using the following equation:

$$HR\!-RS\ index = v_{avg} - \left(\frac{HR_{ex} - HR_{standing}}{k}\right)$$

Where:

$$HR_{standing} = RHR + 26$$

$$k = \left(\frac{HR_{max} - HR_{standing}}{v_{peak}}\right)$$

v_{avg} = Average v for the final 60-s of each SRT_{RPE} stage, v_{peak} = v reached at VO_{2max}, RHR = morning resting heart rate for the given day.

Chapter 3: The Self-Paced Submaximal Run Test: Associations with The Graded Exercise Test and Reliability

3.0 ABSTRACT

Purpose. To assess the reliability and construct validity of a self-paced, submaximal run test (SRT_{RPE}) for monitoring aerobic fitness. The SRT_{RPE} monitors running velocity (v), heart rate (HR_{ex}) and blood lactate concentration (B[La]) during three, 3-min stages prescribed by Ratings of Perceived Exertion (RPE) 10, 13 and 17.

Methods. Forty, trained endurance runners (14 female) completed a treadmill graded exercise test (GXT) for determination of maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and 4 $mmol{\cdot}L^{-1}$ (vLT2) B[La]. Within 7 days, participants completed the SRT_{RPE}. Construct validity between the SRT_{RPE} and GXT parameters was assessed through linear regression. Eleven participants completed a further two trials of the SRT_{RPE} within a 72-hour period, to quantify test-retest reliability.

Results. There were large correlations between v at all stages of the SRT_{RPE} and $\dot{V}O_{2max}$ (*r* range = 0.57 – 0.63), $v\dot{V}O_{2max}$ (0.50 – 0.66) and vLT2 (0.51 – 0.62), with vRPE 17 displaying the strongest associations ($r > 0.60$). Intraclass correlation coefficients ($ICC_{3,1}$) were moderate to high for parameters, v (range 0.76 – 0.84), HR_{ex} (0.72 – 0.92) and $\%HR_{max}$ (0.64 – 0.89) at all stages of the SRT_{RPE}. The corresponding coefficients of variation were 2.5 – 5.6%. All parameters monitored at intensity RPE 17 displayed the greatest reliability.

Conclusion. The SRT_{RPE} showed large associations with parameters of the GXT, providing evidence of construct validity between the two tests. Low TE/CVs for v selected at each RPE anchored intensity, suggest that true individual changes can be detected with reasonable accuracy.

3.1 INTRODUCTION

The frequent and reliable monitoring of an individuals' responses to endurance training is an important component within the management of appropriate training stress and recovery (Coutts, Kempton and Crowcroft 2018). However, the determinants of endurance performance are multifaceted (Joyner and Coyle 2008a; Noakes 2008), making the selection of an appropriate monitoring tool a complex task. In section 1.7 the rationale behind the development of the SRT_{RPE} was explained in depth. The current study aims to assess the validity and reliability of the $SRT_{RPE.}$

The SRT_{RPE} is adapted from the original Lamberts Submaximal Cycle Test (LSCT) (Lamberts et al. 2011) and variations of the Lamberts Submaximal Run Test (LSRT) (Vesterinen et al. 2016; Siegl et al. 2017). Previously, Vesterinen et al. (2016) demonstrated large to very large correlations between velocity (v) ($km{\cdot}h^{-1}$) at 60%, 80% and 90% heart rate maximum (HR_{max}) with maximal oxygen consumption ($\dot{V}O_{2max}$) (r = 0.60, 0.75 and 0.85, respectively) and v at 4 $mmol{\cdot}L^{-1}$ (vLT2) (r = 0.83, 0.89, 0.78, respectively). This suggests construct validity between submaximal v and parameters of the GXT, demonstrating that both tests measure an analogous construct of fitness (Currell and Jeukendrup 2008). The current study aims to assess the association between self-selected v ($km{\cdot}h^{-1}$) at each stage of the SRT_{RPE} with the same laboratory-based determinants of endurance performance; $\dot{V}O_{2max}$, v at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and 4 $mmol{\cdot}L^{-1}$ (vLT2) B[La], to assess construct validity between the two tests. In particular, the association between $vSRT_{RPE}$ and $\dot{V}O_{2max}$ and vLT2 will be highlighted as these measures have previously shown large association with endurance performance (3km – marathon) in recreational runners (Costil et al. 1973, Farrell et al. 1993; Noakes, Myburgh and Schall 1990; Yoshida et al. 1993) and are popular parameters used to assess runners within literature and in an applied setting.

In addition, the current study seeks to explore the reliability of a SRT_{RPE}, which refers to the reproducibility of its parameters measured over repeated trials on the same individuals. A better reliability suggests a greater capacity to monitor true changes within measurements. Previously, Lim et al (2016) aimed to establish the test-retest reliability of a field based, perceptually regulated exercise test, displaying a coefficient of variation (CV) for v ($km{\cdot}h^{-1}$) measured for 2-min running at RPE 10 (6.4%; ± 90% CI: 3.1%), RPE 13 (2.9% ± 1.1%) and RPE 17 (2.9% ± 0.8%) between two retest trials. It will be important to similarly quantify the measurement error of the short self-paced efforts which the SRT_{RPE}, for the known ‘noise’ in the measurements to be accounted for during future decision-making processes regarding true changes in performance on the $\text{SRT}_{\text{RPE.}}$

3.2 METHODS

Study population

Forty endurance runners (14 females: 35 ± 3 years; $\dot{V}O_{2max}$ 49.00 ± 7.20 $mL \cdot kg^{-1} \cdot min^{-1}$) (26 males: 38 ± 7 years; $\dot{V}O_{2max}$ 57.50 ± 5.63 $mL \cdot kg^{-1} \cdot min^{-1}$) were recruited. All participants had over 2-years' experience of completing running-based endurance training (> 30km per week), with at least one-year competitive experience. All participants gave informed, written consent; completed a health questionnaire and confirmed that they had been free from injury in the previous 6-months. A sub-set of eleven runners within this cohort undertook additional tests required for reliability analysis (see study design) (5 females: 37 ± 8 years; $\dot{V}O_{2max}$ 50.00 ± 5.70 $mL \cdot kg^{-1} \cdot min^{-1}$) (6 males: 35 ± 10 years; $\dot{V}O_{2max}$ 61.47 ± 6.43 $mL \cdot kg^{-1} \cdot min^{-1}$). All participants gave informed, written consent (Appendix II) and completed a health questionnaire (PAR-Q) and confirmed that they had been free from injury in the previous 6-months. The study was approved by the local University Research Ethics and Advisory Group (Prop 71_2017_18, Prop 107_2017_18, Prop 83_2018_19)

Study design

On their first visit all participants completed a treadmill-based maximal exercise test (GXT) to assess $\dot{V}O_{2max,}$ HR_{max} and the running v at B[La] 2 $mmol \cdot L^{-1}$ (vLT1) and 4 $mmol \cdot L^{-1}$ (vLT2). On their second visit, > 2-days after and within 1-week of visit 1, participants performed 1 familiarisation of the $SRT_{RPE,}$ then, following 30-min passive recovery recorded another SRT_{RPE} trial, which was used within the validity analysis. For analysis of reliability a subset of participants (n = 11) completed an additional visit (> 2-days and within 72-hours of visit 2) in which an additional trial of the SRT_{RPE} was performed in isolation.

Two Phase Graded Exercise Test (GXT)

Participants undertook a two-phase GXT for the assessment of individual B[La] profile and $\dot{V}O_{2max}$. The GXT was conducted out as detailed in Chapter 2. In brief, Phase-one assessed B[La] profile and was comprised of 5 – 7 submaximal exercise bouts starting a v which represented the transition from walk to run, with running v ($km \cdot h^{-1}$) increasing by 1 $km \cdot h^{-1}$ every 4-min, until B[La] exceeded 4 $mmol \cdot L^{-1}$. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase-one and increased by 0.5 $km \cdot h^{-1}$ every min until participants point of exhaustion. Participant's vLT1, vLT2, $\dot{V}O_{2max}$ and v $\dot{V}O_{2max}$ were determined as described in section 2.1.3.

The Self-paced Submaximal Run Test (SRT_{RPE})

The SRT_{RPE} was performed as specified in Chapter 2. In brief, participants completed three, 3-min stages interspersed by 1-min recovery with submaximal exercise intensity prescribed by RPE 10, RPE 13 and RPE 17. During the 1-min recovery between stages, a 5µL sample of whole fresh blood was collected from the fingertip and subsequently analysed for B[La]. Participants v (km·h^{-1}) was recorded using the Polar V800 GPS watch (1 Hz sampling rate) and HR_{ex} using a Polar H10 heart rate monitor (sampling rate of 1Hz). In calculating average v and HR_{ex} at each stage, the first 120-s of v and HR_{ex} data was excluded to ensure the target RPE had been reached (see Chapter 2 for more detail). Mean outdoor testing conditions were: Windspeed 1.2 m/s (range = 0.4 m/s – 1.8 m/s), temperature 8.5 ºC (range = 4ºC – 13ºC)

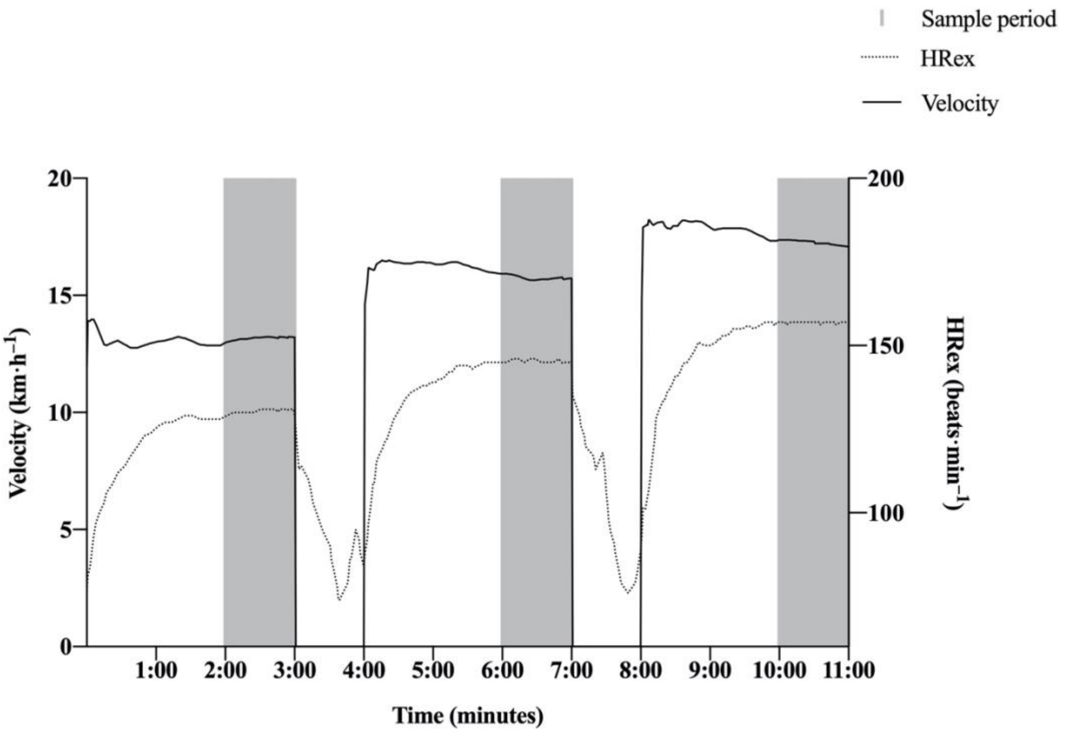


Figure 3. 1 Schematic of the Self-paced submaximal run test (SRT_{RPE})

Statistical analysis

All data was assessed for normality of distribution prior to statistical analysis using the Shapiro-Wilk test. Raw data for v (km·h^{-1}), HR_{ex} (beats·min^{-1}), %HR_{max} and B[La] (mmol.L^{-1}) were summarised as mean ± SD for each three trials. Prior to analysis, all data were log-transformed to reduce bias associated with non-uniformity of error and were subsequently back-transformed to obtain a reliability statistic in raw and percentage units.

Using log-transformations was thought to be important as the errors of measurements were predicted to be uniformly multiplicative, as is usually seen in physiological data, as values increase. Log transformation converts such errors into uniform additive errors (Hopkins 2000). Analyses are not trustworthy when the errors are not uniform, so log transformation is important. This was with the exception of %v$\dot{V}O_{2max}$, %HR_{max}, where raw units are already expressed in percentage points.

A regression model, with v or %HR_{max} for each stage of the SRT_{RPE} as the independent variable and parameters of the GXT ($\dot{V}O_{2max}$, v$\dot{V}O_{2max}$, and vLT2) as the dependent variable(s) was computed to examine the construct validity of the STR_{RPE}. A separate analysis was carried out with only vSRT_{RPE} as the independent variable, and subgroups of males and females. The strength of these relationships were assessed by a Pearson's product–moment correlation coefficient (*r*) while the shared variance was given as the coefficient of determination (R^2). Standard errors of the estimate (SEE) were used to represent random bias in raw and %units (derived from analysis of the log-transformed data for %units). Uncertainty in estimates, and ranges of values compatible with the data sample, assumptions and statistical models, were expressed as 90% confidence intervals (CI) (Greenland 2019). Intervals for Pearsons *r* and SEE values were derived from an F and chi-squared distributions, respectively. The strength of correlations were determined using the following criteria: trivial (<0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9), almost perfect (0.9 – 1.0) (Batterham and Hopkins 2006). Analysis was performed using Microsoft Excel (Version 16.28, Microsoft, Redmond, WA, USA), using a spreadsheet downloaded from (sportsci.org/2015/ValidRely.htm).

To examine the re-test reliability of STR_{RPE}, the systematic change in each outcome measure was given as the mean difference between consecutive trials. Typical error (TE, also expressed as a coefficient of variation [CV]) was also calculated between consecutive trials, estimated as the standard deviation of change scores divided by the square root of 2. These values were then pooled to give the overall TE and CV. In addition, Intraclass correlation coefficients ($ICC_{3,1}$) was assessed using a 2-way mixed-effects model (Shrout and Fleiss 1979). Confidence intervals for the mean change were calculated using a t-distribution. For TE, CI were calculated using the chi-squared distribution and for the $ICC_{3,1}$ an F-distribution was used (Hopkins 2000). Analysis was performed using Microsoft Excel (Version 16.28, Microsoft, Redmond, WA, USA), using a spreadsheet downloaded from (sportsci.org/2015/ValidRely.htm).

A minimum effect test (MET) was applied to provide a practical, probabilistic interpretation of the mean change in each outcome measure between trial 1 – 2 and 2 – 3 (Murphy and Myors 1999). For v and internal load measures (HR_{ex} and B[La]), we used a smallest important threshold of 0.2 multiplied by the pooled, between-participant SD of all three trials. The thresholds for interpretation of the magnitude of $ICC_{3,1}$ were: very low (<0.20), low (0.20 – 0.50), moderate (0.50 – 0.75), high (0.75 – 0.90) very high (0.90 – 0.99), extremely high (>0.99) (Malcata, Vandenbogaerde and Hopkins 2014).

3.3 RESULTS

Group performance in GXT and SRT_{RPE}.

Table 3.1 displays the mean ± SD results for results of the GXT for both male and female participants.

Table 3. 1 Results for the Graded Exercise Test (GXT) (mean ± SD)

	Female (n=14)	Male (n=26)
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	49.00 ± 7.20	57.50 ± 5.63
$v\dot{V}O_{2max}$ ($km \cdot h^{-1}$)	13.80 ± 1.38	16.09 ± 1.26
vLT1 ($km \cdot h^{-1}$)	10.75 ± 1.24	12.04 ± 1.34
vLT2 ($km \cdot h^{-1}$)	12.31 ± 1.25	14.10 ± 1.38

Abbreviations: $\dot{V}O_{2max}$ (maximal oxygen consumption), $v\dot{V}O_{2max}$ (velocity at $\dot{V}O_{2max}$) and vLT1 (velocity at 2 $mmol.L^{-1}$) and vLT2 (velocity at 4 $mmol.L^{-1}$).

Table 3.2 displays the physiological responses (HR_{ex}, $\%HR_{max}$ and B[La]), absolute (v) and relative ($v\dot{V}O_{2max}$) intensity associated with each stage of the SRT_{RPE}. Figure 3.2 shows that the mean absolute difference ($km \cdot h^{-1}$) between vLT2 evaluated by GXT and v at each stage of the SRT_{RPE} was: -2.51 ± 1.58 $km \cdot h^{-1}$ for RPE 10, - 0.34 ± 1.52 $km \cdot h^{-1}$ for RPE 13 and 1.53 ± 1.40 $km \cdot h^{-1}$ for RPE 17.

Table 3. 2 Test-retest reliability of the parameters of the self-paced submaximal run test, over three repeated trials. (n = 11)

	Mean ± SD				**Reliability Statistics (90% CI)**				
	Trial			**Overall**	**Systematic Change**				
	1	**2**	**3**		**Trial 2 – 1**	**Trial 3 – 2**	**TE**	**CV$_{TEM\%}$**	**ICC$_{3,1}$**
v (km·h^{-1})									
RPE 10	10.86 ± 1.18	10.71 ± 0.98	10.86 ± 1.17	10.81 ± 1.11	-0.15 (-0.60–0.31)	0.15 (-0.32–0.62)	0.60 (0.47–0.88)	5.5 (4.3–8.1)	0.76 (0.49–0.90)
RPE 13	12.63 ± 1.06	12.83 ± 1.10	12.85 ± 1.07	12.77 ± 1.08	0.20 (-0.21–0.62)	0.02 (-0.42–0.46)	0.55 (0.44–0.81)	4.5 (3.5–6.6)	0.78 (0.53–0.91)
RPE 17	15.02 ± 1.41	15.06 ± 1.25	14.74 ± 1.00	14.94 ± 1.23	0.04 (-0.38–0.46)	-0.32 (-0.75–0.12)	0.55 (0.43–0.81)	3.9 (3.5–6.6)	0.83 (0.64–0.94)
% v$\dot{V}O_{2max}$									
RPE 10	68.6 ± 8.8	67.5 ± 5.5	68.4 ± 6.5	68.16 ± 7.1	-1.1 (-4.0–1.8)	0.9 (-2.2–3.9)	3.9 (3.1–5.7)	5.5 (4.3–8.1)	0.74 (0.48–0.90)
RPE 13	79.7 ± 7.3	80.9 ± 7.2	81.0 ± 6.6	80.6 ± 7.1	1.2 (-1.33–3.8)	0.09 (-2.7–2.9)	3.5 (2.8–5.1)	4.5 (3.5–6.6)	0.80 (0.56–0.92)
RPE 17	94.6 ± 7.4	95.1 ± 8.9	93.0 ± 6.3	94.2 ± 7.6	0.45 (-2.3–3.2)	-2.09 (-4.8–0.6)	3.5 (2.6–5.1)	3.9 (3.5–6.6)	0.83 (0.62–0.93)
HR$_{ex}$ (beats·min^{-1})									
RPE 10	132.6 ± 10.4	136.5 ± 13.6	133.2 ± 14.0	134.1 ± 12.8	3.9 (-1.9–9.8)	-3.3 (-8.7–2.2)	7.3 (5.8–10.7)	5.6 (4.4–8.3)	0.72 (0.44–0.89)
RPE 13	147.3 ± 11.1	146.7 ± 15.0	144.3 ± 15.7	146.1 ± 14.1	-0.5 (-5.5–4.5)	-2.4 (-7.3–2.4)	6.3 (5.0–9.3)	4.7 (3.7–6.9)	0.83 (0.63–0.94)
RPE 17	160.5 ± 12.4	161.0 ± 13.1	156.3 ± 13.4	159.3 ± 13.0	0.4 (-2.5–3.4)	-4.6 (-8.0–-1.3)	4.1 (3.2–6.0)	2.5 (2.0–3.7)	0.92 (0.82–0.97)

%HR_{max}									
RPE 10	73.9 ± 5.7	76.0 ± 6.4	74.2 ± 6.8	74.7 ± 6.3	2.1 (-1.0–5.3)	-1.8 (-4.8–1.2)	4.0 (3.2–5.9)		0.64 (0.32–0.85)
RPE 13	82.1 ± 5.5	81.8 ± 7.8	80.4 ± 7.5	81.4 ± 7.0	-0.3 (-3.1–2.5)	-1.4 (-4.1–1.2)	3.5 (2.8–5.2)		0.79 (0.55–0.92)
RPE 17	89.4 ± 5.4	89.7 ± 6.4	87.1 ± 6.4	88.7 ± 6.1	0.3 (-1.3–1.9)	-2.6 (-4.4–-0.8)	2.2 (1.8–3.3)		0.89 (0.75–0.96)
B[La](mmol.L^{-1})									
RPE 10	1.5 ± 0.4	1.6 ± 0.5	1.8 ± 0.4	1.6 ± 0.4	0.0 (-0.2–0.3)	0.2 (-0.1–0.6)	0.4 (0.3–0.6)	24.8 (19.1–38.3)	0.26 (-0.11–0.63)
RPE 13	1.8 ± 0.6	1.8 ± 0.6	2.3 ± 0.7	2.0 ± 0.6	0.1 (-0.3–0.5)	0.5 (0.0–0.9)	0.6 (0.4–0.8)	32.2 (24.6–50.5)	0.27 (-0.10–0.64)
RPE 17	3.5 ± 1.6	2.9 ± 1.1	3.7 ± 1.1	3.4 ± 1.3	-0.6 (-1.1–-0.1)	0.9 (0.2–1.6)	0.8 (0.6–1.1)	28.6 (22.0–44.6)	0.69 (0.39–0.87)

Abbreviations: RPE (Rating of perceived exertion) v (Velocity) $v\dot{V}O_{2max}$ (Velocity at $\dot{V}O_{2max}$) HR_{ex} (Exercising heart rate) HR_{max} (Heart rate maximum) B[La] (Blood lactate concentration) TEM (Test error of the measurement) $CV_{TEM\%}$ (TEM as a Coefficient of variation) $ICC_{1,3}$ (Intraclass correlation coefficient). Trial 1–2 corresponds to SRT_{RPE} performed at visit 2 with 30-minutes passive recovery between Trials. Trial 3 corresponds to the SRT_{RPE} completed on visit 3 >2-days and within 1-week of Trial 1 and 2.

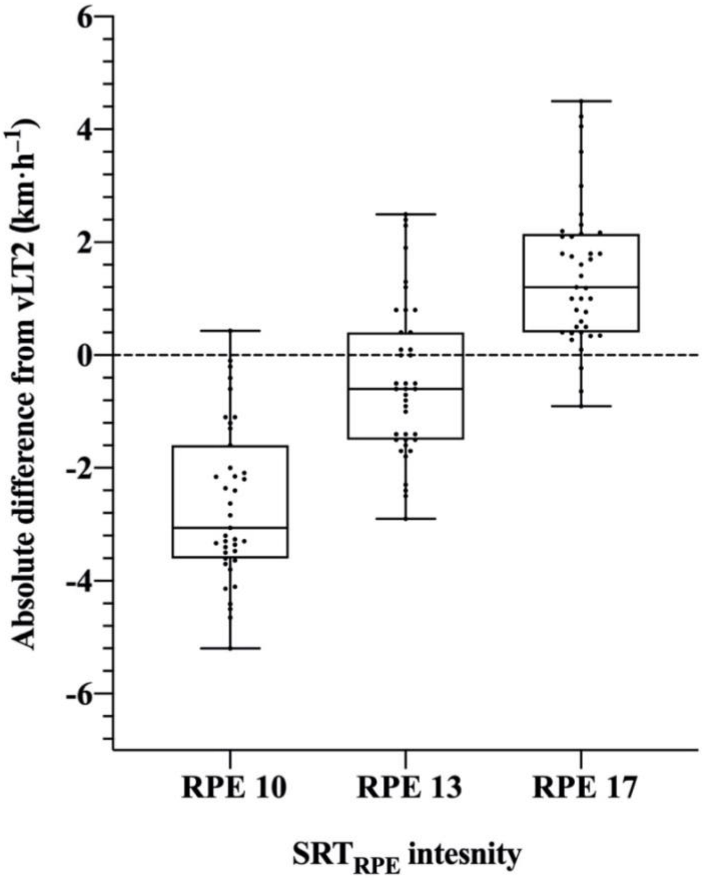


Figure 3. 2 Box-plot for the difference in velocity (v) selected at RPE 10, 13 and 17 and velocity at 4 mmol·L^{-1} B[La] (vLT2). The box defines the upper and lower quartile and the median for the absolute difference in velocity (km·h^{-1}). Whiskers show the minimum and maximum differences.

Concurrent validity of the SRT$_{RPE}$

Table 3.3 displays the inferential validity statistics for v at each stage of the SRT$_{RPE}$ with parameters of the GXT ($\dot{V}O_{2max}$, v$\dot{V}O_{2max}$, and vLT2). For all participants (n = 40), vRPE 17 had the strongest association with parameters of the GXT (*r* range = 0.60 – 0.66, large). SEE (%) were ~8 – 12% for all measures. Table 3.4 displays the inferential validity between %HR$_{max}$ at each SRT$_{RPE}$ stage with GXT parameters. In all cases %HR$_{max}$ shares trivial – small associations to GXT parameters. Figures 3.3, 3.4 and 3.5 display results of regressions analysis between v and GXT parameters for females and males. Results show associations between v at each stage of the SRT$_{RPE}$ and GXT variables to be stronger for females than males.

Table 3. 3 Regression analysis between the velocity measured during self-paced submaximal running test and parameters of the graded exercise test. (n = 40)

	r **(90% CI)**	$\boldsymbol{R^2}$	**SEE raw (90% CI)**	**SEE % (90% CI)**
$\boldsymbol{\dot{V}O_{2max}}$ **(mL·kg^{-1}·min^{-1})**				
RPE 10	0.57 (0.36 – 0.73)	0.33	6.4 (5.4 – 8.0)	12.3 (10.3 – 15.4)
RPE 13	0.56 (0.35 – 0.72)	0.31	6.5 (5.5 – 8.0)	12.4 (10.4 – 15.6)
RPE 17	0.63 (0.44 – 0.77)	0.39	6.1 (5.2 – 7.6)	11.6 (9.7 – 14.6)
$\boldsymbol{v\dot{V}O_{2max}}$ **(km·h^{-1})**				
RPE 10	0.50 (0.27 – 0.67)	0.25	1.5 (1.3 – 1.9)	10.6 (8.9 – 13.2)
RPE 13	0.57 (0.36 – 0.72)	0.32	1.5 (1.2 – 1.8)	10.0 (8.4 – 12.5)
RPE 17	0.66 (0.49 – 0.79)	0.44	1.3 (1.1 – 1.6)	9.0 (7.6 – 11.3)
vLT2 (km·h^{-1})				
RPE 10	0.51 (0.28 – 0.68)	0.26	1.4 (1.2 – 1.7)	11.0 (9.2 – 13.8)
RPE 13	0.57 (0.36 – 0.72)	0.32	1.4 (1.1 – 1.7)	10.5 (8.8 – 13.2)
RPE 17	0.62 (0.43 – 0.76)	0.39	1.3 (1.1 – 1.6)	10.0 (8.3 – 12.5)

Abbreviations: maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and velocity at 4 mmol.L^{-1} (vLT2), v (Velocity) RPE (Rating of perceived exertion) SEE (Standard error of the estimate).

Table 3. 4 Regression analysis between the HR_{max} measured during self-paced submaximal running test and parameters of the graded exercise test. (n = 40)

	r (90% CI)	R^2	SEE raw (90% CI)	SEE % (90% CI)
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})				
RPE 10	-0.07 (-0.37 – 0.25)	0.00	7.6 (6.2 – 9.8)	15.7 (12.7 – 20.8)
RPE 13	0.00 (-0.31 – 0.31)	0.00	7.6 (6.3 – 9.9)	15.8 (12.8 – 20.8)
RPE 17	-0.20 (-0.48 – 0.12)	0.04	7.5 (6.1 – 9.7)	15.5 (12.5 – 20.4)
$v\dot{V}O_{2max}$ (km·h^{-1})				
RPE 10	-0.23 (-0.50 – 0.09)	0.05	1.7 (1.4 – 2.1)	12.1 (9.8 – 16.0)
RPE 13	0.01 (-0.31 – 0.32)	0.00	1.7 (1.4 – 2.2)	12.5 (10.1 – 16.4)
RPE 17	-0.24 (-0.51 – 0.08)	0.06	1.7 (1.4 – 2.1)	12.1 (7.6 – 11.3)
vLT2 (km·h^{-1})				
RPE 10	0.10 (-0.40 – 0.22)	0.01	1.7 (1.4 – 2.2)	13.8 (11.2 – 18.2)
RPE 13	0.03 (-0.28 – 0.34)	0.00	1.7 (1.4 – 2.2)	13.59 (11.3 – 18.3)
RPE 17	-0.18 (-0.47 – 0.14)	0.03	1.7 (1.7 – 2.2)	13.6 (11.1 – 18.0)

Abbreviations: maximal oxygen consumption ($\dot{V}O_{2max}$), velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and velocity at 4mmol.L^{-1} (vLT2), v (Velocity) RPE (Rating of perceived exertion) SEE (Standard error of the estimate).

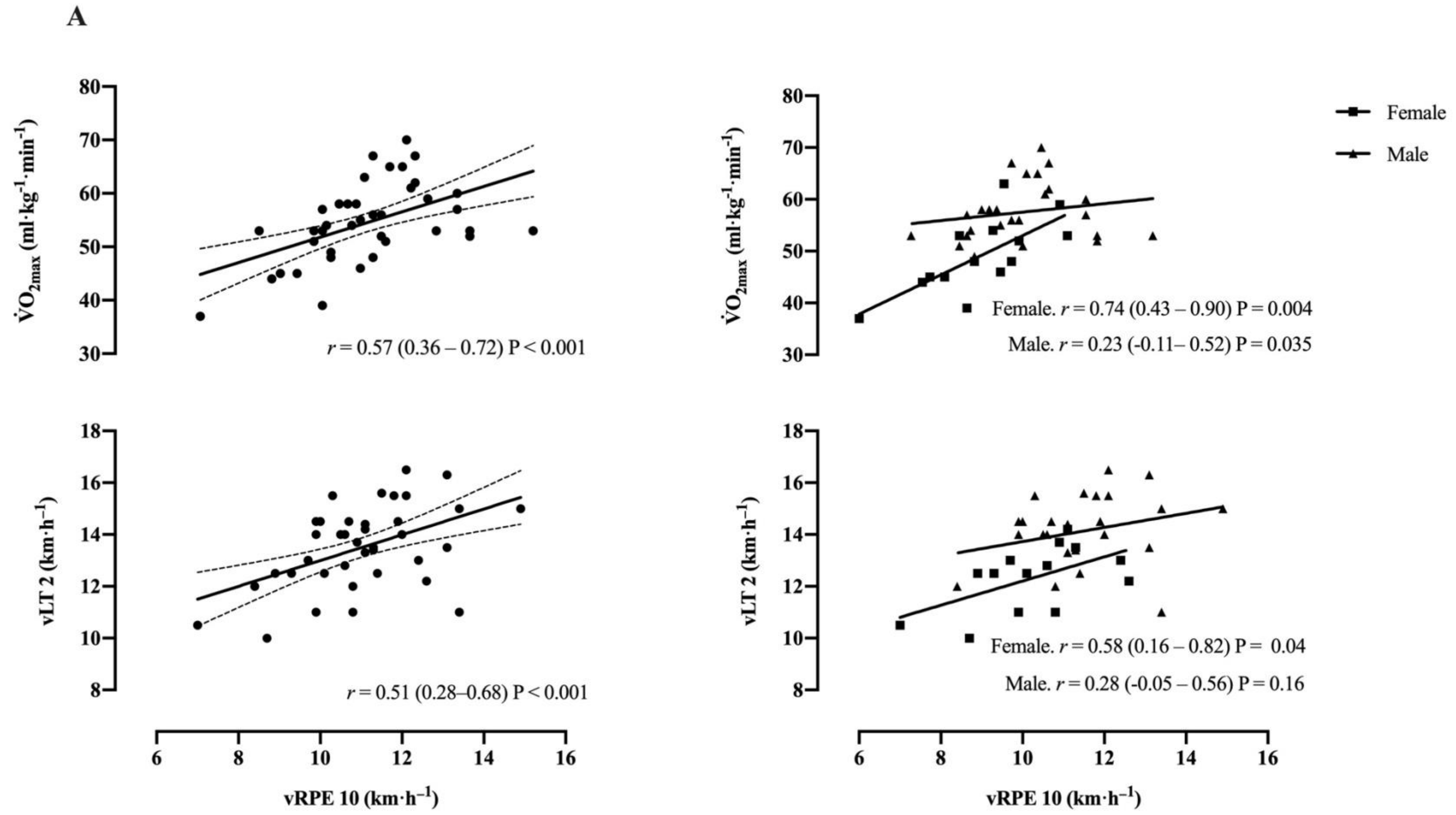


Figure 3. 3 Regression analysis between velocity selected (v) at RPE 10 maximal oxygen capacity ($\dot{V}O_{2max}$) and velocity at 4 mmol·L^{-1} B[La] (vLT2). Group correlations (n = 40) females (n = 14), male (n = 26). Pearson's product moment correlation (r) with 90% confidence intervals

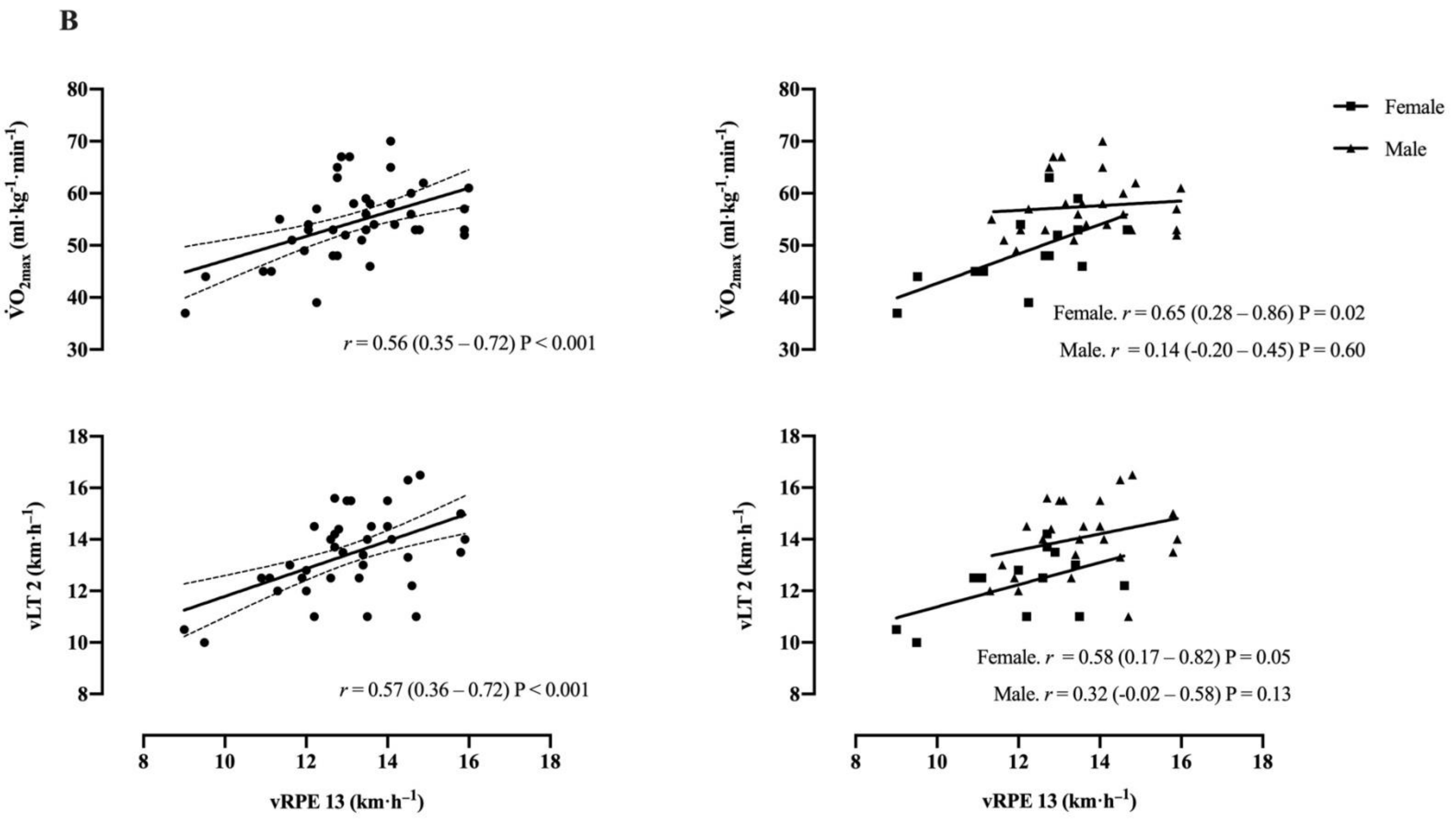


Figure 3. 4 Regression analysis between velocity selected (v) at RPE 13 with maximal oxygen capacity ($\dot{V}O_{2max}$) and velocity at 4 mmol·L^{-1} B[La] (vLT2). Group correlations (n = 40) females (n = 14), male (n = 26). Pearson's product moment correlation (*r*) with 90% confidence intervals

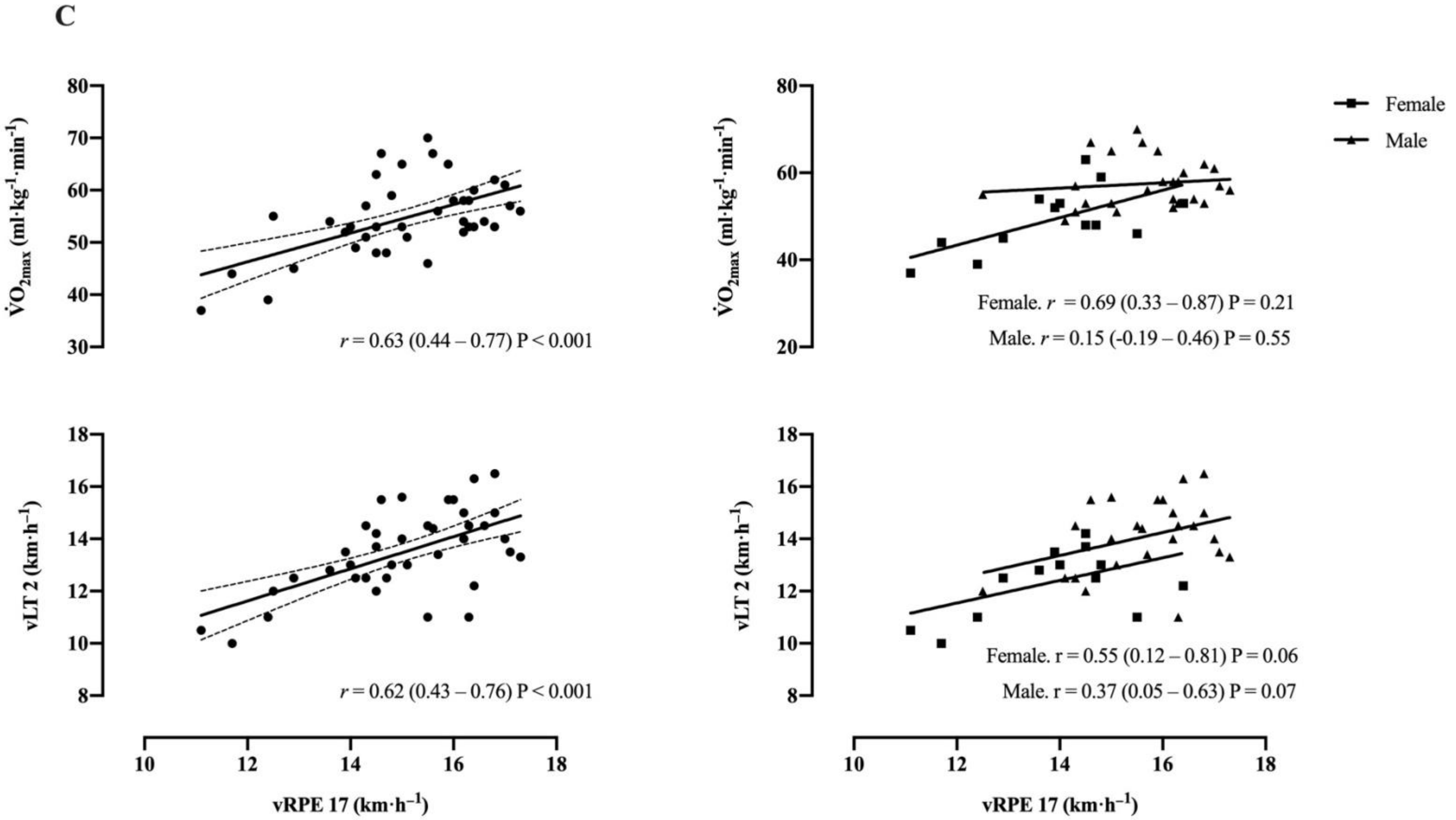


Figure 3. 5 Regression analysis between velocity selected (v) at RPE 17 with maximal oxygen capacity ($\dot{V}O_{2max}$) and velocity at 4 mmol·L^{-1} B[La] (vLT2). Group correlations (n = 40) females (n = 14), male (n = 26). Pearson's product moment correlation (*r*) with 90% confidence intervals

Test-retest reliability of the SRT_{RPE}

Table 3.2 displays the inferential statistics for the test-retest reliability of the SRT_{RPE}. The MET revealed no meaningful changes in v, HR_{ex}, $\%HR_{max}$ and B[La] between trial 1 – 2 (performed on the same day, separated by 30-min passive recovery) and 2 – 3 (> 2-days and within 1-week between each trial) ($P_{MET} > 0.05$). Figure 3.4 illustrates individual values for v in trial 1, 2 and 3 for each SRT_{RPE} intensity.

CV's for v ranged from 3.9% – 5.5%, and from 2.5% – 5.6% for HR_{ex}, with variation consistently lower at greater submaximal intensities. The typical error for $\%HR_{max}$ ranged 2.2% – 4.0%. B[La] displayed the highest CVs' ranging from 24.8 – 28.6%. $ICC_{3.1}$'s were moderate to high for parameters v (range 0.76 – 0.84), HR_{ex} (0.72 – 0.92) and $\%HR_{max}$ (0.64 – 0.89) at all stages of the SRT_{RPE}. B[La] displayed the lowest $ICC_{3.1}$ (0.26 – 0.69).

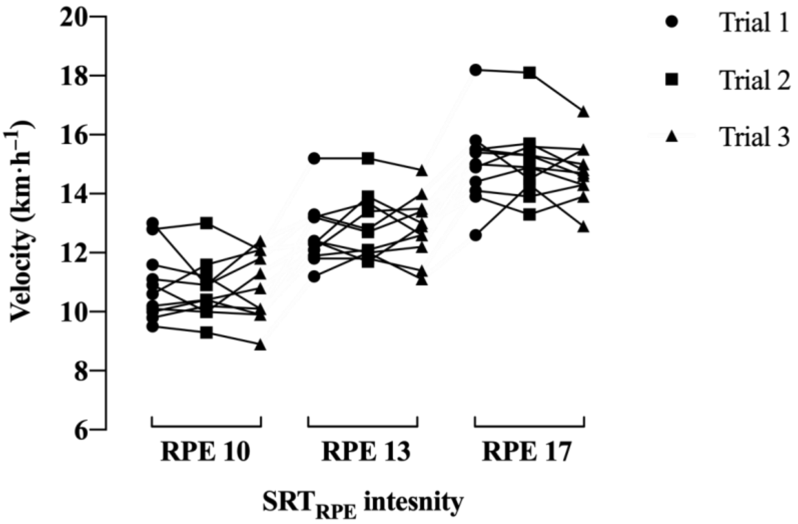


Figure 3. 6 Individual raw values for the velocity at each stage of the SRT_{RPE} over three repeated trials.

3.4 DISCUSSION.

This study sought to assess the construct validity and reliability of parameters of the novel SRT_{RPE}. Results show large association (range $r = 0.50 – 0.66$) between v at each stage of the SRT_{RPE} and parameters of the GTX, suggesting results of the SRT_{RPE} can validly reflect an individuals' level of aerobic fitness. A moderate to high reliability for parameters: v (ICC range, 0.76 – 0.84), HR_{ex} ($ICC_{1,3}$ range, 0.72 – 0.92) and $\%HR_{max}$ (0.64 – 0.89) was measured during self-paced, submaximal efforts.

Of the parameters measured within the GXT, $\dot{V}O_{2max}$ has previously shown to have a very large inverse relationship ($r = -0.91$) between time to complete a 10-mile run (Costill et al 1973) and performance time in marathon running ($r = 0.88$) (Maughan and Leiper 1983). In addition, vLT2 has shown a strong relationship (r range = 0.78 – 0.92) with endurance running performance (3km – marathon) (Farrell et al. 1993; Noakes, Myburgh and Schall 1990; Yoshida et al. 1993). Therefore, these two parameters have been selected for closer analysis (see figure 3.3, 3.4 and 3.5) of their association with SRT_{RPE}.

The v at RPE 10, 13 and 17 showed large associations with $\dot{V}O_{2max}$ ($r = 0.56 – 0.63$) and vLT2 ($r = 0.50 – 0.62$) (Table 2). In comparison, previous authors have described greater associations between LSCT and GXT parameters (Lamberts et al. 2011), which may result from their use of standardised, laboratory conditions. Vesterinen et al (2016) showed the v at intensities 60%, 80% and 90% HR_{max} recorded in outdoor conditions, displayed comparative correlations with $\dot{V}O_{2max}$ (r range = 0.58 – 0.75), yet greater associations with vLT2 (r range = 0.78 – 0.89) than the current study. This discrepancy may result from differing methods of assessments of vLT2 between studies, or disparity in the duration in intervals of the GXT (4-min) and SRT_{RPE} (3-min) analysed in the current study. The current study may be limited by the determination of vLT2 using the fixed criteria of 4 $mmol \cdot L^{-1}$. This methodology has previously been criticised as it does not take into account the large individual variability in the trajectory of a person's lactate accumulation curve. A more appropriate methodology, which may have more validly reflected individuals vLT2 is to use modelling of the inclination of the lactate curve (Keul et al. 1979) or inflection point (Machado et al. 2006), future research should look t rectify this limitation.

The associations of v at RPE 10, 13 and 17 with $\dot{V}O_{2max}$ (r = 0.56 – 0.63) and vLT2 (r = 0.50 – 0.62) would not be considered great enough for the SRT_{RPE} to replace the GXT measures or predict these measures from (Currell and Jeukendrup 2008). However, it is important to state the SRT_{RPE} was not intended for this use or replacing or predicting GXT results. This

9-min, submaximal protocol is intended as a practical, non-exhaustive protocol through which athletes responses to endurance type training could be monitored. As such the analysis of construct validity in the current study shows that individuals responses to the SRT_{RPE} represent the construct of endurance fitness (as tested by the GXT) in a ‘good-enough’ manner, for a test which is far more accessible, time efficient and practical or repeated monitoring in comparison the GXT (Atkinson 2002).

The analysis of the regression error (SEE) shows for example, for a given vRPE 17 the associated $\dot{V}O_{2max}$ may vary by 9.0% (7.6 – 11.3%) and vLT2 by 10.0% (8.3 – 12.5%). The magnitude of this error is greater than previously identified meaningful differences for both $\dot{V}O_{2max}$ (Stratton et al. 2009) and vLT2 (Altmann et al. 2020), suggesting that v measured during the SRT_{RPE} would not accurately predict the treadmill based GXT results.

When separated, female participants displayed greater associations between the independent and dependent variables resulting from lower values of v in SRT_{RPE} and GXT parameters, when compared to males who ‘clustered’ higher on both (figure 3.3, 3.4 and 3.5). These results highlight the potential constraints in generalising overall correlation results to more homogeneous subset (e.g. elite cohorts) (Atkinson and Nevill 1998). In addition, the results provide further evidence that athletes homogenous in $\dot{V}O_{2max}$ show variability in performance v, explaining $\dot{V}O_{2max}$’s smaller associations with endurance performance in such cohorts (Conley, Douglas L. 1980; Alvero-Cruz et al. 2019) and support the preferential use of field-based exercise tests for monitoring (Alvero-Cruz et al. 2019).

The results support previous evidence that RPE 10, 13 and 17 correspond to intensities below, approximately at, or above vLT2 (figure 3.2) (Demello et al. 1987; Seip et al. 1991). Of the 40 participants, only one regulated vRPE 10 above their vLT2 (+0.43 $km{\cdot}h^{-1}$) and 3 participants regulated vRPE 17 below their vLT2 (each -0.90, -0.64 and -0.23 $km{\cdot}h^{-1}$ below vLT2). However, it is evident that the prescription of intensity by RPE 13 still leads to a large range of responses around vLT2 between individuals (0.34 ± 1.52 $km{\cdot}h^{-1}$), and therefore the SRT_{RPE} is still limited in the same way as the LSCT in not being able to directly regulate intensities around this key threshold.

Results displayed in table 3.4 show that in all cases $\%HR_{max}$ shared trivial – small associations with GXT parameters. This implies that regardless of between-participant variation in aerobic fitness (for example $\dot{V}O_{2max}$ range = 44 – 70 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) relative heart rate response ($\%HR_{max}$) at each fixed RPE intensity (RPE 10, 13 and 17) remains stable between-participants. This close relationship between RPE and relative $\%HR_{max}$ has been previously reported in treadmill-based exercise and cycle ergometry (Scherr et al. 2013). These current results approve the method of anchoring intensity by an internal load metric and accredits RPE as a valid and practical alternative to the use of $\%HR_{max}$ to anchor intensity.

Results revealed no meaningful difference for v, $v\dot{V}O_{2max}$, HR_{ex}, $\%HR_{max}$ and B[La] between trials 1 - 2 and 2 - 3 ($P_{MET} > 0.05$) providing no evidence of systematic bias (Atkinson and Nevill 1998). This suggests that 1 familiarisation trial (trial 1) would be sufficient in future studies. In addition, that athletes already had a good appreciation for the pace corresponding to RPE 10,13 and 17 from the graded exercise test, and prior experience, evidenced by a low standard deviation in relative pace (% $v\dot{V}O_{2max}$, and % HR_{max}) in trial 1 (familiarisation), and the ability to replicate these paces in trials 2 and 3. However, the study may be limited in performing two trials (1 - 2) on the same day (Hopkins 2000). Nevertheless, evidence of low variability between trials 1 - 2 suggests that the SRT_{RPE} can reliably be used multiple times within a day which may benefit monitoring of responses to morning and evening training. In addition, low variability between trials 2 - 3 suggest acceptable retention of an understanding of the paces corresponding to RPE 10, 13, and 17 over a number of days (2 – 7 days). The relative reliability of v during SRT_{RPE} is comparable to previous research describing the variability in 2-mins track-based v ($km \cdot h^{-1}$) produced at RPE 10 (6.4% ± 3.1%), RPE 13 (2.9% ± 1.1%) and RPE 17 (2.9% ± 0.8%) (Lim et al. 2016). Together the current results suggest that 3-mins is sufficient in allowing participants to reach and maintain a their target pace (v) based upon the RPE value and knowledge of the end-point of 3-min; minimising the time required for testing compared to similar submaximal protocols (i.e. ~6-mins less versus LSCT).

Field-based maximal exercise tests such as distance fixed time-trials are often preferred for athlete monitoring due to their high ecological validity and reliability (Thorpe et al. 2017; Alvero-Cruz et al. 2019). Previously, the average v for maximal effort 1500m and 5km time-trials have displayed CV’s of 2.0% (95% CI: 1.2 – 4.0%) and 3.3% (95% CI: 2.1 – 6.8%) respectively (Laursen et al. 2007). As such, the within-individual variability of vRPE 17 seen during the current study is comparable (CV = 3.9%, 90% CI: 3.0 – 5.7%). This provides evidence that the SRT_{RPE}, which provides a more time-efficient and less physically demanding alternative to maximal performance tests, is also comparable in sensitivity.

The potential sensitivity of the SRT_{RPE} can be explored by comparing the magnitude of measurement error in the test (noise) to prior reported meaningful changes in these parameters (signal) (Atkinson and Nevill 1998; Hopkins 2000). Previous literature, assessing a comparable cohort, reported 5.1% improvement in average v over 5000m, on an outdoor track following 6-weeks of endurance training. Treadmill based submaximal v (vLT2) has similarly been shown to vary by 4.4 – 6.3% following 6-week's training (Carter, Jones and Doust 1999; Stratton et al. 2009). This magnitude of expected change (signal) is greater than the CV (noise) for v at all stages of the $SRT_{RPE,}$ suggesting an acceptable sensitivity of the test.

The utility of HR_{ex} to sensitively monitor aerobic fitness has been debated due to its sensitivity to confounding variables outside of training stress (Achten and Jeukendrup 2003). Previous research has shown a day-to-day variation in HR_{ex} of 6 – 8 $beats·min^{-1}$ at intensities 60 – 80% maximal and 3 – 5 $beats·min^{-1}$ at intensities 80 – 90% of maximal (Lamberts et al. 2004). This is comparable to the random error found in the current study (table 3.2). Additionally, previous research reported a comparable magnitude of variability (CV range = 2.3 – 7.0%) in % HR_{max} during self-paced combined arm and leg cycling at RPE 9, 13 and 17 (Hill et al. 2020). The variability shown in the current study should be accounted for when determining true-change in this parameter.

The measurement error was greatest for B[La] with a CV range of 24.8 – 28.6%. This high magnitude of variation has similarly been reported between repeated 1000m efforts at RPE 17 (CV = 16.8%) (Edwards et al. 2011). These results suggest that B[La] during the SRT_{RPE} may be too unreliable for monitoring purposes. In addition, the B[La] values were lower at each stage on the SRTRPE than would have been expected. For example despite most participants reaching a v equivalent to vLT2 at stage 2 (measured at 4 $mmol.L^{-1}$ during treadmill running) , B[La] was 2.0 ± 0.6 $mmol.L^{-1}$. This may be the result of lactate not having enough time to efflux from the working muscle and appear within the capillary blood over the 3-min, submaximal interval. Commonly, intervals of 5-min or greater are recommended for the measurement of appearance of B[La] within finger-tip capillaries (Bonaventura et al. 2015), as such it could be concluded that the measurement of capillary B[La] during the SRT_{RPE}, is not an accurate representation of the metabolic demand of the interval and should not be used for this analysis.

Future research aiming to monitor individual's responses using the SRT_{RPE} should be cautious that results may be influenced by environmental conditions and reliability of the

GPS and HR_{ex} monitors used. It would be advised to complete a separate reliability analysis if conditions or equipment vary from those used in the current study.

In conclusion, the SRT_{RPE} showed large associations with parameters of the GXT, providing evidence of an ability to discriminate between individuals of varying aerobic fitness. This is an important start in exploring the utility of the SRT_{RPE} as a monitoring tool, however future studies must confirm the sensitivity of the SRT_{RPE} to track fluctuations of fitness within an individual. Low TE/CV's for v selected at each RPE anchored intensity, suggest that true individual changes can be detected with reasonable accuracy. Future research should use the test errors displayed in the current results to set a range inside of which the true value likely lies. This will be important in accounting for this component of variance when assessing the magnitude of change in an individual's responses (Atkinson, Williamson and Batterham 2019).

Chapter 4. The utility of the Self-Paced Submaximal Run Test to monitor individual responses to training.

4.0 ABSRACT

Purpose. To assess the utility of the self-paced submaximal run test (SRT_{RPE}) to monitor individuals' responses to training by comparing within-participant changes in SRT_{RPE} and time trial performance over a 16-week observation period.

Methods. Nine competitive endurance runners (4 male, 5 female) completed their normal training over a 16-week observation period. At baseline and following 4, 8, 12 and 16 weeks of training participants performed the SRT_{RPE} as a warm-up prior to a 12-min time trial (12minTT) on a track. The SRT_{RPE} monitored running velocity (v) during three, 3-min stages prescribed by Ratings of Perceived Exertion (RPE) 10, 13 and 17. Repeated measures correlations and linear mixed effects models were used to assess the between- and within-participant associations of SRT_{RPE} and 12minTT over the 16-week period.

Results. The between- and within-participant associations for v at each stage of the SRT_{RPE} with v12minTT were very large (*r* range = 0.70 – 0.78) and moderate to large (*r* = 0.32 – 0.57), respectively. vRPE 17 showed the largest between-participant association (*r* = 0.78 [90% confidence interval: 0.35 to 0.94]) while vRPE 13 showed the largest within-participant association with v12minTT (*r* = 0.57 [0.31 to 0.75]). A meaningful change in v12minTT (0.6%) was associated with a 0.26, 0.14 and 0.18 $km \cdot h^{-1}$ change in v at RPE 10, 13 and 17 respectively.

Conclusion. Moderate to large within-participant associations with v12minTT, infer the $SRT_{RPE's}$ ability to track endurance performance changes within individuals. Monitoring vRPE 13 may be most insightful for monitoring the threshold of meaningful change as 0.14 (-1.65 – 1.93 $km \cdot h^{-1}$).

4.1 INTRODUCTION

The primary aim of training prescription is to structure the appropriate balance of training factors (stress and recovery) to optimise the stimulus for adaptation and mitigate the negative consequences of under-recovery (Cunanan et al. 2018). However, acute responses to training factors are highly variable; both between and within-participants (Bouchard and Rankinen 2001; Hecksteden et al. 2015; Williamson, Atkinson and Batterham 2017), making the trajectory of adaptations complex to predict. Therefore, frequently and objectively monitoring an individual's responses to training and recovery are considered an important component in guiding the ongoing revision of programmed training.

Following a period of training, the objective assessment of endurance performance is most commonly completed through distance/duration limited time trials and/or time to exhaustion trials (Currell and Jeukendrup 2008). However, as discussed in Chapter 2 the maximal nature of such testing could be considered too fatiguing to be regularly completed with athletes for monitoring purposes. The SRT_{RPE} was developed as a practical and less demanding alternative, built upon previous evidence that shifts in the triangulated relationship between external load measures (velocity/power output) and internal intensity reflected by psycho-physiological measures (Heart Rate [HR_{ex}] and Rating of Perceived Exertion [RPE]) (Lamberts et al. 2011; Vesterinen, Nummela, Äyrämö, et al. 2016) can infer a state of fitness and fatigue.

Chapter 3 assessed the validity and reliability of the novel SRT_{RPE}. Results showed a moderate to large correlation between velocity (v) selected during the three stages of the SRT_{RPE} (intensity prescribed by RPE 10, 13 and 17) and maximal oxygen consumption ($\dot{V}O_{2max}$) (Range $r = 0.57 – 0.63$), v at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) ($r = 0.50 – 0.66$) and 4 $mmol.L^{-1}$ B[La] (vLT2) ($r = 0.51 – 62$). This suggests that v during the SRT_{RPE} was related to the construct of endurance fitness. Importantly for monitoring purposes, results showed an acceptable test-retest reliability for v monitored at RPE 10, ($CV_{TEM\%}$ = 5.5% [90%CI; 4.3 – 8.1%]), RPE 13 ($CV_{TEM\%}$ = 4.5% [3.5 – 6.6%]), and the lowest variability at RPE 17 ($CV_{TEM\%}$ =3.9% [3.5 – 6.6%]). The exploration of the short-term reliability of the SRT_{RPE}, allowed for the speculation of the ability of the test to detect longitudinal changes in performance; by examining the signal (expected responses) to noise (measurement error) ratio (Hopkins et al. 2009) (section 3.4). However, in order to directly assess the sensitivity of performance in the SRT_{RPE} to within-participant responses to endurance training, longitudinal analysis using repeated measures is required.

Previous research exploring the ability of the Lamberts Submaximal Cycle Test (LSCT) (Lamberts et al 2011) and Lamberts Submaximal Run Test (LSRT) (Vesterinen, Nummela, Äyrämö, et al. 2016) (See Chapter 2) to track responses to training showed that an increase in the external load performed to reach the same submaximal internal intensity (%HR_{max}) was representative of a positive adaptation to time trial performance (Lamberts et al. 2010) and associated with a positive change in aerobic fitness (Vesterinen et al. 2016) following endurance training. However, the current understanding of the utility of submaximal tests to monitor individuals' adaptations to training is limited by only evaluating data from single case studies (Lamberts et al. 2010), or analysis which utilises between-participant correlations in pairs of change scores (pre-post a training intervention), which uses a between-participant model (Vesterinen et al. 2016). In order to fully understand how responses to submaximal tests can be utilised to monitor and predict within-participant change in competitive endurance performance, a regression analyses between multiple data points for each individual collected over a longitudinal period is required.

This study aims to assess the utility of the SRT_{RPE} to track individual responses to endurance training by assessing associations between SRT_{RPE} and 12minTT over a 16-week observation period. The 12minTT has been selected as it will provide a direct measure of running performance, as appose to the treadmill based GXT in Chapter 3. In addition, the 12minTT test will be performed in an outdoor setting which should reduce the limitations seen in Chapter 3 in comparing performance and physiological responses to running on a track versus treadmill. The 12minTT has also shown large correlations (r = 0.90) with treadmill assessed $\dot{V}O_{2max}$, making is a useful proximal measure of this determinant of endurance fitness (Cooper 1968). The current study will assess both the between- and within-participant associations between SRT_{RPE} and 12minTT by using repeated measures correlations and linear mixed effects models to extend our knowledge of the longitudinal validity of the SRT_{RPE} (between-participant analysis) and its ability to track individuals responses to training (within-participant analysis).

4.2 METHODS

Study population

Nine competitive endurance runners: 4 male (age: 34 ± 9 y; $\dot{V}O_{2max}$ 59.3 ± 3.7 $mL\cdot kg^{-1}\cdot min^{-1}$, 5 female (age 39 ± 3 y; $\dot{V}O_{2max}$ 50 ± 5.7 $mL\cdot kg^{-1}\cdot min^{-1}$), participated in the study. All participants had over 2 years' experience of completing running-based endurance training (> 30km per week), with at least one-year competitive experience. All participants gave informed written consent, completed a health questionnaire and confirmed that they had been free from injury in the previous 6 months. Ethical approval was obtained from the School of Sport and Exercise Science Research Ethics Advisory Group (Approval number: Prop 71_2017_18).

Study design

On their first visit, participants completed a treadmill based maximal exercise test (see maximal incremental run test) to assess maximal oxygen uptake ($\dot{V}O_{2max}$). On their second visit, participants completed two familiarisation trials of the SRT_{RPE} on a synthetic running track, separated by 30-min passive recovery. Visit 3 was completed within 72-hours of visit 2 and served as a baseline testing session in which participants completed the SRT_{RPE} as a warm-up, prior to completion of a 12minTT (see: Twelve minute time trial). Visit 3 marked the commencement of the 16-week observational period during which participants continued with their normal training. Within the 16-weeks, participants returned every 4-weeks to repeat the same assessment of SRT_{RPE} and 12minTT performance described in visit 3.

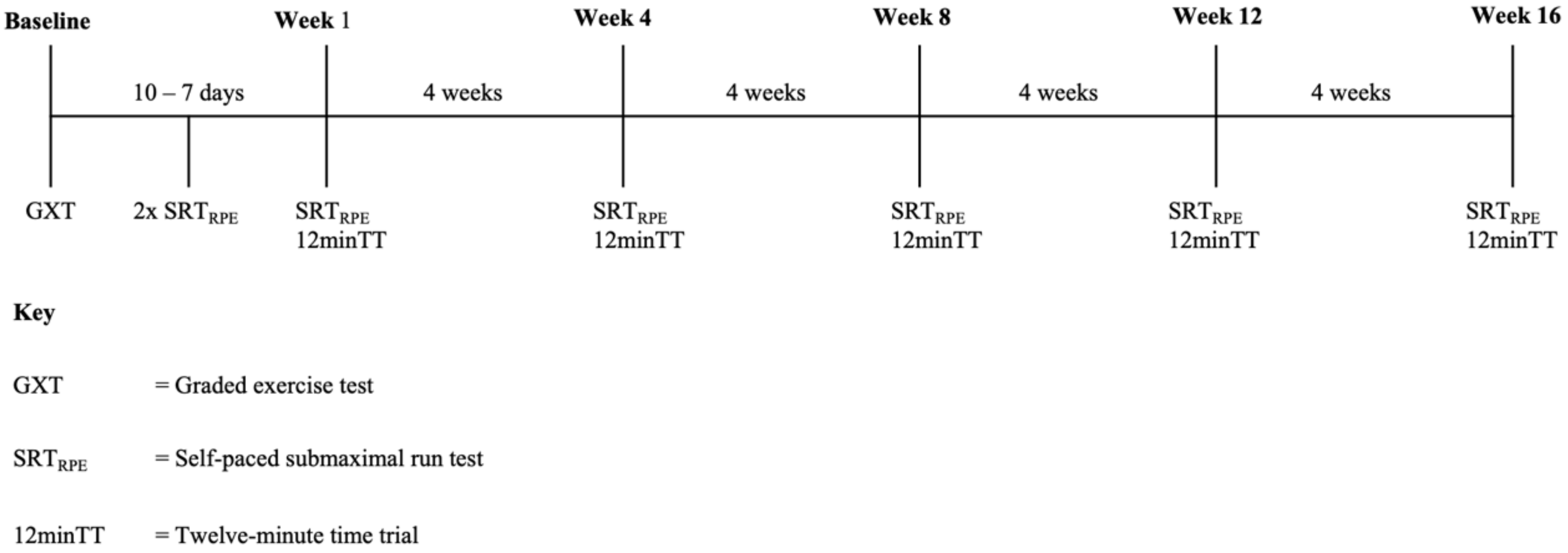


Figure 4. 1 Study Schematic

Two Phase Graded Exercise Test (GXT)

Participants undertook a two-phase GXT for the assessment of individual blood lactate (B[La]) profile and $\dot{V}O_{2max}$. The GXT was conducted as detailed in Chapter 2. In brief, Phase-one assessed B[La] profile and was comprised of 5 – 7 submaximal exercise bouts with v increasing by 1 $km \cdot h^{-1}$ every 4-min, until capillary B[La] concentration exceeded 4 $mmol \cdot L^{-1}$. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase-one and increased by 0.5 $km \cdot h^{-1}$ every minute until volitional exhaustion. Participants v at the first and second lactate thresholds (vLT1, vLT2), $\dot{V}O_{2max}$ and v at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) were calculated as described in Chapter 2.1.3.

The Self-paced Submaximal Run Test (SRT_{RPE})

The SRT_{RPE} was performed as specified in Chapter 2. In brief, participants completed three, 3-min stages interspersed by 1-min recovery with submaximal exercise intensity prescribed by RPE 10, RPE 13 and RPE 17. During the 1-min recovery between stages, a 5 µL sample of whole fresh blood was collected from the fingertip and subsequently analysed for B[La] concentration. Participant v was recorded using the Polar V800 GPS watch (1 Hz sampling rate) and HR_{ex} using a Polar H10 heart rate monitor (sampling rate of 1Hz). In calculating average v and HR_{ex} at each stage, the first 120-s of v and HR_{ex} data was excluded to ensure a the target RPE pace had been reached (see Chapter 2 for more detail). Following familiarisation (visit 2) participants completed the SRT_{RPE} as a warm-up at visits 3 (week 1 of observation) and further visits marking week 4, 8, 12 and 16 of the observation period. Mean outdoor testing conditions were: Windspeed 1.2 m/s (range = 0.4 m/s–1.8 m/s), temperature 11.5 ºC (range = 4ºC – 18ºC)

12 min time trial (12min TT)

Participants completed the 12minTT on five occasions separated by approximately 4-weeks. The SRT_{RPE}, followed by 5-min self-selected stretching, was used as a standardised warm up, prior to each 12minTT. Participants were instructed to cover the greatest distance and maintain the highest v possible during the 12minTT. Either an end RPE ≥ 17; and B[La] concentration ≥ 8 $mmol \cdot L^{-1}$ was used to confirm a maximal effort was provided.

v ($km \cdot h^{-1}$) and HR_{ex} ($beats \cdot min^{-1}$) were recorded using a Bluetooth chest strap and wristwatch GPS monitor (1 Hz sampling rate). Participants were blinded to their v and the time elapsed using a sweat-band or sleeve to cover the watch face, a whistle was blown to signify the end of the time trial. Average v (v12minTT) was calculated using the average of the second by second, recordings with exclusion of the first 120-s to reduce the confounding influence of a fast start (Tomazini et al. 2015)

Training load

All participants were instructed to record both v and HR_{ex} using a Bluetooth chest strap and wrist-watch GPS monitor (1 Hz sampling rate) during all running sessions and provide a session RPE (Herman et al. 2006) using Borg's category ratio 10-point (CR10) scale (Borg 1998) approximately 30-min following the completion of every training session, over the 16-week observational period. Due to a large number of missing HR_{ex} data session-RPE was used to calculate training loads (sRPE-TL) using the following equation:

$$t \times \mathrm{sRPE}_{10}$$

Where ***t* =** Session duration (time, minutes) and **sRPE_{10}** = Session rating of perceived exertion from the CR10 Scale (deciMax units).

Statistical analysis

Data are expressed as mean ± SD for all parametric data (v during SRT_{RPE} and v12minTT), while nonparametric data (sRPE-TL) were expressed as median (interquartile ranges). Assumptions of statistical tests such as the normal distribution, equality of variance and sphericity of data were checked using the Shapiro-Wilk, Levene's and Mauchly's tests respectively. Where the assumption of sphericity was violated the Greenhouse-Geiser adjustment was applied to the degrees of freedom. Where appropriate, post-hoc tests using the Bonferroni correction were applied. A one-way analysis of variance (ANOVA) with repeated measures (RM) was used to compare sRPE-TL, v12minTT and $vSRT_{RPE}$ over the 5 time points (week 1, 4, 8, 12 and 16). The statistical significance level was set to $P < 0.05$. Analysis was performed with IBM SPSS Statistics v.26 -programs (SPSS Inc, Chicago, IL, USA).

Between- and within-participant relationships between $vSTR_{RPE}$ and v12minTT were assessed according to Bland and Altman (Bland and Altman 1995b; Bland and Altman 1995a) using Statistical Analysis System (SAS$^{®}$) software (University Edition, SAS Institute Inc., Cary, NC, USA). First, the five $vSRT_{RPE}$ and v12minTT performances were averaged for each athlete. These means were then assessed via a bivariate correlation (PROC CORR) (Bland and Altman 1995b). Next, a general linear model (ANCOVA, PROC GLM) was used to assess overall within-participant correlations. v12minTT was specified as the depended variable and $vSRT_{RPE}$ stages were separately regressed as continuous covariates. Participant

ID was then added as a categorical factor with unequal slopes and intercepts. The overall within-participant correlation and corresponding confidence intervals were then calculated as per Bland and Altman method (Bland and Altman 1995a; Altman and Bland 2011) using the model sum of squares. The strength of correlations were determined using the following criteria: trivial (<0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9), almost perfect (0.9 – 1.0) (Batterham and Hopkins 2006)

To further describe the within-participant associations between $vSTR_{RPE}$ and v12minTT, a linear mixed effects models (PROC MIXED) was used to determine the change in v12minTT associated with a 1 $km \cdot h^{-1}$ change in $vSTR_{RPE}$ at each stage. Models were performed on both the raw and natural log-transformed v12minTT data, to express statistics in $km \cdot h^{-1}$ and percentages. $vSRT_{RPE}$ was centred around the group mean before being entered in the model as described above. A random slope and random intercept were specified with an unstructured covariance matrix. Subsequent outcomes were the slope fixed effect, with degrees of freedom given by the Satterthwaite method, and the associated residual error, representing the standard (typical) error of the association.

Finally, the fixed slope values were converted to represent the magnitude of change in $vSRT_{RPE}$ associated with the aforementioned SWC in v12minTT (0.6%). This was also performed for additional threshold representing moderate (race-to-race CV [2%] × 0.9 = 1.8%), large (2% × 1.6 = 3.2%), very large (2% × 2.5 = 5%) and extremely large (2% × 4.0 = 8%) performance changes (Hopkins et al. 2009). Each predicted value was presented with 90% prediction interval, given by multiplying the prediction error by the appropriate value from the t distribution with the model degrees of freedom. The prediction error was calculated using the following equation (Goose-Tolfrey et al. 2020)

$$\text{Prediction error} = \sqrt{}(2 \cdot TE^2 + (\Delta v \cdot SE_{slope})$$

Where, TE = the within-participant typical error of the estimate (the square root of the model residual), Δv = the magnitude of change in $vSRT_{RPE}$, and SE_{slope} = the standard error of the fixed slope for $vSRT_{RPE}$ the given RPE intensity.

4.3 RESULTS

Figure 4.2 displays the group median and interquartile ranges for 4-week training load (sRPE) between each testing session. A one-way ANOVA with RM showed no significant difference in summated sRPE-TL over time each 4-week training period, $F_{3,24} = 1.55$, $P = 0.228$. One-way ANOVA with RM showed no significance difference in v12minTT over time; $F_{4,32} = 2.57$, $P = 0.057$, and no significant difference in v at each stage of the $\mathrm{SRT}_{\mathrm{RPE}}$ over time ($P > 0.05$).

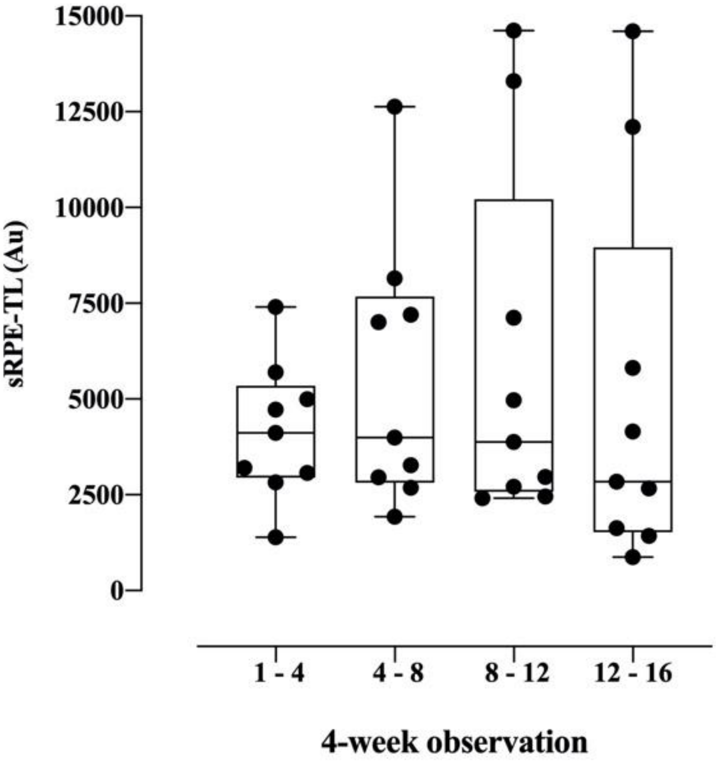


Figure 4. 2 Box-plot for summated 4-week training load (sRPE-TL). The box defines the upper and lower quartile and the median for the group summated 4-week sRPE-TL (Au) data points represent individual participants summated 4-week sRPE-TL (Au)

Between-participant associations for vSRT$_{\text{RPE}}$ and v12minTT are presented in figure 4.4. The magnitudes of correlations were very large for vRPE 10 (*r* = 0.70, [90% Confidence intervals; 0.19 – 0.91]) and vRPE 13 (*r* = 0.74, [0.28 – 0.93]) with the strongest association of v12minTT being with vRPE 17 (*r* = 0.78, [0.35 – 0.94]).

The within-participant associations between v12minTT and vSTR$_{\text{RPE}}$ stages is depicted in figure 4.5. The magnitude of correlations with v12minTT were moderate for vRPE 10 (*r* = 0.32, [90% CI 0.00 – 0.57]) and vRPE 17 (*r* = 0.41, [0.11 – 0.64]), and large for vRPE 13 (*r* = 0.57, [0.31 – 0.75]) (see figure 4.6 and table 4.1). The corresponding slopes representing the change in v12minTT associated with a 1 km·h^{-1} change in vRPE ranged from 2.3 – 4.2%, with typical (standard) errors of the estimate being ~3% (table 4.1).

Changes in vSRT$_{\text{RPE}}$ associated with the chance of an athlete improving their v12minTT by a small, moderate, large, very large and extremely large magnitude are displayed in figures (figures to come). The model calculated the 90% prediction limits for the estimated meaningful change in v12minTT (0.6%) as (-6.3 – 7.5%). From this the mean change (prediction limits) in v at each stage of the SRT$_{\text{RPE}}$ associated with a 0.6% (-6.3 – 7.5%) change in v12minTT was calculated as: vRPE 10 = 0.26 km·h^{-1} (-2.97 – 3.49 km·h^{-1}), vRPE 13 = 0.14 km·h^{-1} (-1.65 – 1.93 km·h^{-1}), v RPE 17 = 0.18 km·h^{-1} (-2.02 – 2.38 km·h^{-1}).

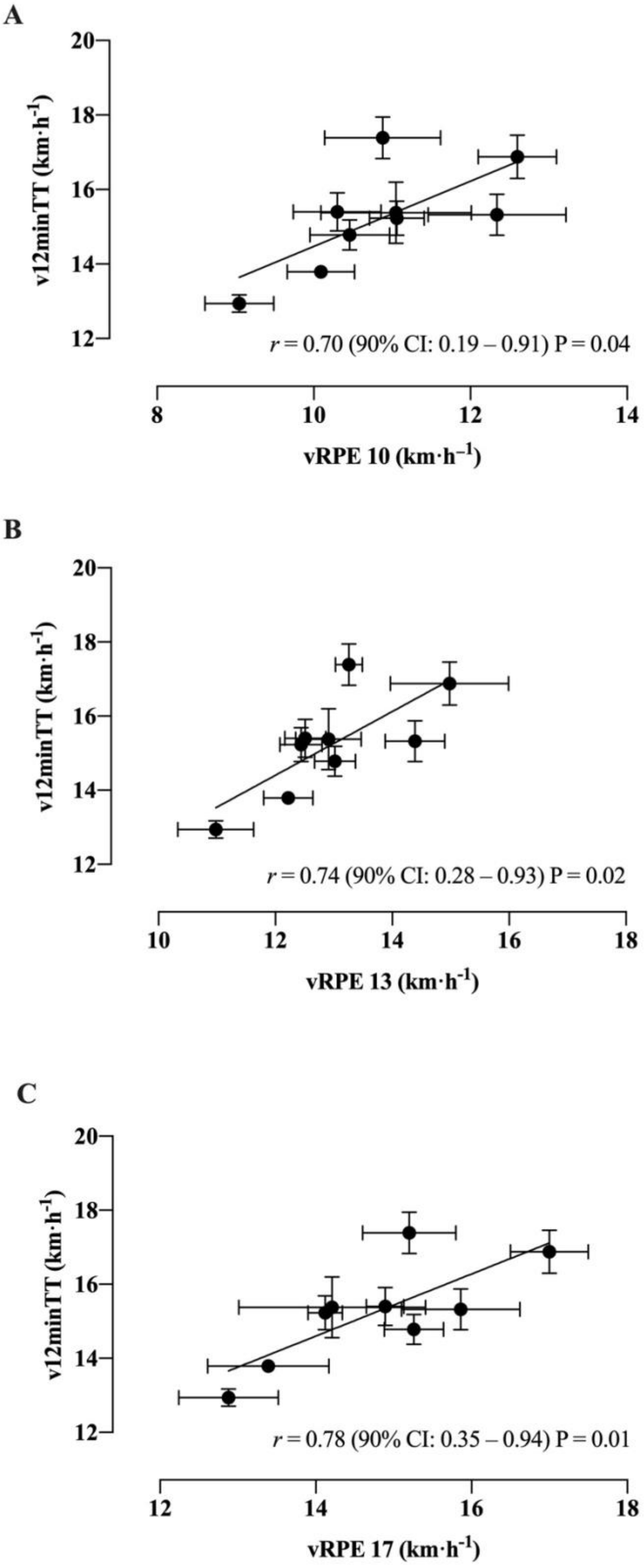


Figure 4. 3 Between-participant relationships for v at (A) RPE 10, (B) RPE 13, (C) RPE 17 of the SRT_{RPE} and v12minTT. Data points represent participant mean v ± SD from 5 repeated pairs of data over a 16-week observation period.

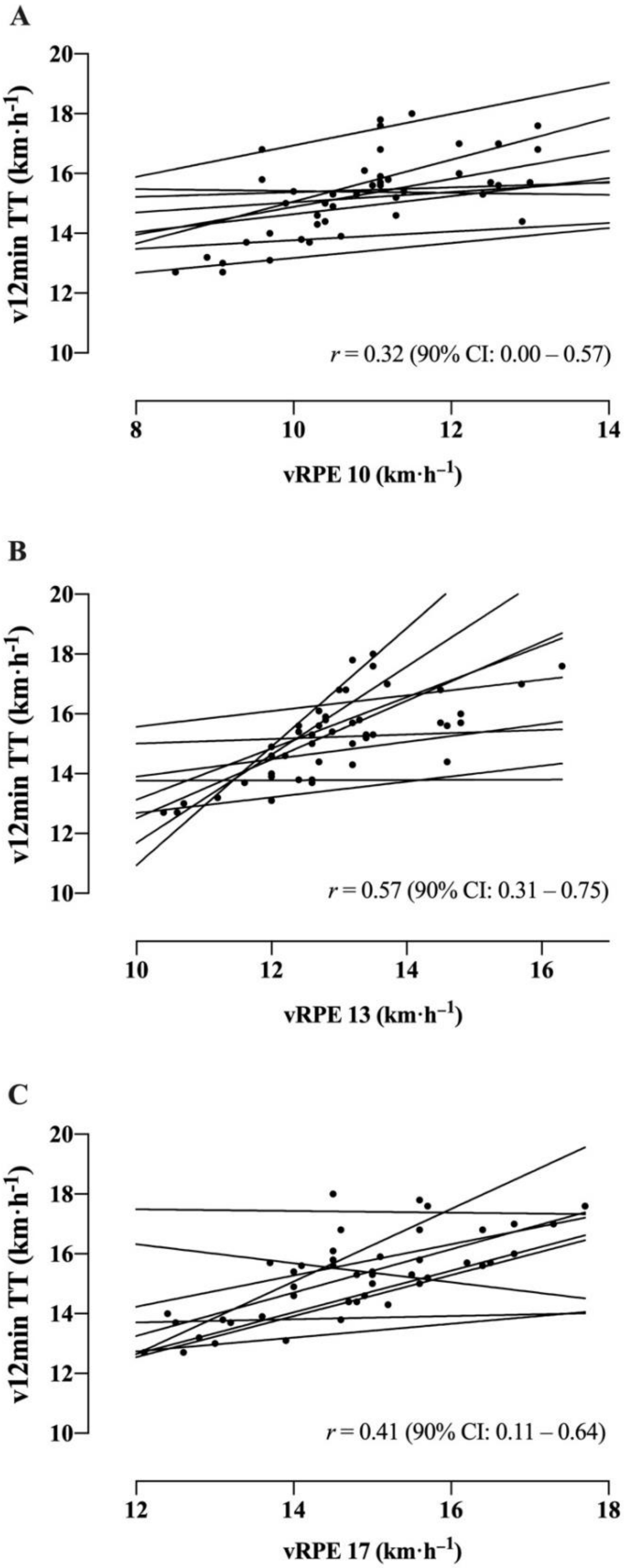


Figure 4. 4 Within-participant relationships for v at (A) RPE 10, (B) RPE 13, (C) RPE 17 of $\mathrm{SRT}_{\mathrm{RPE}}$ and v12minTT over 5 time points. Each line represents the regression line (random slope, random intercept) between 5 data points (black circles) from each individual participant

Table 4. 1 Within participant associations between v during self-paced, submaximal run test and v 12minTT over a 16 week observational period. (n=9)

	Within-participant association with 12minTT mean velocity (90% CI)					
	***r*[a]**	**Intercept[b]**	**Slope[c]**		**Typical error**	
			km·h^{-1}	**%**	**km·h^{-1}**	**%**
vRPE 10	0.32 (0.00 – 0.57)	15.18 ±1.19 (14.38–15.97)	0.35 (0.15 – 0.55)	2.34 (1.01 – 3.69)	0.47 (0.40 – 0.59)	3.13 (2.62 – 3.93)
vRPE 13	0.57 (0.31– 0.75)	15.19 ±1.02 (14.52 – 15.85)	0.65 (0.26 – 1.03)	4.23 (1.80 – 6.71)	0.44 (0.36 – 0.55)	2.86 (2.36 – 3.66)
vRPE 17	0.41 (0.11 – 0.64)	15.29 ±0.96 (14.49 – 15.90)	0.49 (0.32 – 0.66)	3.43 (2.30 – 4.58)	0.44 (0.37 – 0.55)	2.88 (2.38 – -3.69)

Abbreviations: v (Velocity) RPE (Rating of Perceived Exertion) 12minTT (Twelve minute time trial)

[a] mean centred: Within-participant correlation via the Bland and Altman method (90% CI).

[b] mean centred: v12minTT (km·h^{-1}) associated with vRPE 10 = [10.9 km·h^{-1}], vRPE 13 = [13.0 km·h^{-1}], vRPE 17 = [14.8 km·h^{-1}].

[c] change in v12minTT associated with a 1 km·h^{-1} change in vRPE

4.4 DISCUSSION

The main finding of the current study was a large within-participant association between vRPE13 and v12minTT (*r* = 0.57, [90% CI; 0.31 – 0.75]), with a mean estimated (prediction limits) change in v of 0.14 km·h^{-1} (-1.65 – 1.93 km·h^{-1}), being associated with a meaningful change in v12minTT (0.6%). A further novel result was the very large between-participant associations between vSRT$_{RPE}$ and v12minTT (*r* range = 0.70 – 0.78) when assessed over a longitudinal (16-week) period.

The between-participant associations between vSRT$_{RPE}$ and v12minTT using the Bland and Altman (Bland and Altman 1994) method for the correlation of repeated measures are displayed in figure 4.3. The results showed a large to very large positive correlation between v12minTT and vSRT$_{RPE}$ (*r* range = 0.70 – 0.78) throughout the 16-week period. This longitudinal assessment of validity makes a novel contribution to the literature, where previously validity between maximal and submaximal tests is assessed from a single ‘one-shot’ measurement (Vesterinen, Nummela, Äyrämö, et al. 2016). This analysis also extends the findings of Chapter 3, showing that the longitudinal associations between SRT$_{RPE}$ and 12minTT are greater than those between the SRT$_{RPE}$ and GXT taken at a single time point. This provides evidence that the SRT$_{RPE}$ may be more closely associated with outdoor running performance (12minTT) than treadmill-based assessments of endurance ability (GXT). In particular, the results of the current study show that between-participants, self-selected pace at vRPE 17 was the best determinant endurance performance capability (12minTT) over a longitudinal period.

Primarily, the present study sought to address the limitations of previous literature (Lamberts et al. 2010; Vesterinen et al. 2016) by specifically assessing the utility of the SRT$_{RPE}$; a submaximal exercise test, in monitoring within-participant responses to training over time (figure 4.4). To do so, within-participant modelling was used to appropriately handle the repeated measures of vSRT$_{RPE}$ and v12minTT performance. To our knowledge, this is the first study to take such an approach for the examination of submaximal vs maximal performance within endurance runners. The results demonstrated that vRPE 13 had the highest association with v12minTT (*r* = 0.57, [0.31 – 0.75]), determining that v at intensity of RPE 13 is the most sensitive index to track within-participant changes in v12min TT over the 16-week period (figure 4.4 B).

In order to further assess the within-participant relationships, a linear mixed model was used which allowed the relationship between vSRT$_{RPE}$ and v12minTT for each individual to be accounted for. This model was subsequently used to estimate the mean change in vSRT$_{RPE}$ associated with the estimated meaningful change in v12minTT. The model predicted that a meaningful change in v12minTT (0.6%) would be associated with a mean change (prediction limits) in vRPE 10 = 0.26 km·h^{-1} (-2.97 – 3.49 km·h^{-1}), vRPE 13 = 0.14 km·h^{-1} (-1.65 – 1.93 km·h^{-1}), v RPE 17 = 0.18 km·h^{-1} (-2.02 – 2.38 km·h^{-1}), which can subsequently be used to as thresholds for meaningful changes in each variable, within-individuals. An alternative, more frequently used calculation of meaningful change, is to use 0.2 x standard deviation, which would have resulted in predictions of: vRPE 10 = 0.22 km·h^{-1}, vRPE 13 = 0.20 km·h^{-1} and vRPE 17 = 0.21 km·h^{-1}. This, in comparison to the results of the current model, estimates larger threshold values for vRPE 13 and vRPE 17, which highlights how this calculation (0.2 x SD) does not account for the greater association that higher submaximal intensities will inevitably have with maximal time trial performance.

The results of the current study may be limited by not including a familiarisation trial for the 12minTT. This may have resulted in time trial performances being influenced by a learning-effect which may have clouded the variance in performance due to training effects alone. This would have reduced the associations between the SRT$_{RPE}$ and 12minTT performance, if changes in 12minTT performance were disproportionately improved as a result of a learning effect. Results are also limited by a small sample size that is homogenous in nature, and thus the extrapolation of the findings to different populations of athletes should be done with caution. Future research should look to assess the effect of manipulating training factors (intensity, duration, recovery) on SRT$_{RPE}$ performance; using the model predicted meaningful changes in vRPE and typical errors defined in Chapter 1 to assess the sensitivity of the SRT$_{RPE}$ to manipulated training. In addition, future research should seek to assess the within-individual association between SRT$_{RPE}$ and other endurance performance measures, which extend beyond a duration of 12-min.

Conclusions

Within-participants, individual responses to the SRT$_{RPE}$ measured over a 16-week observation, showed a moderate to large association with endurance performance (v12minTT). In particular, variances in vRPE 13 using the calculated meaningful change and 90% prediction limits (0.14 ± 1.79 km·h^{-1}) could be used to monitor within-participant variances in endurance performance ability (12minTT specifically) throughout a training cycle.

Chapter 5: The utility of the Self-Paced Submaximal Run Test to monitor responses to an ultra-marathon.

5.0 ABSTRACT

Purpose. The aim of the study was to examine the sensitivity of the self-paced submaximal run test ($\mathrm{SRT}_{\mathrm{RPE}}$) in monitoring responses to an ultra-marathon.

Methods. Eleven experienced runners participated in a 6-hour ultra-marathon. The $\mathrm{SRT}_{\mathrm{RPE}}$ assessed velocity (v) and exercise heart rate ($\mathrm{HR}_{\mathrm{ex}}$) during 3, 3-min stages prescribed by Rating of Perceived Exertion (RPE) 10, 13 and 17, 7-days pre-race, ~48-hours and 7-days post-race. The variance in $\mathrm{HR}_{\mathrm{ex}}$ associated with a given submaximal v was calculated using the heart rate-run speed (HR–RS) index. The effect of ultra-marathon was assessed though nil hypothesis testing (analysis of variance with repeated measures) and a test of minimum-effect hypotheses (minimum-effects test). A Pearson correlation was used to determine the association between running training stress score (rTSS) from the ultra-marathon and change in $\mathrm{SRT}_{\mathrm{RPE}}$ responses between each time point.

Results. During the ultra-marathon, participants completed 50.2 ± 5.0 km resulting a mean ± SD running training stress score (rTSS) 302 ± 49. The v associated with RPE 17 showed a meaningful decrease from 7-days pre-race – 48-hours post-race (-0.78 $\mathrm{km{\cdot}h^{-1}}$ [90% CI; -0.99 – -0.57 $\mathrm{km{\cdot}h^{-1}}$]) p_{MET} = <0.001 which was negatively associated with rTSS (r = -0.60 [0.85–-0.11]) P = 0.06. vRPE 17 subsequently showed a meaningful increase between 48-hours post-race – 7-days post-race (+0.83 $\mathrm{km{\cdot}h^{-1}}$, [0.46 – 1.19 $\mathrm{km{\cdot}h^{-1}}$]) p_{MET} = 0.004, which was positively associated with rTSS (r = 0.67 [0.22 – 0.88]) P = 0.04. From 48-hours post-race to 7-days rTSS was positively associated with change in HR-RS index at RPE 13 (r = 0.68 [-0.89 – -0.24]) P = 0.02, and negatively associated with change in HR-RS index at RPE 17 (r = 0.85 [0.58–0.95]) P = 0.001.

Conclusion. Performance (v) at intensities RPE 17 was most highly affected by and most strongly associated with prior training stress (rTSS). Responses from the $\mathrm{SRT}_{\mathrm{RPE}}$ revealed that runners who experienced a higher rTSS displayed an acutely (at 48-hours post-race) greater blunting in $\mathrm{HR}_{\mathrm{ex}}$ response to a v at RPE 13 and a more prolonger blunting (7-days-post race) in $\mathrm{HR}_{\mathrm{ex}}$ response to a given v at RPE 17. In conclusion, responses to intensities RPE 13 and 17 in the $\mathrm{SRT}_{\mathrm{RPE}}$, are informative in monitoring over-reaching relative to the magnitude of stress imposed by endurance exercise.

5.1 INTRODUCTION

In Chapter 3 the SRT_{RPE} was shown to have an acceptable reliability, presumed to make it sensitive to the expected magnitudes of changes in performance brought about by typical endurance training. In Chapter 4, the study confirmed this sensitivity, showing the ability of the SRT_{RPE} to track changes in endurance performance (12minTT) stimulated by 4-weeks of normal training. In particular, variance in v at RPE 13 was the most highly associated with within-individual variances in 12minTT performance. However, as participants completed their normal training, and arrived for testing in a recovered state, the utility of the SRT_{RPE} in flagging functional over reaching has yet to be explored.

Endurance athletes may be exposed to sessions of high training load either as a programmed part of a training micro-cycle or through competition demands. Acute exercise of the same absolute exercise load has been shown to cause large inter-induvial variances in the transient disturbances to homeostasis and may differentially affect an individual's ability (readiness) to training in subsequent sessions (Turner et al. 2016; Nuuttila et al. 2020; Larsen et al. 2020). It would be of benefit for the SRT_{RPE} to be able to sensitivity flag acute episodes of functional over-reaching within-individuals, to allow individuals to receive the appropriate dose of recovery between sessions, preventing the performance, psychological and physiological demises associated with over-training/under recovery (Meeusen et al. 2013).

Previous research has shown the completion of an ultra-marathon causes substantial disturbances to running performance and physiological homeostasis (Kim, Lee and Kim 2007; Siegl et al. 2017a; Burr et al. 2012). Therefore, studies have utilised ultra-marathon races to examine the sensitivity of submaximal parameters to acute periods of large exercise stress. In the 2-days following completion of a 56km ultra-marathon, Siegl et al (2017) recorded a practically important (Hopkins et al. 2009) blunting in the HR_{ex} of runners in response to intensities equating to 70% and 85% of the individuals peak treadmill run speed (PTRS). Conversely, Chambers et al (1998) measured a tendency for HR_{ex} to be higher for a given submaximal v in the days following a 90km Ultra-marathon.

Due to a number of methodological and statistical differences and limitations in the research it is difficult to draw conclusions as to why there is inconsistency in the reported effects of ultra-marathon running on responses to submaximal running. Firstly, there is a large variation in the timing of testing individuals after the race. This leaves gaps in the understanding of the sensitivity of submaximal parameters in monitoring the recovery kinetics and when monitoring should occur to best detect over-reaching. In addition, there has been little regard to the influence of the between-individual variation in load imposed by the same race. Chambers et al. (1998) found no association between the relative intensity (%HR_{max}) of the 90km ultra-marathon and magnitude of changes in submaximal responses. However, this load metric does not account for the time spent at this intensity and thus does not fully describe the load imposed (Sanders et al. 2017).

As such, the following research aims to assess responses to an ultramarathon-race, both at 48-hours and 7-days after the event to better understand recovery kinetics. The study will use a range of training load metrics to understand the sensitivity of SRT_{RPE} responses to between-individual variations in training loads. The results of Chapter 3 and 4 will be used to set thresholds for a meaningful change in the parameters of the SRT_{RPE} between time points.

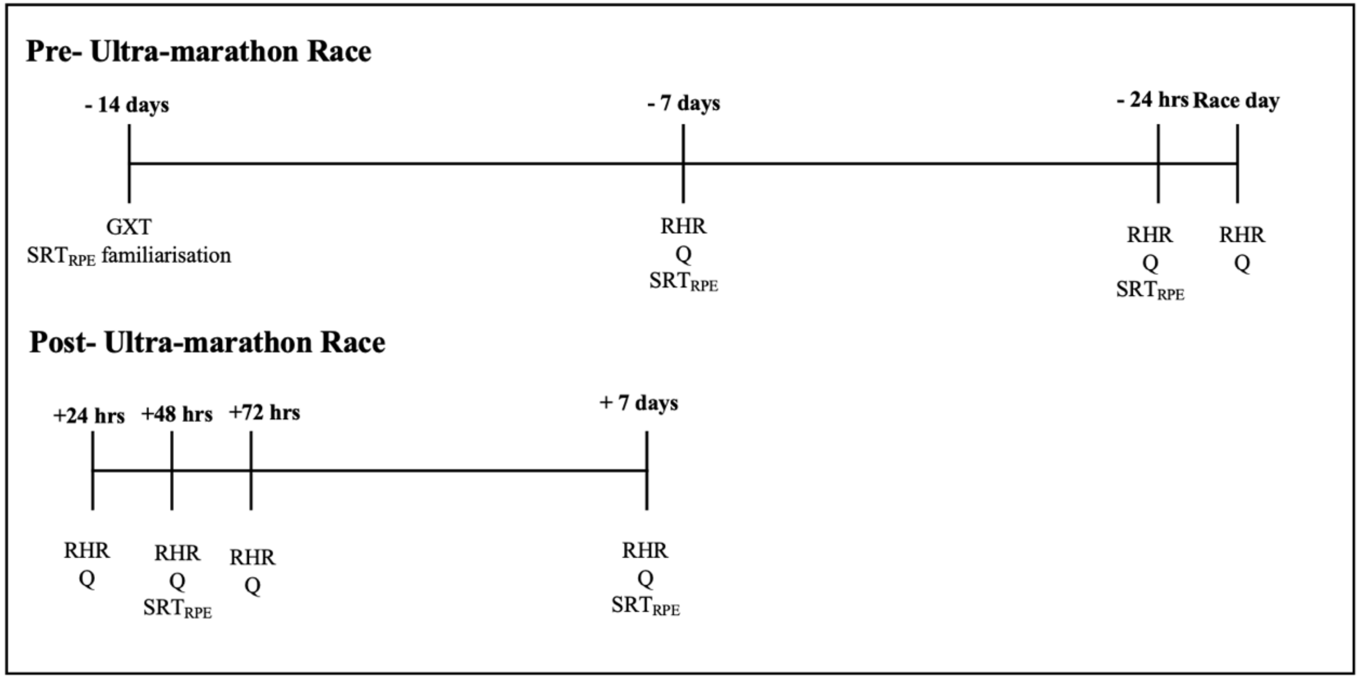
5.2 METHODS

Study population

Eleven competitive runners; 3 female (age: 31 ± 8 y; $\dot{V}O_{2max}$ 40.3 ± 1.8 $mL \cdot kg^{-1} \cdot min^{-1}$), 8 male (age: 39 ± 9 y; $\dot{V}O_{2max}$ 53.8 ± 3.9 $mL \cdot kg^{-1} \cdot min^{-1}$) participated in the study. All participants had previously completed >1 ultra-marathon event within the 12 months prior to the ultra-marathon race. Participants were deemed healthy to participate following completion of the PAR-Q health questionnaire and being free from injury in the 6 months prior to commencement of testing. After being fully informed of the study protocol and possible risks associated with participation, all participants gave written consent. Ethical approval was obtained from the School of Sport and Exercise Science Research Ethics Advisory Group (Approval number: Prop 107_2017_18).

Study design

All participants visited the laboratory on 4 occasions (see figure 5.1). Visit 1 was completed 14 days prior to the race, during which participants completed a graded exercise test (see: Two phase graded exercise test) used to assess $\dot{V}O_{2max}$. Following 20-min passive recovery, participants completed a familiarisation of SRT_{RPE} on an outdoor 400 m track. Visits 2, 3 and 4 were completed 7-days pre-race, ~48-hours and 7-days post-race (see: Ultra-marathon race). The morning of each visit, participants were instructed to record resting heart rate (RHR) upon awakening (see: Resting Heart Rate). Upon arrival participants completed the Daily Analysis of Life Demands of Athletes (DALDA) questionnaire (see: Daily Analysis of Life Demands of Athletes) before performing an SRT_{RPE} . All participants arrived at the laboratories at the same time of day for each visit, in a fasted state and having refrained from caffeine in the 12-hours prior to arrival. Between visit 1 and the ultra-marathon, participants were instructed to continue their normal training but arrive to the laboratory following 24-hours rest. After completion of the ultra-marathon, participants were instructed to refrain from any exercise for the following 7-days. Participants were instructed to complete additional DALDA questionnaires and RHR measures at time points 24-hours pre-race, 24-hours post-race and 72-hours post-race.



Key

- = Pre-race

\+ = Post-race

GXT = Graded exercise test

SRT_{RPE} = Self-paced submaximal run test

RHR = Resting heart rate

Q = Daily Analysis of Life Demands of Athletes questionnaire

Figure 5. 1 Study Schematic

Two phase graded exercise test (GXT)

Participants undertook a two-phase GXT for the assessment of individual B[La] profile and $\dot{V}O_{2max}$. The GXT was conducted out as detailed in Chapter 2. In brief, Phase-one assessed B[La] profile and was comprised of 5–7 submaximal exercise bouts starting a v which represented the transition from walk to run, with running v (km·h^{-1}) increasing by 1 km·h^{-1} every 4-min, until B[La] exceeded 4 mmol·L^{-1}. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase-one and increased by 0.5 km·h^{-1} every min until participant's point of exhaustion. Participant's vLT1, vLT2, $\dot{V}O_{2max}$ and v $\dot{V}O_{2max}$ were determined as described in Chapter 2.1.3.

The Self-paced submaximal run test (SRT_{RPE})

The SRT_{RPE} was performed as specified in Chapter 2. In brief, participants completed three, 3 min stages interspersed by 1 min recovery with submaximal exercise intensity prescribed by RPE 10, RPE 13 and RPE 17. Participant v was recorded using the Garmin Forerunner 235 (1Hz sampling rate) and HR_{ex} using a Polar H10 heart rate monitor (sampling rate of 1Hz). In calculating average v and HR_{ex} at each stage, the first 120-s of v and HR_{ex} data was excluded to ensure the target pace based on RPE and knowledge of the 3-min endpoint had been reached (see Chapter 2 for more detail). Following familiarisation (visit 1) participants completed the SRT_{RPE} at the same time of day 7-days pre-race, ~48-hours post-race (Range = 37 – 49-hours) and 7-days post-race. Mean outdoor testing conditions were: Windspeed 1.0 m/s (range = 0.2 m/s–1.8 m/s), temperature 5 ºC (range = 2ºC – 8ºC)

Heart rate run speed (HR-RS) index

The basis of HR-RS index in the linear relationship between HR_{ex} and v. As such HR-RS index represents the absolute difference in the theoretical and actual v for a given HR_{ex}. Calculated using the following equation:

$$HR\text{–}RS\ index = v_{avg} - \left(\frac{HR_{ex} - HR_{standing}}{k}\right)$$

Where:

$$HR_{standing} = RHR + 26$$

$$k = \left(\frac{HR_{max} - HR_{standing}}{v_{peak}}\right)$$

v_{avg} = Average v for the final 60-s of each SRT_{RPE} stage, v_{peak} = v reached at VO_{2max}, RHR = morning resting heart rate for the given day.

Resting Heart Rate (RHR)

Upon waking at home, participants attached a Polar H7 heart rate sensor (Polar Electro, Kempele, Finland), and recorded data for 5-min while lying in a supine position, with eyes closed. Recording using their own GPS device on indoor mode (Buchheit 2014). This was recorded prior to each laboratory visit in addition to: 24-hours pre-race, 24-hours post-race and 72-hours post-race

Daily analyses of life demands for athletes (DALDA) questionnaire

Participants completed the DALDA questionnaire at laboratory visits immediately prior to completion of the SRT_{RPE} and at the same time of day, at time points 24-hours pre-race, 24-hours post-race and 72-hours post-race at home (figure 5.1). DALDA assessed general stress levels (Part A) and stress-reaction symptoms (Part B). Participants rated each variable as being ‘worse than normal’, ‘normal’ or ‘better than normal’(Rushall 1990).

Ultra-marathon race

The ultra-marathon was a 6-hour time-restricted event in which participants completed 5km loops of a mixture of high quality trail path and concrete path. Participants were instructed to complete as many loops as possible in the given time, with the aim of completing a minimal distance of 42.1km (marathon distance). Participants were able to stop and rest after each loop and take on nutrition and water throughout the event. v and

HR_{ex} were recorded throughout using participants own Bluetooth chest strap and wrist-watch GPS monitor (1 Hz sampling rate). Distance and duration (in s) were recovered from the GPS data. Windspeed 1.5 m/s (range = 0.8 m/s–2.2 m/s), temperature 8 ºC (range = 4ºC – 12ºC)

Ultra-marathon training load.

Individualised Training Impulses (iTRIMP).

Exercise load was estimated using the validated method of iTRIMP (Sanders et al. 2017), through the following equation.

$$\sum_{\mathrm{s}=1}^{\mathrm{n}} (t_{\mathrm{s}} \times \Delta \mathrm{HR}_{\mathrm{s}} \times \mathrm{y})$$

Where**, n**= Total Number of heart rate samples; **s**= heart rate sample; ***t* =**Duration (time, minutes), $\mathbf{\Delta HR_s}$= Sample mean fractional elevation in heart rate; **y** =Weighting factor: $ae^{b\Delta HRs}$

Where for $\mathbf{ae^{b\Delta HRs}}$; **a** = individual ΔHR–B[La] intercept*, **b** = individual ΔHR–B[La] growth factor*, ***e*** = base of the Napierian (natural) logarithm.

Training Stress Score (rTSS)

rTSS was calculated using the following equation (McGregor, Weese and Ratz 2009)**.**

$$\mathrm{rTSS} = \frac{\mathrm{time\ (s)\ x\ NP\ x\ IF}}{3{,}600 - \mathrm{s\ x\ TP}}$$

Where, **NP** = Normalised pace, calculated using TrainingPeaks software accounting for variance in gradient; **FTP** = threshold pace in which velocity at lactate threshold was used. **IF =** Intensity factor, calculated from the following equation.

$$IF = \frac{NP}{FTP}$$

Statistical analysis

Data are expressed as mean ± standard deviation (SD) for all parametric data (duration, distance, iTRIMP and rTSS of race and v, HR_{ex}, HR-RS, End HR and HRR_{60} during SRT_{RPE} and RHR), while nonparametric data (DALDA scores) were expressed as median (interquartile ranges). The DALDA was assessed by the number of 'worse than' scores for symptoms of stress that were scored at each time point.

Assumptions of statistical tests such as the normal distribution, equality of variance and sphericity of data were checked using the Shapiro-Wilk, Levene's and Mauchly's tests respectively. Where the assumption of sphericity was violated the Greenhouse-Geiser adjustment was applied to the degrees of freedom. Where appropriate, post-hoc tests using the Bonferroni correction were made. A one-way ANOVA with RM was used to compare; Parameters of the SRT_{RPE} (v, HR_{ex}, HR-RS, End HR and HRR_{60}) over the three time points: 7-days pre-race, 48-hours post-race and 7-days post-race. A separate one-way ANOVA with RM was used to compare; RHR and DALDA worse than scores over the 6 time points: 7-days pre-race, 24-hours pre-race, 24-hours, 48-hours and 72-hours post-race and 7-days follow up. When appropriate, a Bonferroni post hoc test was used. The statistical significance level was set to $P < 0.05$. Analysis was performed with IBM SPSS Statistics v.26 -programs (SPSS Inc, Chicago, IL, USA).

Dependent (paired) samples *t*-tests were used to assess differences in the group mean v, HR_{ex}, HR-RS, End HR and HRR_{60} during SRT_{RPE} between pairs of: 7-days pre-race to 48-hours post-race, 7-days pre-race to 7 days post-race and 48-hours pre-race to 7-days-post race. Difference between time points was reported in raw values with 90% CI. Dependent (paired) samples *t*-test were used to assess variance in pairs of RHR and DALDA scores over 6 time points: 7 days pre-race, 24 hours pre-race, 24-hours, 48-hours and 72-hours post-race and 7 days follow up. Effect sizes from paired samples t-tests were calculated to quantify the magnitude of the differences. The following criteria was used to set thresholds for determination of effect sizes: small ($d = 0.20$), moderate ($d = 0.5$), large ($d = 0.8$) (Cohen 2013)

A minimum effects test (MET) was used to provide a practical, probabilistic interpretation of these differences between time-points. For v at each stage of the SRT_{RPE}, a practically important change was defined as a 0.26, 0.14 and 0.18 $km \cdot h^{-1}$ change in v at RPE 10, 13 and 17 respectively (see Chapter 3). For variables HR_{ex}, HR-RS, End HR, HRR_{60} and RHR, threshold values set by 0.2 × the between-participant standard deviation from baseline measures (Murphy and Myors 1999). For DALDA the group average over 7-days pre-race and 24-hours pre-race was used to set the normal range, outside of which any score was considered meaningful (Rushall 1990).

A Pearson's correlation was used to assess association between measures of training load (iTRIMP and rTSS) and absolute change in responses to SRT_{RPE} (v, HR-RS Index) or change in DALDA worse than scores. The strength of correlations were determined using the following criteria: trivial (<0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9), almost perfect (0.9 – 1.0) (Batterham and Hopkins 2006). Statistical Analysis System (SAS) software (Version 9.4, SAS Institute, Cary, NC, USA) was used for analysis.

5.3 RESULTS

Ultra-marathon performance

Participants completed 50.2 ± 5.0km and raced for a duration of 05:32 ± 00:53 (HH:MM) at an intensity of 84 ± 7% of HRmax. The calculated iTRIMP was 707 ± 184 (Au) and rTSS was 302 ± 49. The furthest distance covered was 57km in a time of 05:44 (HH:MM) with resultant iTRIMP = 493 (Au) and rTSS = 287. The lowest distance covered was 42.6km in a time of 04:07 (HH:MM), which resulted in an iTRIMP = 739 (Au) and rTSS = 309

Self-paced Submaximal Run Test (SRT_{RPE})

Group absolute values measured in response to the SRT_{RPE} at time points 7-days pre-race, ~ 48-hours post-race and 7-days post-race are shown in table 5.1. One way ANOVA with RM showed no significant difference in vRPE 10 nor vRPE 13 over time ($P > 0.05$). There was a significant difference in vRPE 17 over time; $F_{2,20}= 14.760$, $P < 0.001$.

Repeated measures ANOVA showed no significant difference in $\%HR_{max}$ at all stages of the SRT_{RPE} over time ($P > 0.05$). There was also no significant difference in HR-RS index at RPE 10 or 13 over time ($P > 0.05$). However, ANOVA showed a significant difference in HR-RS Index at RPE 17 over time; $F_{2,20} = 4.93$, $P = 0.018$.

Table 5. 1 SRT$_{RPE}$ responses (mean ± SD) 7-days pre-race, +48-hours and 7-days post-race

SRT$_{RPE}$ Variable	**7-days pre-race**	**~ 48-hours post-race**	**7-days post-race**
RPE 10			
v (km·h^{-1})	10.27 ± 2 .05	10.08 ± 2.00	10.40 ± 1.99
%HR$_{max}$	71.8 ± 8.2	72.8 ± 7.5	72.7 ± 8.4
HR-RS Index (Au)	3.14 ± 1.25	2.67 ± 1.26	3.05 ± 1.50
RPE 13			
v (km·h^{-1})	12.87 ± 2.26	12.40 ± 1.80	12.57 ± 1.94
%HRmax	86.2 ± 5.4	83.6 ± 4.4	84.3 ± 4.8
HR-RS index (Au)	1.86 ± 0.88	2.08 ± 0.63	2.07 ± 0.98
RPE 17			
v (km·h^{-1})	14.88 ± 2.26	14.10 ± 2.42*	14.93 ± 2.05*
%HR$_{max}$	93.2 ± 2.7	91.7 ±3.9	92.3 ± 4.2
HR-RS index (Au)	1.98 ± 0.75	1.56 ± 1.01	2.22 ± 0.86*
HRR$_{60}$	53 ± 13	54 ± 11	54 ± 11

Abbreviations: SRT$_{RPE}$ (Self-paced submaximal run test), RPE (Rating of perceived exertion) v (Velocity) %HR$_{max}$ (percentage of maximal heart rate) HR-RS (Heart rate - run speed), HRR$_{60}$ (Hear rate recovery in 60-s) * significant decrease from previous test (P < 0.05)

Results show that vRPE 17, displayed a meaningful decrease (p_{MET} = <0.001) from 7-days pre-race – 48-hours post-race (0.78 km·h^{-1}, [90% CI; -0.99 – -0.57 km·h^{-1}]) (table 5.2, figure 5.2C). From ~ 48-hours post-race – 7-days post-race there was a meaningful increase (p_{MET} = 0.004) in vRPE 17 (0.83 km·h^{-1}, [0.46 – 1.19 km·h^{-1}]) (table 5.2, figure 5.2F). There was no meaningful change in responses to SRT$_{RPE}$ from 7-days pre-race – 7-days post-race.

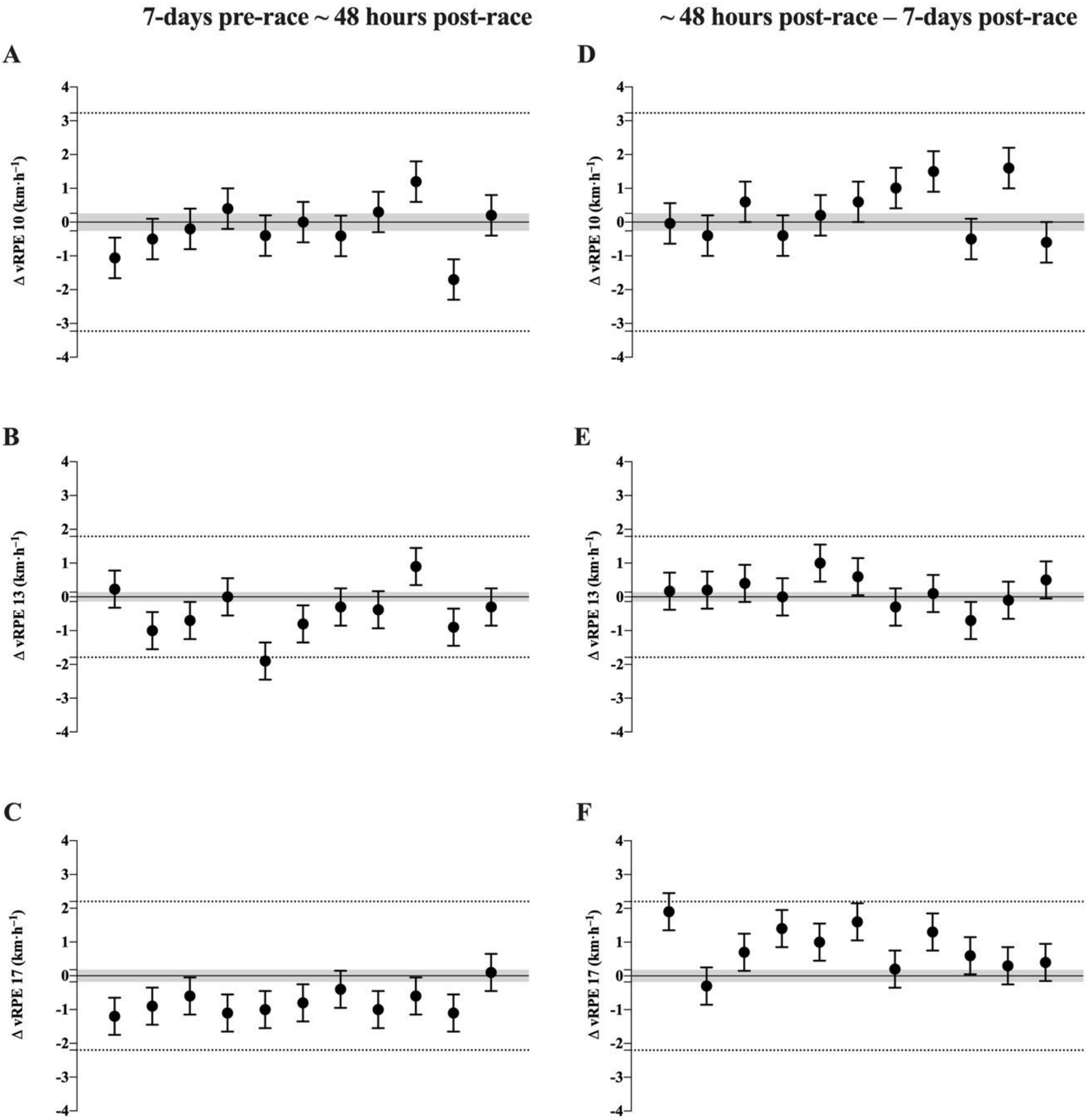


Figure 5. 2 Individual change in v ± typical error at from 7-days pre-race to ~48-hours post-race at intensity (A) RPE 10, (B) RPE 13 and (C) RPE 17 of the SRTRPE, and from ~48-hours post-race to 7-days post-race at intensity (D) RPE 10, (E) RPE 13 and (F) RPE 17. The grey line indicates predicted meaningful change and the dotted line shows 90% prediction limits. Each mark is an individual participant with order of participant kept constant between graphs.

Table 5. 2 Mean (90%CI) absolute change in parameters between each three time points: 7-days pre-race, ~ 48-hours post-race and 7-days post-race.

SRT$_{RPE}$ Variable	7-days pre-race – ~ 48-hours post-race			~ 48-hours post-race – 7-days post-race			7-days pre-race – 7-days post-race		
	Mean Difference (90% CI)	Cohen's Effect Size (90% CI)	p_{MET}	Mean Difference (90% CI)	Cohen's Effect Size (90% CI)	p_{MET}	Mean Difference (90% CI)	Cohen's Effect Size (90% CI)	p_{MET}
RPE 10									
v (km·h^{-1})	-0.20 (-0.62 – 0.22)	-0.27 (-0.75 – 0.26)	0.60	0.33 (-0.11 – 0.76)	0.41 (-0.12 – 0.92)	0.40	0.13 (-0.32 – 0.60)	0.15 (-0.35 – 0.65)	0.70
%HR$_{max}$	1.0 (-0.83 – 2.87)	0.28 (-0.23 – 0.79)	0.70	-0.10 (-1.55 – 1.34)	-0.03 (-.0.53 – 0.46)	0.96	0.91 (-1.05 – 2.88)	0.24 (-0.27 – 0.74)	0.74
HR-RS Index (Au)	-0.47 (-0.87 – 0.12)	-0.73 (-1.28 – 0.15)	0.14	0.38 (-0.01 – 0.77)	0.53 (-0.01 –1.05)	0.28	-0.09 (-0.40 – 0.21)	-0.17 (-0.67 – 0.33)	0.81
RPE 13									
v (km·h^{-1})	-0.47 (-0.87 – 0.07)	-0.64 (-1.18 – -0.08)	0.08	0.17 (-0.08 – 0.42)	0.37 (-0.15 – 0.87)	0.42	-0.30 (-0.56 – -0.04)	-0.62 (-1.16 – -0.06)	0.15
%HR$_{max}$	- 2.6 (-5.23 – 0.00)	-0.55 (-1.08 – -0.01)	0.15	0.76 (-0.48 – 2.00)	0.31 (-0.20 – 0.81)	0.67	-1.86 (-4.16 – 0.45)	-0.47 (-0.98 –0.07)	0.27
HR-RS index (Au)	0.22 (-0.28 – 0.72)	0.24 (-0.27 – 0.74)	0.43	-0.02 (-0.34 – 0.31)	-0.03 (-0.52 – 0.47)	0.79	0.20 (-0.27 – 0.68)	0.23 (-0.28 –0.73)	0.45
RPE 17									

v (km·h^{-1})	-0.78* (-0.99 – -0.57)	-2.03 (-2.90 – -1.12)	< 0.001	0.83* (0.46 – 1.19)	1.23 (0.54 – 1.88)	0.004	0.05 (-0.29 – 0.38)	0.08 (-0.42 – 0.57)	0.74
$\%\text{HR}_{\text{max}}$	-1.42 (-3.07 – 0.22)	-0.49 (-1.00 – 0.05)	0.17	0.60 (-0.16 – 1.37)	0.38 (-0.15 – 0.89)	0.43	-0.82 (-2.74 – 1.10)	-0.26 (-0.77 – 0.25)	0.40
HR-RS index (Au)	-0.42 (-0.77 – 0.07)	-0.65 (-1.19 – -0.09)	0.31	0.66 (0.27 – 1.05)	0.92 (0.30 – 1.50)	0.08	0.24 (-0.17 – 0.64)	0.32 (-0.20 –0.82)	0.64

Abbreviations: SRT_{RPE} (Self-paced submaximal run test), RPE (Rating of perceived exertion) v (Velocity) $\%\text{HR}_{\text{max}}$ (percentage of maximal heart rate) HR-RS (Heart rate -run speed), HRR_{60} (Hear rate recovery in 60 s) CI (confidence interval) p_{MET} (probably that a meaningfully positive change occurred) *(meaningfully difference change from $p_{\text{MET}} < 0.05$)

Daily Analysis of Life Demands of Athletes (DALDA) questionnaire

Number of ‘worse than’ scores for symptoms of stress are shown as Median (Interquartile range) over 6 time points in table 5.3. There was a significant difference in ‘worse than’ scores over the 6 time-points; $F_{5.50} = 10.146$, $P < 0.001$. Test of the means-effects hypothesis showed a meaningful increase in ‘worse than scores’ at 24-hours post-race compared to 7-days pre-race by 5 (90% CI= 4 – 7) $p_{MET} = 0.021$. By 72-hours post-race worse than scores had shown a meaningful decrease compared to 7-days pre-race (-5, [-7 – -2]). Individual DALDA “worse than’ scores shown in figure 5.3.

Morning resting heart rate (RHR)

Due to error in the data, the following results reflect the data collected from 6 participants. RHR measures over 6 time points are shown in table 5.3. Test of the means-effects hypothesis showed a meaningful increase in RHR (4 beats·min^{-1}, 90% CI; 1–7 beats·min^{-1}) $p_{MET} = 0.011$ at 24-hour post-race compared with 7-days pre-race. Figure 5.4 displays the % change in RHR from 24-hours pre-race.

Table 5. 3 Change in DALDA and RHR from 7-days pre-race.

	Δ 24-hours post	**Δ 48-hours post**	**Δ 72-hours post**	**Δ 7-days post**
DALDA (‘worse than’ responses)				
Mean (Q1 – Q4)	5 (4 – 7)	2 (0 – 4)	0 (0 – 2)	0 (0 – 2)
Effect Size (*d*)	1.75 (0.92 – 2.53)	0.71 (0.14 – 1.26)	0.27 (-0.24 – 0.77)	0.22 (-0.29 – 0.71)
p_{MET}	<0.001	0.13	0.75	0.79
RHR (beats·min^{-1})				
Mean (90% CI)	4 (3 – 5)	2 (0 – 3)	-1 (-3 – 1)	-2 (-5 – 1)
Effect Size (*d*)	2.74 (1.27 – 4.10)	0.71 (-0.02 – 1.39)	-0.27 (-0.89 – 0.38)	-0.57 (-1.22 –0.13)
p_{MET}	<0.001	0.26	0.60	0.31

Abbreviations: DALDA (Daily analysis of life demands of athletes), RHR (Morning resting heart rate), Q1–Q4 (interquartile range), *d* (Cohen’s d), p_{MET} (probability of a meaningful effect)

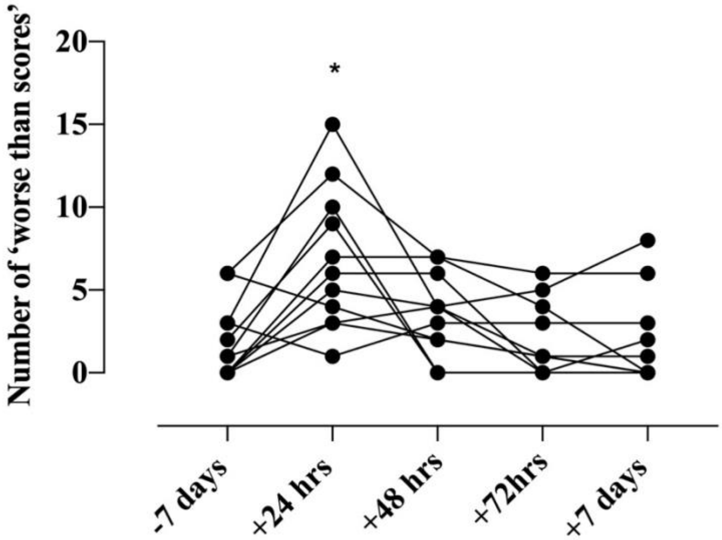


Figure 5. 3 Individual DALDA ‘worse than’ scores over the 14-day observation period. *signifies meaningful change ($p_{MET} < 0.05$) from 7-days pre-race

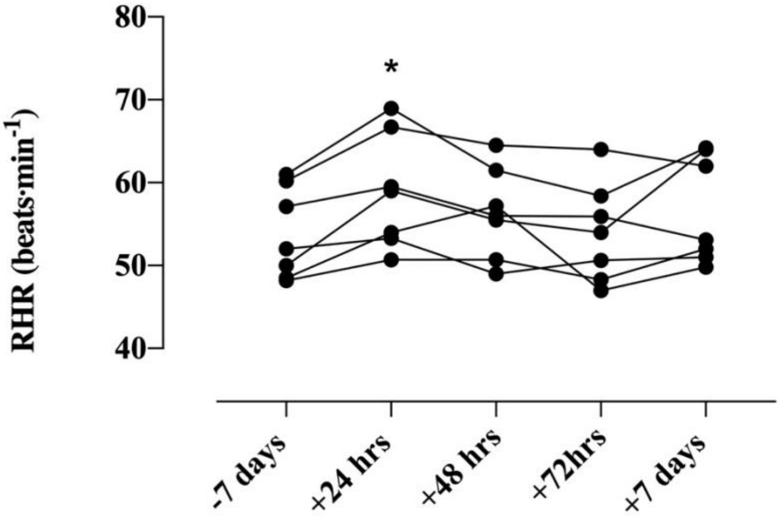


Figure 5. 4 Individual values of morning resting heart rate. *signifies meaningful change ($p_{MET} < 0.05$) from 7-days pre-race

Associations with individual training load

SRT_{RPE}

rTSS displayed the most significant associations with changes in v and HR-RS Index, compared with other training load metrics; Duration, Distance and iTRIMP (table 5.4 & table 5.5). As such, the results from these associations will be described in more detail below.

Velocity

The was a small association between rTSS of the race and absolute change in vRPE 10 and vRPE 13 (7-days pre-race to 48-hours post-race (*r* range = -0.17 – 0.27) and 48-hours pre-race to 7-days post-race (*r* range = 0.05 – -0.04). There was a large, negative association between rTSS and absolute change in vRPE 17 from 7-days pre-race to 48-hours post-race (*r* = -0.60, [90% CI; -0.85 – -0.11]) *P* = 0.06 and a positive association 48-hours pre-race to 7-days post-race (r = 0.67, [0.22 – 0.88]) *P* = 0.04 (figure 5.7).

HR-RS Index.

There was a large correlation between rTSS and HR-RS index at RPE 13 from 7-days pre-race to 48 hours post-race (r = 0.59, [0.10 – 0.85]) *P* = 0.06, and a small to moderate association with change in HR-RS index at RPE 10 and 17 (*r* range = -0.12 – 0.29). There was a large, negative correlation between rTSS and change in HR-RS index at RPE 10; *r* = 0.54 (-0.83 – -0.02) *P* = 0.09 and RPE 13; *r* = -0.68 (-0.89 – -0.24) *P*= 0.02 . Conversely, there was a very large positive correlation with RPE 17 (*r* = 0.85, [0.58 – 0.95]) *P* = 0.001 from 48-hours post-race to 7-days post-race (figure 5.6 and figure 5.7)

DALDA.

There was a moderate correlation between rTSS and change in 'worse than scores' from 7-days pre-race to 24-hours post-race (r = 0.53, 90% CI; 0.01 – 0.82) *P* = 0.10. Small correlation between rTSS and 'worse-than' scores at 48-hours post-race (r = 0.17, [-0.39 – 0.64]), 7-days post-race (r = 0.15, [-0.41 – 0.62]) (*P*>0.05)

Table 5. 4 Pearson correlation coefficient (90% CI) for association between individuals training load and change in SRT$_{\text{RPE}}$ response from 7-days pre-race to ~48-hours post-race

	Δ 7-days pre-race – ~48-hours post-race			
SRT$_{\text{RPE}}$ response	**Duration (mins)**	**Distance (km)**	**iTRIMP (Au)**	**rTSS**
Δv (km·h^{-1})				
RPE 10	-0.27 (-0.70 – 0.29)	-0.36 (-0.75 – 0.20)	0.14 (-0.42 – 0.62)	0.05 (-0.49 – 0.56)
RPE 13	0.04 (-0.50 – 0.55)	-0.42 (-0.78 – 0.13)	0.38 (-0.18 – 0.75)	-0.04 (-0.55 – 0.50)
RPE 17	-0.34 (-0.73 – 0.23)	-0.11 (0.60 – 0.44)	-0.46 (-0.79 – 0.08)	-0.60 (-0.85 – - 0.11)
ΔHR-RS index (Au)				
RPE 10	0.35 (-0.22 – 0.74)	0.22 (-0.34 – 0.67)	0.28 (-0.29 – 0.70)	0.26 (-0.31 – 0.69)
RPE 13	0.70 (0.28 – 0.90)	0.49 (-0.05 – 0.81)	0.28 (-0.28 – 0.70)	0.59 (0.10 – 0.85)
RPE 17	0.43 (-0.12 – 0.78)	0.53 (0.01 – 0.83)	-0.12 (-0.61 – 0.43)	-0.12 (-0.61 – 0.43)

Abbreviations: SRT$_{\text{RPE}}$ (Self-paced submaximal run test), RPE (Rating of perceived exertion) v (Velocity) HR-RS (Heart rate -run speed), * ($P<0.05$)

Table 5. 5 Pearson correlation coefficient (90% CI) for association between individuals training load and change in SRT_{RPE} response from ~48-hours post-race to 7-days post-race

	Δ ~48 hours post-race – 7-days post			
SRT_{RPE} response	**Duration (mins)**	**Distance (km)**	**iTRIMP (Au)**	**rTSS (Au)**
Δv (km·h^{-1})				
RPE 10	-0.31	-0.24	0.20	0.05
	(-0.71 – 0.26)	(-0.68 – 0.32)	(-0.36 – 0.65)	(-0.49 – 0.56)
RPE 13	-0.18	0.10	-0.28	-0.04
	(-0.64 – 0.38)	(-0.45 – 0.59)	-0.70 – 0.29)	(-0.55 – 0.50)
RPE 17	-0.21	-0.51	0.39	0.67*
	(-0.66 – 0.35)	(-0.82 – 0.01)	(-0.16 – 0.76)	(0.22 – 0.88)
ΔHR-RS index (Au)				
RPE 10	-0.23	0.00	-0.20	-0.54
	(-0.67 – 0.34)	(-0.52 – 0.52)	(-0.66 – 0.36)	(-0.83 – -0.02)
RPE 13	-0.15	0.33	-0.70*	-0.68*
	(-0.63 – 0.40)	(-0.23 – 0.73)	(-0.90 – -0.28)	(-0.89 – -0.24)
RPE 17	-0.11	-0.56	0.57	0.85*
	(-0.60 – 0.44)	(-0.84 – -0.05)	(0.07 – 0.84)	(0.58 – 0.95)

Abbreviations: SRT_{RPE} (Self-paced submaximal run test), RPE (Rating of perceived exertion) v (Velocity) HR-RS (Heart rate - run speed), * ($P<0.05$)

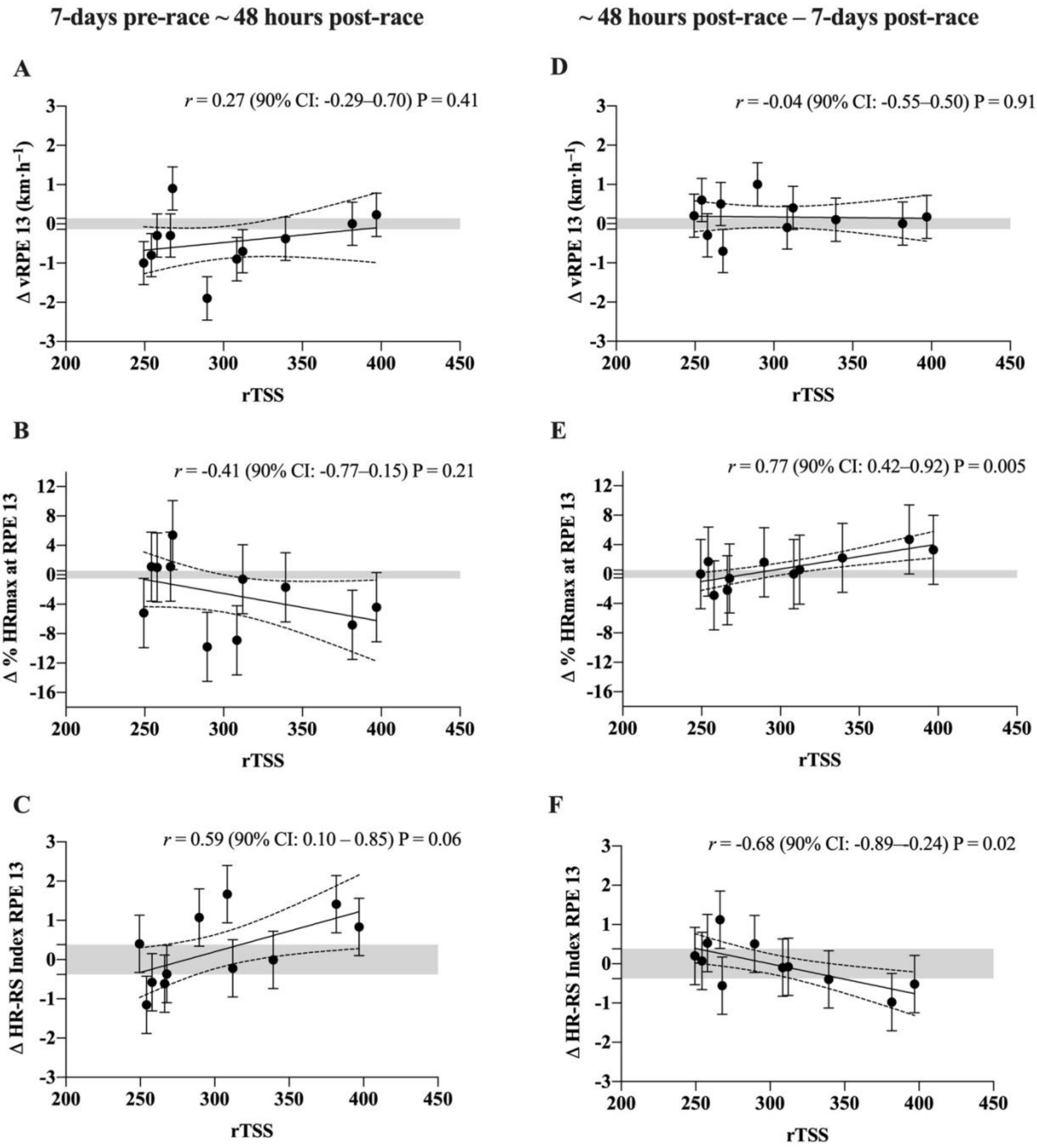


Figure 5. 5 Association between rTSS and change in (A) v, (B) %HR$_{max}$ and (C) HR-RS Index at RPE 13 from 7-days pre-race to ~48 hours post-race. Association between rTSS and change in (D) v, (E) %HR$_{max}$ and (F) HR-RS Index at RPE 13 from ~48 hours post-race to 7-days post-race. Black points show individual values for absolute change ± typical error. The grey bar represents the threshold for meaningful change in the given parameter. The solid blackline shows the trendline while dotted lines represent 90% confidence intervals.

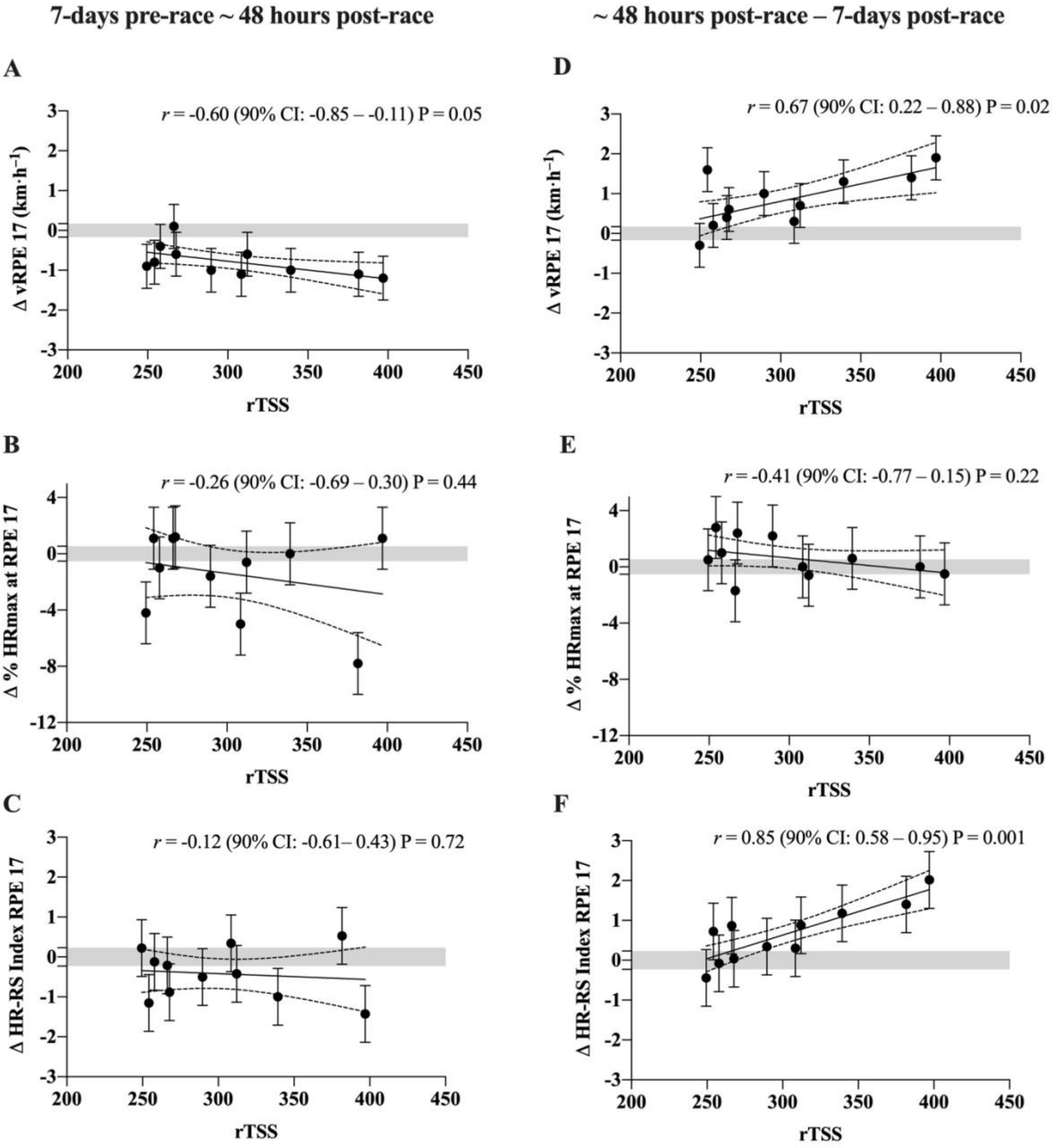


Figure 5. 6 Association between rTSS and change in (A) v, (B) %HR$_{\text{max}}$ and (C) HR-RS Index at RPE 17 from 7-days pre-race to ~48 hours post-race. Association between rTSS and change in (D) v, (E) %HR$_{\text{max}}$ and (F) HR-RS Index at RPE 17 from ~48 hours post-race to 7-days post-race. Black points show individual values for absolute change ± typical error. The grey bar represents the threshold for meaningful change in the given parameter. The solid blackline shows the trendline while dotted lines represent 90% confidence intervals.

5.5 DISCUSSION

The aim of the study was to assess the utility of the SRT_{RPE} to monitor functional over-reaching following an ultra-marathon. The primary finding of the study was that there was a meaningful reduction in self-selected v at an intensity representing RPE 17 ~48-hours post-race compared to pre-race (-0.78 $km \cdot h^{-1}$, [90% CI; -0.99 – -0.57 $km \cdot h^{-1}$]) p_{MET} = <0.001, followed by a meaningful increase (0.83 $km \cdot h^{-1}$, [0.46 – 1.19 $km \cdot h^{-1}$]) $p_{MET} = 0.004$ between ~48-hours post-race and 7-days post-race. The magnitude in change of v RPE 17 between ~48-hours post-race and 7-days post-race showed a significant positive associated with rTSS ($P < 0.05$). There were convergent associations between rTSS and the magnitude of change in HR-RS Index at RPE 13 ($r = -0.62$) and RPE 17 ($r = 0.85$) from 48-hours post – 7-days post as discussed below.

As a manipulation check, the results of the DALDA questionnaire suggest that the race successfully imposed a fatiguing exercise challenge to participants. As shown in figure 5.3 participants reported a meaningful increase in symptoms of stress in the 24-hours post-race (+5, [90% CI; 4 – 7]) $p_{MET} = 0.021$, which was elevated 48-hours post-race and returned to baseline by 72-hours post-race. This agrees with previous literature describing a similar difference in ‘symptoms of stress’ recorded before (3.0 [1.0 – 3.0]) and following (7.5 [4.0 – 9.0]) a 56km ultra-marathon ($P = 0.028$) (Siegl et al. 2017a). In addition, a significant increase in RHR at 24-hour post-race (4 $beats \cdot min^{-1}$, [1 – 7 $beats \cdot min^{-1}$]) $p_{MET} = 0.011$, agrees with previous findings of acutely increased resting heart rate (60-min – 24-hours post -race) in response to ultra-marathon running (Burr et al. 2012; Fazackerley, Fell and Kitic 2019)

The results of the current study demonstrate that v selected at RPE 13 and 17 of the SRT_{RPE} were most sensitive (when accounting for typical error in the measurements) to performance decrement following ultra-marathon; with 18%, 45% and 82% of participants showing a meaningful decrease in v at RPE 10, 13 and 17 respectively (see figure 5.2). These results agree with previous literature suggesting that intensities which represent ~70% – 85% peak running speed and 80 – 90% HR_{max} are most informative in monitoring perturbations in performance following fatiguing endurance training/competition. The current study built upon previous research by assessing the recovery kinetics of performance responses to submaximal exercise over 7-days recovery. The results showed that between 48-hours post-race and 7-days post, 45%, 27% and 64% of participants recorded a meaningful increase in v at stages RPE 10, 13 and 17 respectively, such that there was no meaningful difference in v at each stage from 7-days pre-race to 7-days post-race. Furthermore, variation in v monitored during RPE 17 of the SRT_{RPE} showed large associations with individualised training stress scores (rTSS), confirming its utility in flagging sustained performance decrement following ultra-marathon.

The two metrics used in the current study to calculate the stress imposed by the ultra-marathon are contrasting; iTRIMP uses HR_{ex} data and thus represents an internal load metric whereas rTSS uses v and thus reflects an external load metric. Previous literature suggests that the internal stimulus of exercise is an important factor predicting adaptations to training (Campbell et al. 2017; Impellizzeri, Marcora and Coutts 2019), therefore it is interesting that in the current study rTSS was more highly associated with the magnitudes of sustained performance decrement than iTRIMP. This may result from a higher measurement error (reduced reliability) of HR_{ex} recording during ultra-marathon (Lamberts et al. 2004; Wallace et al. 2014), making iTRIMP a less accurate reflection of the actual stress imposed. However, the present findings agree with previous research tracking performance changes in runners over 15-weeks, which similarly showed, by use of mathematical modelling, that the relationships between rTSS and modelled 1500m time-trial performance was greater than that shown for the internal training load metrics of sRPE-TL and iTRIMP (Wallace, Slattery and Coutts 2014) .

The current study used the HR-RS index to calculate the absolute difference in the theoretical and actual HR_{ex} for a given v. Results highlighted that heart rate responses to the three contrasting running intensities of the SRT_{RPE} were differently affected by the magnitude of prior training stress. An almost mirrored first positive ($r = 0.59$) to negative ($r = -0.68$) association between HR-RS Index at RPE 13 and rTSS suggest that those with greater rTSS showed the greatest decrease in HR_{ex} and v at RPE 13 at ~48-hours post-race, which recovered by 7-days post-race. Conversely, for RPE 17 the negative association between rTSS and HR-RS Index at 7-days post, suggests those who experience a lower rTSS maintained a depressed HR_{ex}, despite recovering v.

Previous research has similarly shown a blunting in HR_{ex} at 70% PTRS (-3.4 $\text{beats}\cdot\text{min}^{-1}$) and 85% PTRS (-2.1 $\text{beats}\cdot\text{min}^{-1}$) 2-days following a 56km Ultra-marathon. A decrease in submaximal HR_{ex} associated with a given external load has also been recorded shortly following (65-hours) (Hammes et al. 2016) and in the 3– 6 days (ten Haaf et al. 2019; Decroix, Lamberts and Meeusen 2018) following longer periods of intensive training in cyclists. This agreement between studies which used the Lamberts submaximal cycle test protocol, suggest that the SRT_{RPE} was similarly sensitive in monitoring recovery in endurance athletes. The current study extends previous findings by showing that the magnitude of depression of HR_{ex} and time course of recovery is associated to the size of the individual training stress. These findings disagree with Chambers et al, (1997) in which runners displayed a tendency for submaximal HR_{ex} to be elevated in the days following a 90km race, which become significantly greater than non-race finishers at 25-days post. A possible discrepancy causing varying HR_{ex} responses between studies is a failure to account for changes in plasma volume (Stuempfle et al. 2003; Knechtle, Knechtle and Rosemann 2011). Previous research has shown that an elevated HR_{ex} can be accounted for in part, to increased plasma volume, alongside a number of possible physiological variances such as; increase in free plasma catecholamine levels (Sagnol et al. 1990) or increased large arterial stiffness (Burr et al. 2012).

It is important to highlight that the current study is limited in not including a control group and only estimating a 'normal' response to SRT_{RPE} from a single test 7-days before the race. As participants were training up-until the event, some participants may have been over-reached at 7-days pre-race and thus not reflective of a 'normal' condition. Although the typical error in the measurement found in Chapter 3 was used to better estimate the 'true' change in parameters, the inclusion of a control group would have allowed for an additional comparison with the normal day-to-day variation in parameters within a non-fatigued state.

Conclusions

The ultra-marathon race stimulated significant perturbations to participants' homeostasis through a significant increase in DALDA reported symptoms of stress, and significant increase in RHR at 24-hours following completion of the ultra-marathon race. These results show that the SRT_{RPE} was sensitive to a period of over-reaching and recovery following the ultra-marathon race. Specifically, monitoring v and HR-RS index at RPE 17, is informative in evaluating sustained performance decrement and recovery in endurance runners. Large associations between rTSS and response to SRT_{RPE} suggest the test is responsive to the magnitude of prior training stress.

Chapter 6: The utility of the Self-Paced Submaximal Run Test to monitor individual responses to a period of over-load training.

6.0 ABSTRACT

Purpose. The aim of the study is to assess if the $\mathrm{SRT_{RPE}}$ can monitor within-individual responses to a period of intensified training. The effect of 3-weeks progressive over-load training on responses to the $\mathrm{SRT_{RPE}}$ and a three-kilometre time trial (3kmTT) will be compared.

Methods. Five competitive endurance runners (4 males) completed 2-weeks of normal training (NT) followed by 3-week over-load training (OL) phase in which weekly training load was progressively increased by +30% of NT duration. In the final week of NT and at the end of each of the three-weeks of OL, participant completed the $\mathrm{SRT_{RPE}}$, 3kmTT and the Daily Analysis of Life Demands of Athletes (DALDA) questionnaire. The effect of intensified training on parameters of the $\mathrm{SRT_{RPE}}$; velocity (v) and heart rate run speed index (HR-RS Index), as well as 3kmTT time and DALDA responses was assessed though analysis of variance and a test of minimum-effects. A general linear model was used to assess within-individual association between $\mathrm{SRT_{RPE}}$ variables, 3kmTT performance and training load during OL.

Results. Training duration was progressively increased by a mean value of; +45%, +28 and +32% each week. Participants showed a non-significant decrease in 3kmTT time (-1.18% [90% CI; - 4.51 – 2.16%]) from NT to the end of the 3-week OL phase. Only v at RPE 13 stage of the $\mathrm{SRT_{RPE}}$ was showed a meaningful decrease (-5.37% [-9.76 – -0.99%]) from NT to the end of OL. Within-individuals weekly training duration over OL showed moderate associations with v recorded at stages RPE 13 and 17 (*r* range = -0.30 – -0.46) and HR-RS Index at RPE 13 and 17 (*r* range = 0.34 – 0.49). Individual variance in 3kmTT showed trivial–moderate associations with v during $\mathrm{SRT_{RPE}}$ (*r* range = 0.00 – -0.32) and small – moderate association with HR-RS Index at each stage of the $\mathrm{SRT_{RPE}}$ (*r* range = 0.27 – 0.37).

Conclusion. There was large inter-individual variability in performance of 3kmTT in response to the same relative increase in training load. Within-individual variability in 3kmTT time was not strongly associated with individual's training load. Comparatively, within-individual variance in v and HR-RS Index at intensities RPE 13 and RPE 17 in the $\mathrm{SRT_{RPE}}$, showed a greater association training load.

6.1 INTRODUCTION

Periods of intensified training, using increased intensity (Skovgaard, Almquist and Bangsbo 2017), volume (Lehmann et al. 1991; Bosquet, Léger and Legros 2001) or both (Coutts, Wallace and Slattery 2007) are often imposed to stress endurance athletes beyond their current capacity, with the aim of leading to a super-compensation in performance following an appropriate taper period (1 – 3 weeks) (Esteve-Lanao et al. 2005; Thomas and Busso 2005; Aubry et al. 2014). Where previously it was thought that supercompensation relied upon athlete's physiology being stressed to the result of functional over-reaching (F-OR); classified by the transient decrement in sport-specific performance capacity, (Meeusen et al. 2006), more recent research provides evidence against this practice. Research has shown that functionally over-reached athlete's had reduced performance enhancement following rest compared to acutely fatigued athletes (no performance decrement) (Aubry et al. 2014), in addition to negative cardiovascular, hormonal (Le Meur, Hausswirth, et al. 2013) and metabolic consequences (Woods et al. 2018) as well as sleep disturbance and high prevalence of illness (Hausswirth et al. 2014). As such, it may be more beneficial to initiate recovery prior to the occurrence of F-OR, which would require the careful monitoring of individual responses to training.

Classically, exhaustive time-trial protocols have been used within research to distinguish individuals presenting with F-OR (Coutts, Wallace and Slattery 2007; Bosquet, Léger and Legros 2001). However, time-trials would be unsuitable for athletes to complete on a weekly basis in order to monitor the early signs of over-reaching. In Chapters 3 and 4 the $vSRT_{RPE}$ showed large associations with $v\dot{V}O_{2max}$ and time trial performance (12minTT). It is therefore possible to suggest that the SRT_{RPE} might be an insightful proxy measure of stagnation or decrement in sport-specific performance (related to F-OR) during intensified training. In Chapter 5, the SRT_{RPE} was shown to be responsive to over-reaching and restoration of homeostasis. In particular, the reduction in v at RPE 17 and the blunting of HR_{ex} response to RPE 13 and 17 were important indicators of over-reaching, found relative to the magnitude of exercise loads imposed. However, the results of Chapter 5 are limited as the sport-specific performance of runners was not measured alongside the responses to SRT_{RPE}. Comparison of the agreements between the SRT_{RPE} responses and direct assessments of endurance performance will be important in determining the utility of the SRT_{RPE} in the diagnosis of F-OR or acute fatigue in athletes.

Several methodologies have been used in literature with the aim of functionally over-reaching participants. Previously, manipulation of the mode and intensity of training through the addition of high intensity interval training (HIIT) sessions has been successful in over-reaching participants (Jeukendrup 1992; Billat et al. 1999; Capostagno, Lambert and Lamberts 2014). However, such protocols may be limited in that each HIIT session, likely leads to large inter-individual variability in responses, dependent on each participants previous training history and experience of HIIT protocols. To better standardise the relative dose of training provided to each participant researchers have increased training volume by the same relative % of participants habitual training (Lehmann et al. 1991; Le Meur, Pichon, et al. 2013; Aubry et al. 2015; Bourdillon et al. 2018). A weekly increase of +30% – + 40% for 3-weeks has shown to lead to symptoms of over-reaching in runners (Lehmann et al. 1991; Le Meur, Pichon, et al. 2013; Aubry et al. 2015; Bourdillon et al. 2018). Lehmann et al (1991) manipulated volume of training through increasing the distance ran each week by +33% for three weeks. However, the intensity of training was not controlled leading to participants compensating for the extra volume through decreasing intensity, showing in Week 1 ~ 90% of training was completed at a low intensity (between 50 and 70% of maximum performance) compared to 98% of training in Week 4. Allowing participants to self-select intensity likely led to variance in the relative training dose provided during the intensified training period. To better standardise the relative training dose applied, the current study aims to increase the volume of training through increasing the relative % of time spent in each intensity zone as dictated by individual's ventilatory thresholds (VT1 and VT2) by +30% each week for 3-weeks compare to habitual training.

The current study aims to clarify if the SRT_{RPE} can monitor within-individual tolerance to a period of intensified training. The effect of 3-weeks over-load training on responses to the SRT_{RPE} and a 3kmTT will be assessed. Within-individual associations between SRT_{RPE} response and 3kmTT performance, will be used to assess the strength of agreement between these performance measures. The within-individual association between responses to the performance tests (SRT_{RPE} and 3kmTT) and training load variable will be used to indicate their sensitivity to intensified training. Individuals' responses to intensified training will also be assed in a case-study format.

6.2 METHODS

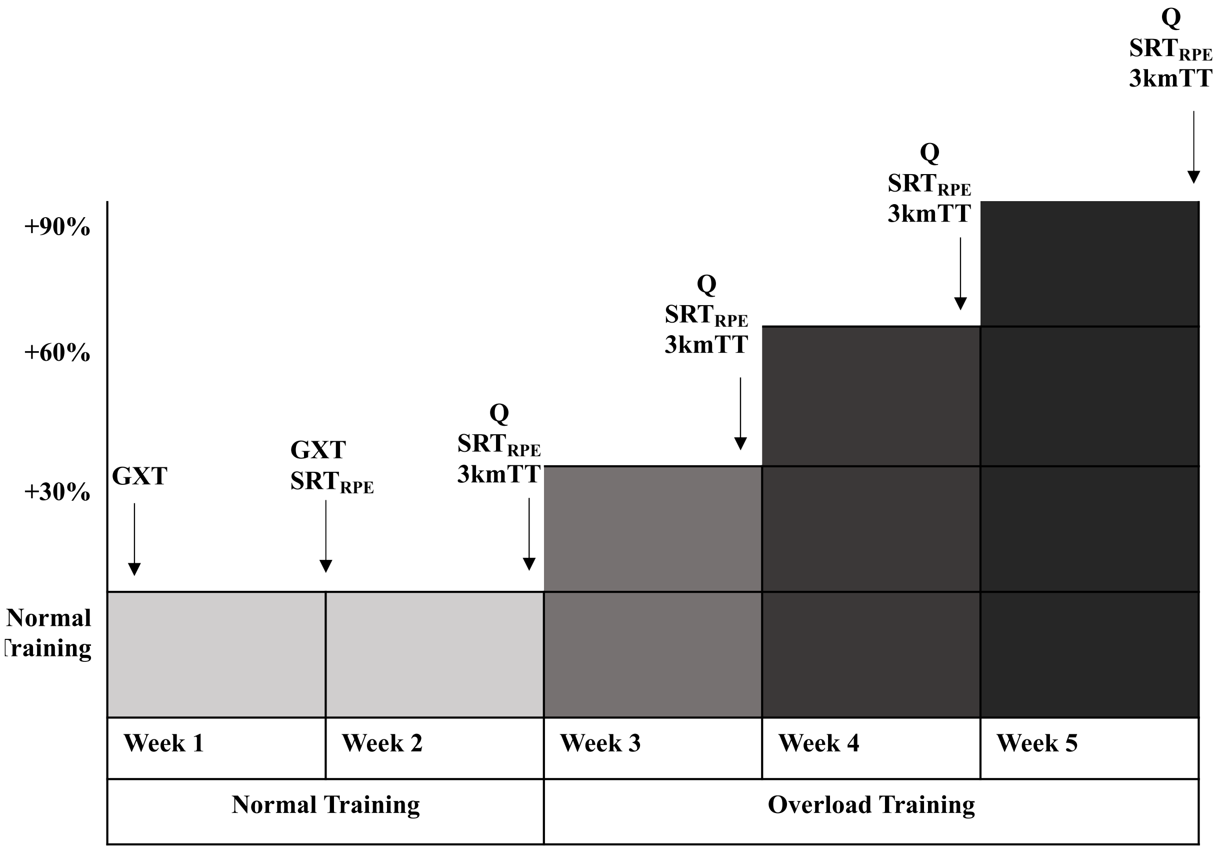
Study population

Eight competitive endurance runners: 7 males (age: 38 ±4 y; $\dot{V}O_{2max}$ 54.6 ± 4.4 $mL \cdot kg^{-1} \cdot min^{-1}$, 1 female (age 37y; $\dot{V}O_{2max}$ 53.0 $mL \cdot kg^{-1} \cdot min^{-1}$), participated in the study. All participants had over 2-year's experience of completing running-based endurance training (> 30km per week), with at least one-year competitive experience. All participants must have been completing at least 3 running session per week for > 2-years, with at least 1 high intensity interval session each week. All participants gave informed, written consent; completed a health questionnaire and confirmed that they had been free from injury in the previous 6 months. Ethical approval was obtained from the School of Sport and Exercise Science Research Ethics Advisory Group (Approval number: Prop 83_2018_19).

Study design

An overview of the study design is shown in figure 6.1. Participants were monitored over 5 weeks, divided into 2 distinct phases. Normal Training (NT) was a 2-week monitoring and familiarisation phase, in which participants completed their typical training from which average training volume (duration of training) and intensity distribution was calculate. During the second phase named Over-Load training (OL) participants completed 3-weeks of programmed training in which training volume increased weekly by +30% (OL-1) +60% (OL-2) and +90% (OL-3) of normal volume (see Training Prescription) (figure 6.1).

Participants were required to attend the laboratory on 6 occasions over the 5-week testing period. Visit 1 and 2 were completed during week 1, and at the end of week of NT. At visit 1 and 2, Participants complete two graded exercise tests (GXT), separated by 48 hours recovery, to obtain values for ventilatory threshold 1 (VT1), and ventilatory threshold 2 (VT2) and maximal aerobic capacity ($\dot{V}O_{2max}$) required to calculate training intensity distribution (Manzi et al. 2009). Following their first GXT and a 20-min passive recovery, participants completed a familiarisation of the SRT_{RPE}. Visit 3, 4, 5 and 6 were completed on day 1,7,14 and 21 of the of the 3-week training period. Upon arrival at each visit participants completed the DALDA questionnaire and The Jackson 8 symptom illness questionnaire. Participants then completed the SRT$_{RPE}$ as a warm-up prior to completion of a 3km time trial (3kmTT) on a synthetic track.



Key

GXT = Graded exercise test

SRT$_{RPE}$ = Self-paced submaximal run test

3kmTT = Three-kilometer time trial

Q = Questionnaires

Figure 6. 1 Study Schematic

Maximal incremental run test.

Participants undertook two, two-phase GXT for the assessment of individual B[La] profile and $\dot{V}O_{2max}$ as described in Chapter 2. In summary, participants completed a 5-min warm up (7–8 km·h^{-1}). Phase-one assessed B[La] profile and was comprised of 5–7 submaximal exercise bouts with running velocity increasing by 1 km·h^{-1} every 4-min, until capillary blood lactate concentration exceeded 4 mmol·L^{-1}. Phase-two proceeded following a 10-min recovery; initiated at the same starting v as phase one and increased by 0.5 km·h^{-1} every min until participants reached volitional exhaustion. $\dot{V}O_{2max}$ was determined as the highest 30-s average oxygen uptake (ACSM 2014). Maximal effort was accepted by attainment of at least two of the following criteria: heart rate within 10 beats·min^{-1} of age-predicted maximum; RER ≥ 1.10; RPE ≥ 17; and B[La] ≥ 8 mmol·L^{-1}. HR_{max}) was considered the highest recorded heart rate. The v at the point of the 30-s average $\dot{V}O_{2max}$ was recorded ($v\dot{V}O_{2max}$).

Determination of ventilatory thresholds.

Determination of both the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) were made by visual inspection of graphs of time plotted against each relevant respiratory variable (according to 5-s time-averaging). The criteria for VT1 were an increase in $VE/\dot{V}O_2$ with no concurrent increase in $VE/\dot{V}CO_2$ and departure from the linearity of VE. The criteria for VT2 were a simultaneous increase in both $VE/\dot{V}O_2$ and $VE/\dot{V}CO_2$.

Training Monitoring

All participants were instructed to record both v and heart rate (HR_{ex}) using a Bluetooth chest strap and wrist-watch GPS monitor (1 Hz sampling rate) during all running sessions. The time distribution was subsequently calculated using three zones: 1) <VT1, 2) VT1-VT2, 3) >VT2, based on HR_{ex}.

Individualised Training Impulses (iTRIMP).

Exercise load was estimated using the validated method of iTRIMP (Sanders et al. 2017), through the following equation.

$$\sum_{s=1}^{n} (t_s \times \Delta HR_s \times y)$$

Where**, n**= Total Number of heart rate samples; **s**= heart rate sample; ***t*** **=**Duration (time, mins), **ΔHR_s**= Sample mean fractional elevation in heart rate; **y** Weighting factor: $ae^{b\Delta HRs}$

Where for $\mathbf{ae^{b\Delta HRs}}$; **a** = individual ΔHR–B[La] intercept*, **b** = individual ΔHR–B[La] growth factor*, ***e*** = base of the Napierian (natural) logarithm.

Training Stress Score (rTSS)

rTSS was calculated using the following equation (McGregor, Weese and Ratz 2009)**.**

$$\mathrm{rTSS} = \frac{\mathrm{time\ (s)\ x\ NP\ x\ IF}}{3{,}600 - \mathrm{s\ x\ TP}}$$

Where, **NP** = Normalised pace, calculated using TrainingPeaks software accounting for variance in gradient; **FTP** = threshold pace in which v VT2 was used. **IF =** Intensity factor, calculated from the following equation.

$$IF = \frac{NP}{FTP}$$

Training Prescription.

During Normal Training (NT), participants completed their normal training for two full weeks (14-days). The weekly (7-day) training volume (duration) was recorded, and duration of time spent training in each <VT1, VT1–VT2 and >VT2 based on running v. The data from each participant's GXT and 3kmTT were also included in this analysis. The average training duration and time in each training zone between week 1 and week 2 was concluded to represent each participant normal training load (NT). From this, the total duration was subsequently increased by +30%, +60% and +90% in Week OL-1, OL-2 and OL-3 of the OL phase. The relative time in each training zone was maintained. Daily training loads were based on time goals rather than distance, with the intent of controlling the relative time in each zone by prescribing target velocities for each session, including the 3kmTT in which time and intensity was predicted based on baseline measures. A criteria of > 10% increase in training volume was required to keep participants within the study.

Daily Analyses of Life Demands for Athletes (DALDA)

Participants were required to complete the DALDA questionnaire (Rushall 1990) at laboratory visits immediately prior to completion of the $\mathrm{SRT}_{\mathrm{RPE}}$ and at the same time of day, on days 1,7,14 and 21 of the of the 3-week OL phase (figure 6.1). DALDA assessed general stress levels (Part A) and stress-reaction symptoms (Part B). Participant rated each variable as being 'worse than normal', 'normal' or 'better than normal'.

Illness Questionnaire

The Jackson 8 symptom illness questionnaire was used to determine the severity of upper respiratory tract infections and illness on days 1,7,14 and 21 of the of the 3-week OL training phase. Eight symptoms of upper respiratory tract infection were presented to participants who were asked to rate the severity of symptoms on a scale of 0 (none) to 3 (severe). If participants showed a score >2 in each of the symptoms on the scale were withdrawn from the study (Taylor et al. 2010).

The Self-paced Submaximal Run Test (SRT_{RPE})

The SRT_{RPE} was performed as specified in Chapter 2. In brief, participants completed three, 3-min stages interspersed by 1-min recovery with submaximal exercise intensity prescribed by RPE 10, RPE 13 and RPE 17. Participant v was recorded using the Garmin Forerunner 235 (1 Hz sampling rate) and HR_{ex} using a Polar H10 heart rate monitor (sampling rate of 1Hz). In calculating average v and HR_{ex} at each stage, the first 120-s of v and HR_{ex} data was excluded to ensure the target pace based on RPE and knowledge of the 3-min endpoint had been reached. Following familiarisation (visit 2; Week 2 NT) participants completed the SRT_{RPE} at the same time of day exactly 7-days apart on days 1,7,14 and 21 of the of the 3-week OL phase. All participants completed a 24-hour recovery prior to each SRT_{RPE}. Windspeed 1.1 m/s (range = 0.4 m/s–1.8 m/s), temperature 7.5 ºC (range = 2ºC – 14ºC)

Performance test (3kmTT)

The participants completed a 3km running time trial (3kmTT) on days 1,7,14 and 21 of the of the 3-week OL training phase. The 3kmTT was used as an alternative to the 12minTT in Chapter 4, as the performance measure of time taken (seconds [-s]) as opposed to distance covered (meters [m]) was thought to be more reliable and precise for monitoring small changes in performance over time based upon the measurement error reported by the GPS devices used to analyse distance covered on the track in Chapter 4. In addition, previous literature reporting within-individual variances in time taken for a 3kmTT was more readily available compared with distance covered in a 12minTT; this information is required for the calculation of thresholds for meaningful changes in within-individual performance (Swinton 2018) (see section statistical analysis- individual case studies). The SRT_{RPE} was performed prior as a warm-up, followed by 5-mins of stretching, prior to each 3kmTT. The time trial was performed individuals on the inside lane of an outdoor 400m synthetic running track. Throughout the 3kmTT, the participants were verbally encouraged, however, participants were not informed of their lap splits. Each 3kmTT was performed at the same time of day. Participants v was recorded using the Garmin

Forerunner 235 (1 Hz sampling rate) and HR_{ex} using a Polar H10 heart rate monitor (sampling rate of 1Hz). Participants were blinded to their v and the time elapsed using a sweat-band or sleave to cover the watch phase. Average v of the 3kmTT was considered the v average from start to finish of the completed distance.

Statistical analysis

Eight participants started the training intervention. One participant removed themselves from the study due injury in Week OL-2 and their data is not included in any final analysis. Of the 7 participants who completed the full 3-week over-load, the data from 1 participant was removed from the group analysis of data at OL-2 and 1 participant from OL-3 as they did not complete the minimum >10% change in training volume during this training week. Mean imputation was used to fill the missing data during one way ANOVA with RM (described below). Only data from the 5 participants who successfully completed >10% increase in training duration throughout the 3-week over-load were included in the minimum effects test. All data from all participants was used for within-individual analysis using the general linear model.

Group analysis

Data are expressed as mean ± standard deviation (SD) for all parametric data including Training load metrics (training duration, iTRIMP, rTSS), v ($km \cdot h^{-1}$) and HR-RS Index (Au) at each stage of the SRT_{RPE}, v ($km \cdot h^{-1}$) and time (s) 3kmTT, while nonparametric data (DALDA) were expressed as median (interquartile ranges). Assumptions of statistical tests such as the normal distribution, equality of variance and sphericity of data were checked using the Shapiro-Wilk, Levene’s and Mauchly’s tests respectively. Where the assumption of sphericity was violated the Greenhouse-Geiser adjustment was applied to the degrees of freedom. Where appropriate, post-hoc tests using the Bonferroni correction were applied. A One-way ANOVA with repeated measures (RM) with mean imposed for missing data was used to compare training load metrics (training duration, iTRIMP, rTSS), v ($km \cdot h^{-1}$) and HR-RS Index (Au) at each stage of the SRT_{RPE}, average v 3kmTT, and 3kmTT time (s) DALDA ‘worse than scores’ over 4 time points (NT, Week 1-OL, Week 2-OL, Week 3-OL). Significance level was set at alpha $P<0.05$.

The percentage change (Mean [90% CI]) in training load metrics (training duration, iTRIMP, rTSS), v ($km \cdot h^{-1}$) at each SRT_{RPE} stage and 3kmTT time were calculated between NT and the end of OL training (NT – OL-3) as well as weekly percentage between: NT – OL1, OL1 – OL2 and OL2 – OL3). Nonparametric data (DALDA scores) were expressed as median (interquartile ranges). The DALDA was assessed by the number of ‘worse than’ scores for symptoms of stress that were scored at each time point.

A minimum effects test (MET) was used to provide a practical, probabilistic interpretation of significant performance changes (Murphy and Myors 1999). The *P*-value from a dependent (paired) samples *t*-tests assessing changes v (km·h^{-1}) and HR-RS Index (Au) at each stage of the SRT$_{RPE}$ and 3km TT time (s) between the pairs; NT– OL-3, NT – OL1, OL1 – OL2 and OL2 – OL3 was used in analysis (n=5). The threshold for meaningful change in v (km·h^{-1}) at RPE 10 , 13 and 17 was set at 0.26, 0.14 and 0.18 km·h^{-1} respectively (see Chapter 3). In the absence of such a threshold for HR-RS index and 3kmTT time, the thresholds for a meaningful change were estimated using 0.2 of the between-participant standard deviation from baseline (Phase I testing) for HR-RS at RPE 10 (=0.19 AU), HR-RS at RPE 13 (= 0.39 AU), HR-RS at RPE17 (= 0.28 AU) and 3kmTT time (11-s).

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Using Statistical Analysis System (SAS®) software (University Edition, SAS Institute Inc., Cary, NC, USA) a general linear model (ANCOVA, PROC GLM) was used to assess overall within-individual correlations. Firstly, 3kmTT time was specified as the depended variable and v and HR-RS Index at each SRT$_{RPE}$ stage were separately regressed as continuous covariates. Secondly, v and HR-RS at each stage of the SRT$_{RPE}$ and 3kmTT time were specified as the depended variables and training load (duration, iTRIMP, rTSS) was separately regressed a continuous covariate. Participant ID was then added as a categorical factor with unequal slopes and intercepts. The overall within-participant correlation and corresponding confidence intervals were then calculated as per Bland and Altman method (Bland and Altman 1995a; Altman and Bland 2011) using the model sum of squares. The strength of correlations were determined using the following criteria: trivial (<0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9), almost perfect (0.9 – 1.0) (Batterham and Hopkins 2006)

Individual Case Studies

Five participants complied with the minimum requirement of a >10% increase in week-week training volume during the OL training phase. The individual results of each 5 participants have been interpreted in a case-by case manner. For individual’s analysis of a positive or negative response, CI for the true change score was calculate based on the observed change ± adjusted typical error (Hopkins 2004). Adjusted typical error was calculated as

$$Adjusted\ typical\ error\ = Typical\ error\ x\ \sqrt{2}$$

Where typical errors inputted were as follows: vRPE 10 (0.60 km·h^{-1}), vRPE 13 (0.55 km·h^{-1}) vRPE 17 (0.55 km·h^{-1}) as reporter in Chapter 3; HR-RS Index RPE 10 (1.24 Au), RPE 13 (0.73 Au) and RPE 17 (0.71 Au). From 3kmTT time previous research has shown a variability in performance of CV = 1.4% (Malcata and Hopkins 2014), using the following equation (Swinton et al. 2018):

$$Typical\ error\ = \frac{CV \times Mean_{baseline}}{100}.$$

Typical error was calculated as 9.95-s. The incidence of an individual 'response' was therefore characterised as the observed change score ± adjusted typical error clearing the value of meaningful change for the given variable, as specified above (Swinton et al. 2018; Rabbani, Kargarfard and Twist 2020).

For DALDA, where CI for the true value is not necessary, and individual response will be characterised by a value outside of the normal range. The normal range is considered, the group average for 'worse-than' symptoms of stress recorded in NT (Rushall 1990).

6.4 RESULTS

Group analysis

Training load

Table 6.1 and figure 6.2 display the mean ± SD for accumulated training loads during normal training (NT) and at each week of overload training (Week OL-1, Week OL-2 and Week OL-3). Analysis of group data describes a 45 % (90% CI; 30 – 63%) increase in training duration from NT to Week OL-1 and further + 28% (16 – 42%) and + 32% (19 – 46%) from Week OL-1 to OL-2 and Week OL-2 to Week OL-3, respectively. One way ANOVA with RM showed a significant difference in total training duration ($F_{3,18}$ = 17.30, P <0.001), iTRIMP ($F_{3,18}$ = 10.30, P <0.001) and rTSS ($F_{3,18}$ = 27.70, P <0.001). There was no significant difference intensity distribution over the 4 time points (P >0.05). Table 6.1 details the post-hoc analysis of significant change between each week.

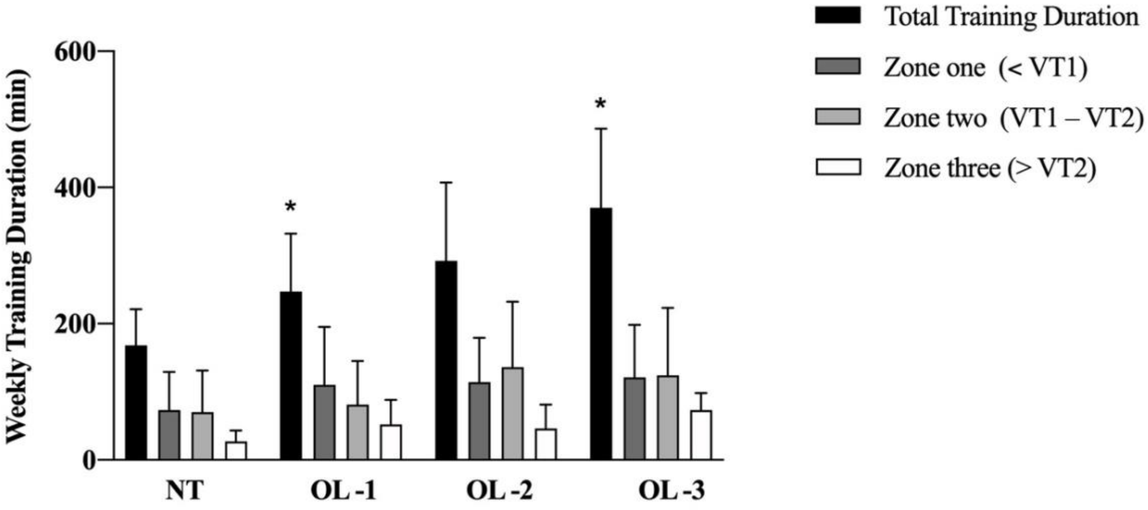

Figure 6. 2 Weekly mean ± SD total training duration and relative intensity distribution for normal training (NT) and over-load training week 1 (OL-1), week 2 (OL-2) and week 3 (OL-3). *signifies significantly different from week prior (P<0.05)

Table 6. 1 Absolute (mean ± SD) and percentage change (mean [90% CI]) in weekly training load (total duration, iTRIMP and rTSS) during 2-weeks normal training and 3-weeks over-load training.

	Accumulated weekly total (Mean± SD)				% Change in the mean (90% CI)			
	NT	**OL-1**	**OL-2**	**OL-3**	**NT – OL-3**	**NT – OL-1**	**OL-1 – OL-2**	**OL-2 – OL-3**
Total Training Duration (Minutes)	168 ± 53	247 ± 85*	292 ± 116	361 ± 160*	138 (110 – 168)	45 (30 – 63)	28 (16 – 42)	32 (19 – 46)
iTRIMP (AU)	341 ± 155	467 ± 193*	548 ± 255	632 ± 300	121 (63 – 199)	42 (20 – 68)	29 (13 – 46)	24 (-13 – 77)
rTSS (AU)	290 ± 77	370 ± 97*	435 ± 99*	512 ± 148*	77 (58 – 95)	29 (19 – 39)	20 (9 – 29)	15 (7 – 23)

Abbreviations: NT (Normal training), OL-1 (Week 1 of Over-load Training) OL-2 (Week 2 of Over-load Training), OL-3 (Week 2 of Over-load Training), iTRIMP (individualised training impulse), rTSS (Running training stress score) * significantly different from week before (*P*<0.05)

DALDA

Number of 'worse than' scores for symptoms of stress are depicted as Median (Interquartile range) at each time point in figure 6.3. Statistical analysis showed no significant variance in DALDA over the 4 time points: $F_{3,18} = 1.34$, $P = 0.292$. Results showed the greatest value of 'worse than scores' following week OL-3 (3[inter quartile range; 2 – 4] worse than scores), however this was not significantly different from OL-2 ($P>0.05$).

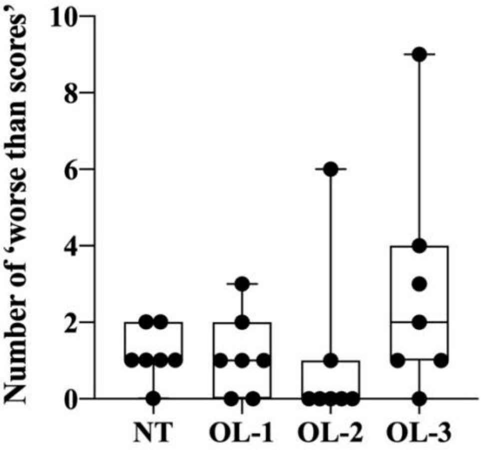

Figure 6. 3 Number of 'worse than' scores for symptoms of stress as reported by the DALDA Questionnaire. The boxes show mean values and interquartile ranges. Each marker represents each participant's value.

3kmTT Performance

There was no significant effect of 3-weeks intensified training on v 3kmTT ($F_{3,18} = 0.840$, $P = 0.968$) or 3kmTT time ($F_{3,18} = 0.188$, $P = 0.902$). There was a mean change of -1.18 % (90% CI; -4.51 – 2.16%) in 3kmTT time from NT to Week 3-OL (table 6.2). This was not shown to be a meaningful change in performance ($p_{\mathrm{MET}} >0.05$) (figure 6.4).

v SRT_{RPE}

ANOVA demonstrated no significant change in vRPE 10 nor vRPE 17 over time points ($P<0.05$), however, there was a significant effect of training week on vRPE 13 ($F_{3,18} = 3.49$, $P = 0.037$) . Results show a meaningful decrease in v at RPE 13 From NT to OL-3 (-0.76 km·h^{-1} [90% CI; -1.39 – -0.14 km·h^{-1}]) (table 6.2). There was a meaningful increase in v RPE 13 from the end of Week OL-1 to OL-2 (0.58 km·h^{-1}[0.14 – 0.86 km·h^{-1}]) (figure 6.4).

Table 6. 2 Mean (90% CI) change in 3kmTT and SRT_{RPE} performance.

	Δ NT – OL-3	**Δ NT-OL-1**	**ΔOL-1 – OL-2**	**ΔOL-2 – OL-3**
3kmTT				
s	-9	-5	-7	5
	(-33 – 16)	(20 –10)	(-24 – 9)	(-3 –14)
%	-1.18	-0.72	-0.95	0.48
	(-4.51 – 2.16)	(-2.5 –1.24)	(-0.99 – -3.33)	(-0.54 –2.10)
p_{MET}	0.54	0.79	0.61	0.87
vRPE 10				
$\text{km}\cdot\text{h}^{-1}$	0.15	-0.54	0.42	0.22
	(-0.46 – 0.61)	(-1.07 – -0.01)	(-0.13 – 0.96)	(-0.58 – 1.02)
%	-1.03	-4.19	3.77	2.16
	(-3.55 – 1.48)	(-8.6 – -0.11)	(-1.26 – 8.52)	(-5.18 – 8.88)
p_{MET}	0.74	0.17	0.29	0.54
vRPE 13				
$\text{km}\cdot\text{h}^{-1}$	-0.76*	-0.70	0.58*	-0.28
	(-1.39 – -0.14)	(-1.40 – 0.00)	(0.14 – 0.86)	(-0.74 – 0.17)
%	5.37*	-4.86	4.75*	-2.05
	(-9.76 – -0.99	(-10.39 – 0.14)	(1.31 – 8.05)	(-5.32 –1.29)
p_{MET}	0.05	0.09	0.04	0.28

vRPE 17				
km·h^{-1}	-0.45	-0.25	0.32	-0.18
	(-1.10 – 0.20)	(-0.78 – 0.28)	(-0.07 – 0.71)	(-0.70 – 0.33)
%	-3.05	-1.71	1.93	-1.06
	(-7.41 – 1.32)	(-5.03 – 1.60)	(-0.66 – 4.53)	(-4.42 – 2.31)
p_{MET}	0.22	0.38	0.24	0.48

Abbreviations: 3kmTT (three kilometre time trial) v (Velocity) RPE (Rating of Perceived Exertion) p_{MET} (probably that a meaningfully positive change occurred) *(meaningfully positive change from baseline $P \leq 0.05$

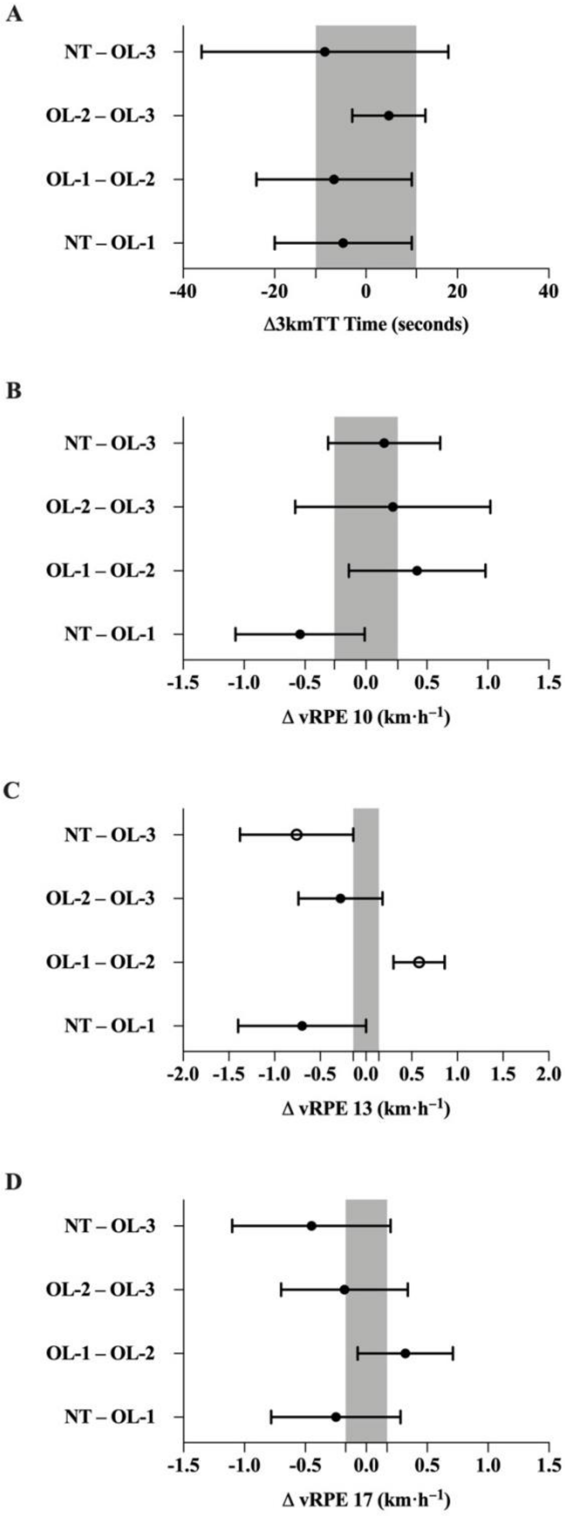

Figure 6.4. Group mean weekly change (90% confidence interval) for (A) v3kmTT time, (B) vRPE 10, (C) vRPE 13, (D) vRPE 17, with time-point on the y axis. Markers are mean change, with 90% CI shown by bars either side. Open circles represent a meaningfully different change (P_{MET} <0.05). The grey bar represents the threshold for meaningful change in each parameter.

HR-RS Index

There was no significant change in HR-RS Index at each stage of the SRT_{RPE} over time ($P > 0.05$), There was no meaningful change in HR-RS Index between each time point ($p_{MET} > 0.05$) (table 6.3)

Table 6. 3 Mean (90% CI) change in HR-RS Index at each stage of the SRT_{RPE} .

HR-RS Index	**Δ NT – OL-3**	**Δ NT – OL-1**	**Δ OL-1 – OL-2**	**Δ OL-1 – OL-2**
RPE 10				
AU	0.27 (-0.27 – 0.81)	-1.11 (-2.50 – 0.28)	2.03 (-0.03 – 4.09)	0.21 (-0.94 – 1.36)
p_{MET}	0.39	0.13	0.07	0.49
RPE 13				
AU	0.78 (0.12 –1.44)	-0.60 (-1.90 – 0.69)	1.93 (0.13 – 3.74)	0.31 (-0.03 – 0.64)
p_{MET}	0.15	0.38	0.07	0.67
RPE 17				
AU	0.79 (0.21 – 1.36)	0.38 (0.04 – 0.72)	0.59 (-0.06 – 1.25)	0.06 (-0.65 – 0.77)
p_{MET}	0.05	0.22	0.16	0.46

Abbreviations: 3kmTT (three-kilometre time trial) v (Velocity) RPE (Rating of Perceived Exertion) p_{MET} (probably that a meaningfully positive change occurred) *(meaningfully positive change from baseline $p_{MET} \leq 0.05$)

Within-individual associations

The within-individual associations between SRT_{RPE} responses with 3kmTT are displayed in table 6.4 (n=7). Within-individual change in 3kmTT performance share trivial – moderate negative association with v at each stage of the SRT_{RPE} (r range = 0.00 – -0.32), and a small – moderate positive corelation with HR-RS Index at each stage of the SRT_{RPE} (r range = 0.27 – 0.37). The within-individual associations between both 3kmTT and training load metrics (total duration, iTRIMP and rTSS) as well SRT_{RPE} with training load metrics are shown in table 6.4

Table 6. 4 Within-individual associations (90% CI)

	3kmTT (s)	Total duration (mins)	iTRIMP (Au)	rTSS (Au)
3kmTT (s)		0.10 (-0.32 – 0.48)	0.04 (-0.36 – 0.42)	0.03 (-0.37 – 0.41)
RPE 10				
v (km·h^{-1})	-0.32 (-0.65 –0.12)	-0.12 (-0.50 –0.30)	-0.06 (-0.44 – 0.35)	-0.03 (-0.42 – 0.36)
HR-RS Index (Au)	0.37 (-0.07 – 0.68)	0.17 (-0.26– 0.54)	0.20 (-0.24 – 0.57)	0.09 (-0.32 – 0.47)
RPE 13				
v (km·h^{-1})	0.00 (-0.39 – 0.38)	-0.46 (-0.74 – -0.04)	-0.34 (-0.67 – -0.10)	-0.46 (-0.74 – -0.04)
HR-RS Index (Au)	0.32 (-0.12 –0.65)	0.34 (-0.10 – 0.66)	0.29 (-0.15 – 0.63)	0.30 (-0.14 – 0.64)
RPE 17				
v (km·h^{-1})	-0.22 (-0.58 – 0.20)	-0.30 (-0.64 – 0.14)	-0.39 (-0.70 – 0.04)	-0.46 (-0.74 – -0.04)
HR-RS Index (Au)	0.27 (-0.17 – 0.62)	0.49 (0.08 – 0.76)	0.40 (-0.03 – 0.70)	0.40 (-0.03 – 0.71)

Abbreviation: 3kmTT (Three kilometre time trial) v (Velocity) RPE(Rating of Perceived Exertion) HR-RS Index (Herat-rate run-speed index) iTRIMP (individualised training impulse) rTSS (Running training stress score)

6.5 DISCUSSION

The main aim of the current study was to assess the effects of a progressive, 3-week overload training intervention on SRT_{RPE} and 3kmTT. Results showed that mean training duration was increased throughout the intervention by +45%, +28 and +32% each week.

The current study found no main effect of 3-weeks intensified training (138% [90% CI 110-168%]) on 3kmTT time (-1.18% [-4.51 – 2.16]). In previous research Coutts et al (2007) recorded a greater magnitude of decrease in 3kmTT performance (-3.7%) in a cohort of experienced triathletes (55.7 ± 4.9 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) following completion of 2-weeks overload training (approximately 290% greater volume than NT). Bosquet, Léger and Legros (2001), reported a similar decline in maximal performance ability as the current study, showing a -2% decrease in maximal aerobic speed (from treadmill based incremental exercise test) within a cohort of 10 moderately – well trained male endurance runners, following 3-weeks training (in which training volume was successively increased from baseline by 33%, 66% and 100%).

In the current study, of the 5 participants who completed the full 3-week OL intervention(increasing training duration by >10% each week) one displayed a meaningful decreased in 3kmTT time (change in performance exceeded the SWC of 10-s), three displayed a non-meaningful change (stagnation) in 3kmTT and one displayed a meaningful increase in 3kmTT performance following the 3-week OL training phase. This provides evidence that the training volume was not significant enough to elicit an over-reaching response in most participants. In comparison to previous research which used a similar relative increase in training volume (+40%) (Le Meur et al. 2013), participants weekly training volume was 16.8 ± 0.9 hours during intensified training, while Coutts et al (2017) reported a training volume of 19.9 ± 4.7 for participants of their study. This absolute training volume is significantly greater than the average 6-hours completed by the current cohort in week OL-3. With this comparison, it is likely that the lower habitual training volumes of the current study cohort meant they had a greater range within which additional training would have been tolerated. As such, a greater relative increase in volume could have been applied.

Variability in the number of participants categorised as over-reached within studies is also highly influenced by the methodology used to set the thresholds for meaningful changes in performance measures. Bourdillon et al (2017), assessed individual response of 15 recreational athletes (>4-hours training each week in their given sport) to 2-weeks training in which volume increased +40%. The authors reported that 8 participants displayed meaningful improvements, while 7 participants displayed meaningful decreases in 3kmTT performance using a threshold of 5-s to define a meaningful change. This threshold was chosen as it represented 50% of the mean-change between baseline and over-load. This threshold is smaller than that estimated to represent a SWC in the current study, as Bourdillon et al (2017) did not account for the error in the observed values. This highlights the discrepancy in statistical analysis of meaningful changes in responses, making comparison of the effect of a similar intervention (+40% volume increase) between studies a complex task.

Results of the current study reported a meaningful decrease in vRPE 13 following the 3-week training intervention (-5.37% [-9.76 – -0.99%]). This magnitude of change was greater in comparison to the change in vRPE 10 (-1.03% [-3.55 – 1.48%]) and vRPE 17 (-3.05% [7.41 – 1.32%]) over the same period. In table 6.5 the individual response of Participant A (Male, age; 43 years, height; 180 cm, weight; 78.5kg; $\dot{V}O_{2max}$ 52 $mL \cdot kg^{-1} \cdot min^{-1}$) provides a case study of the sensitivity of vRPE13. From NT to end of week OL-3 in which training volume increased by 172-min, Participant A displayed an increase in 3km TT times of 13-s. This was concomitant with a meaningful decrease in vRPE 13 (-1.6 $km \cdot h^{-1}$) with smaller, non-meaningful changes in vRPE 10 (-0.5 $km \cdot h^{-1}$) and vRPE 17 (+0.2 $km \cdot h^{-1}$).

Table 6. 5 Individual results for Participant A: Participant A was a 43 year old male (height; 180 cm, weight; 78.5kg; $\dot{V}O_{2max}$ 52 mL·kg^{-1}·min^{-1}). He competed predominantly in 10km (PB: 00:41:44) half marathon (01:33:10).

	NT	OL-1	OL-2	OL-3
Training Load				
Total duration (min)	221	249	369	393
iTRIMP (Au)	427	457	659	631
rTSS (Au)	337	384	456	516
3kmTT Time				
s	678	655	660	673
RPE 10				
v (km·h^{-1})	13.4	13.1	13.6	12.9
HR-RS Index	3.10	2.80	5.71^{ab}	3.04^{a}
RPE 13				
v (km·h^{-1})	15.8	15.9	15.8	14.2^{ab}
HR-RS Index Au	0.68	0.78	4.84^{ab}	2.36^{a}
RPE 17				
v (km·h^{-1})	16.2	16.7	17.3	16.4
HR-RS Index Au	2.17	2.89	3.05	3.03
DALDA				
Worse than scores	1	0	0	1

Abbreviations: 3kmTT (Three kilometre time trial) v (Velocity) RPE (Rating of Perceived Exertion) HR-RS Index (Heart-rate run-speed index) iTRIMP (individualised training impulses) rTSS (Running training stress score) a (meaningfully different from week before) b (meaningfully different from NT)

The finding that vRPE 13 was most greatly affected by training induced over-reaching contradicts the findings in Chapter 5, in which the mean decrease in performance at vRPE 17 (-0.78 km·h^{-1}[-0.99–-0.57 km·h^{-1}]) was greater than the decrease in vRPE 13 (-0.47 km·h^{-1}[-0.87–0.07 km·h^{-1}]) in the ~48-hours after an ultra-marathon. Previous research which used the LSCT to monitor eight professional female cyclist's ($\dot{V}O_{2max}$ 59.5 ± 5.8 mL·kg^{-1}·min^{-1}) on day 1, 5 and 8 of a training camp (Decroix, Lamberts and Meeusen 2018) showed that by day 8 of the training camp, PO measured over the last 5-min of stage 2 (80% HR_{max}) was significantly increased (14.58 ± 3.52 %, $P = 0.009$) as well as PO in the final 2-min of stage 3 (90% HR_{max} 5.0 ± 2.4%, $P = 0.09$). Similarly, to the current study, these results infer a greater un-coupling between external and internal load metrics at the middle stage (representing 80% HR_{max}) of the submaximal test. However, it is likely that the magnitude of change in PO at stage 3, reported by Decroix, Lamberts and Meeusen (2018), was under-represented as some athletes were unable to reach the 90% HR_{max} intensity required. Further research is required to confirm the superior sensitivity of this middle stage to training induced over-reaching, and the possible mechanisms driving this.

Previous research has reported significant change in submaximal performance parameters following intensified training/competition, without concomitant disruption to maximal sport specific performance (Bosquet, Léger and Legros 2001; ten Haaf et al. 2019). In the current study, the within-individual agreement between 3kmTT and SRT_{RPE} performance was examined using a general linear model. Results showed that there was only trivial to moderate agreement (*r* range = 0.00 – 0.37) between the two tests with no agreement (*r* = 0.00) between 3kmTT performance and vRPE 13. For example, Participant B (Male, age; 43 years, height; 186 cm, weight; 80.0kg; $\dot{V}O_{2max}$ 51 $mL \cdot kg^{-1} \cdot min^{-1}$) displayed a meaningful increase in 3kmTT time (+ 31-s), which was agreeably concurrent with a meaningful decrease in vRPE 13 (- 1.3 $km \cdot h^{-1}$) (table 6.6). However, a further meaningful decrease in 3kmTT performance between Week OL-2 to Week OL-3 (+ 13-s) was not in line with a further meaningful decrease in v during SRT_{RPE}; instead, a meaningful increase in HR-RS-Index (blunted HR_{ex} response) was shown. This highlights the inconsistency in how submaximal exercise responses (SRT_{RPE}) translated to sport-specific maximal performance within-individuals. The results displayed in table 6.4 show that there was a greater within-individual association between vRPE 13 and 17 with individual training load metrics (*r* range = -0.30 – -0.46), than with 3kmTT performance (*r* range = 0.00 – -0.22). This provides supporting evidence that variables limiting submaximal performance following intensified training may not limit maximal performance in the same manner.

Table 6. 6 Individual results for Participant B: Participant B was a 43 year old male (height; 186 cm, weight; 80.0kg; $\dot{V}O_{2max}$ 51 mL·kg^{-1}·min^{-1}). He was an ultra-marathon specialist competing at 50mile (PB=10:24:54) – 100mile (PB=23:57:31)

	NT	OL-1	OL-2	Ol-3
Training Load				
Total duration (min)	162	247	257	382
iTRIMP (Au)	262	486	418	537
rTSS (Au)	357	397	445	515
3kmTT Time				
s	767	798^{ab}	789	802^{b}
RPE 10				
v (km·h^{-1})	11.4	11.5	11.3	11.2
HR-RS Index	3.11	2.36	3.01	1.77
RPE 13				
v (km·h^{-1})	13.3	12^{ab}	12.5	12.7
HR-RS Index Au	1.59	2.14	2.64	3.56^{b}
RPE 17				
v (km·h^{-1})	14.3	13.5	14.1	13.9
HR-RS Index Au	1.59	2.36	2.39	3.19^{b}
DALDA				
Worse than scores	1	2	1	1

Abbreviations: 3kmTT (three kilometre time trial) v (Velocity) RPE (Rating of Perceived Exertion) HR-RS Index (Heart-rate run-speed index) iTRIMP (individualised training impulses) rTSS (Running training stress score) a (meaningfully different from week before) b (meaningfully different from NT)

Previous literature has reported blunted HR_{ex} response to submaximal exercise following intensified training (Lehmann et al. 1992; Decroix, Lamberts and Meeusen 2018). Chapter 5 similarly showed that a blunted HR_{ex} response to RPE 13 and 17 were important indicators of over-reaching; relative to the magnitude of competition loads (rTSS). In the current study, the mean HR-RS Index tended to increase from NT to end of week OL-3, at intensity RPE 13 and 17 which would be representative of a lower HR_{ex} for a given v. However, MET suggests that this was not a meaningful change. Within-individuals HR-RS Index at RPE 17 showed a moderate association with training duration (r = 0.49 [0.08 – 0.76]), which supports the findings in Chapter 5. Participant B (table 6.6) provides example of this trend, displaying a meaningful increase HR-RS index at RPE 17 from NT (1.59 Au) to the end of week OL-3 (3.19 Au). The current study sought to build upon the findings of study 5 by exploring how variance in HR-RS Index related to sport-specific performance (3kmTT). The within-individual analysis reveals only small – moderate (r range = 0.27-0.37) association with HR-RS Index and 3kmTT performance. However, in the example of Participant B, it is evident that meaningful increases in HR-RS Index at RPE 13 and RPE 17 and week OL-3 were concomitant with an increase in 3kmTT performance. The utility of monitoring HR-RS index to monitor F-OR warrants further study in a larger sample size.

The study was limited by a low sample size which increases chances of a type II error, particularly in using correlation analysis. In addition, the results are limited by not including a control group, which would have allowed the study to better control for the within-individual random variation in responses (Atkinson, Williamson and Batterham 2019). The variability in responses in the current study may have been exaggerated, in part by the method of training load manipulation. Firstly, the increase in training volume was calculated based on a relative increase from normal training; in most cases the additional duration was added onto each training session such that training schedule was maintained. However, during week OL-3, work/life commitments long duration sessions were often spit into morning and evening sessions. This therefore changed the structure of the prescribed training, which would likely have affected the global response to this weekly training load. In addition, although relative training volume was equivocally increased, duration of time spent in different intensities varied between participants and will likely have affected the magnitude and direction of responses (Hansen et al. 2005; Rønnestad, Hansen and Ellefsen 2014). Furthermore, although all participants completed 24-hour recovery prior to all testing sessions, the response at testing sessions may likely reflect the acute fatigue from previous sessions (3-days) as opposed to the accumulation of weekly volume. Given that weekly structure of training was not controlled between and within individuals, this possible variation in acute session fatigue (3-days) may have negatively affected the strength of the within-individual relationships between weekly training volume and performance responses.

Conclusions

The current study shows that a progressive increase in duration of training by a mean value of; +45%, +28 and +32% each week, did not stimulate a meaningful disruption to 3kmTT performance (-1.18% [90% CI; -4.51 – 2.16%]). The individual variation in vRPE 13 was shown to be most sensitive to the increase in training load (-5.37% [-9.76 – -0.99%]), furthermore both vRPE 13 and vRPE 17 displayed the greatest association with within-individual variance in individualised training load (rTSS), suggesting a possible utility in monitoring of responses to increase training load. An increase in HR-RS Index may be indicative of a decrease or stagnation in performance in response to intensified training, however this warrants further investigation. There was no significant association between responses of the $\mathrm{SRT}_{\mathrm{RPE}}$ with 3kmTT, suggesting that training and over-reaching differentially effects responses to submaximal and maximal exercise capacity.

7.0 General Discussion, Limitations and Future Directions

7.1 General Discussion

The overall aim of this thesis was to explore the utility of the SRT_{RPE}; a novel field-based test for monitoring responses to endurance training and competition in distance runners. The SRT_{RPE} is a novel submaximal exercise test which monitors v and HR_{ex} during 3 x 3-mins running with intensity prescribed by RPE 10, 13 and 17. Previous research has evidenced the effectiveness in assessing the relationship between the triangulated metrics; RPE, PO and HR_{ex}, through the LSCT protocol, for monitoring athletes responses to endurance-type training (Martin and Andersen 2000; Lamberts et al. 2010; Capostagno, Lambert and Lamberts 2019; Sanders et al. 2018). However, the utility of this multivariate analysis in runners, was not as thoroughly researched (Mann et al. 2015; Vesterinen, Nummela, Heikura, et al. 2016; Siegl et al. 2017). Furthermore, as outlined in section 1.7, the use of RPE to standardise exercise intensity is a novel perspective which was hypothesised to have practical benefits to users, and better replicate the psychobiological demands of competitive running.

An important initial step in assessing the utility of the SRT_{RPE} to track meaningful changes in athlete's fitness of fatigue was to quantify the measurement error in the test. Measurement error is the product of systematic bias and random error, between repeated performance tests (Hopkins, 2000). In Chapter 3 a paired samples t-test was used to assess the systematic bias; defining the magnitude of variance which may occur as a result of learning effect, differences in motivation and physical fatigue between three repeated trials. Results revealed no significant difference in the change in the mean between trials 1-2 not 2-3 for all variables of the SRT_{RPE}. This infers that participants were confident in controlling pace corresponding to the RPE scale following just one familiarisation trial. The within-participant variation (random error) in v and HR_{ex}, was quantified as the typical (standard) error of measurement: the standard deviation of an individual's repeated measurements over three trials. The typical error, expressed as a CV showed acceptable variation (CV<5%) in v (3.9 – 4.5%) and HR_{ex} (2.5 – 4.7%) at RPE 13 and 17 (Hopkins 2000). Research investigating the reliability of the perceptually regulated exercise test (PRET) had shown comparable CV for v ($\text{km}\cdot\text{h}^{-1}$) measured for 2-mins running at RPE 10 (6.4% ± 3.1%), RPE 13 (2.9% ± 1.1%) and RPE 17 (2.9% ± 0.8%) between two retest trials (Lim et al. 2016). This was also comparable to within-individual variation in v over maximal effort time trials from 5km to 10km (CV= 3.3 – 3.7%) (Laursen et al. 2007; Nicholson and Sleivert 2001). This provides evidence of comparable sensitive of the SRT_{RPE} with sport-specific time trials (considered the gold-standard for individual monitoring within endurance running) (Meeusen et al. 2013).

In Chapter 3, the measurement error was greatest for B[La] measured following each RPE stage of the SRT_{RPE}, with a CV range of 24.8 – 28.6%. These results suggest that B[La] may be too unreliable for monitoring purposes within this protocol. In addition, the B[La] values were lower at the end of each 3-min interval than would have been expected; for example despite most participants reaching a v equivalent to vLT2 at stage 2 (measured at 4 $mmol.L^{-1}$ during treadmill running), B[La] was 2.0 ± 0.6 $mmol.L^{-1}$. This may be the result of lactate not having enough time to efflux from the working muscle and appear within the capillary blood over the 3-min, submaximal interval. Commonly, intervals of 5-min or greater are recommended for the measurement of appearance of B[La] within finger-tip capillaries (Bonaventura et al. 2015). It was therefore concluded that the measurement of capillary B[La] during the SRT_{RPE}, was not an accurate representation of the metabolic demand of the interval and it was not reported within subsequent Chapters. However, the 1-min interval between each stage of the SRT_{RPE} remained. This recovery period will have influenced the pace selected by the individuals in knowing that each stage had a 3-min endpoint, followed by recovery as opposed to a 9-min total effort. This should be taken into account in future studies looking to replicate the results.

A consideration in advocating the preferential use of RPE to prescribe exercise intensity during the SRT_{RPE} over the use of $\%HR_{max}$; as previously used within the LSCT, was that RPE may allow for better standardisation of intensity around key metabolic thresholds (LT2) (Katch et al. 1978; Demello et al. 1987). Chapter 3 revealed that mean absolute difference ($km\cdot h^{-1}$) between vLT2 evaluated by GXT and v at each stage of the SRT_{RPE} was: -2.51 ± 1.58 $km\cdot h^{-1}$ for RPE 10, -0.34 ± 1.52 $km\cdot h^{-1}$ for RPE 13 and 1.53 ±1.40 $km\cdot h^{-1}$ for RPE 17. These results agree with previous literature that has shown that RPE 10 - 12 and RPE 13 - 14 correspond to the first (2 $mmol\cdot L^{-1}$) and second (4 $mmol\cdot L^{-1}$) Lactate thresholds (LT) during treadmill running in both inactive and active individuals (Eston and Williams 1988), and make a novel contribution to confirm this within a field-based setting on an outdoor track. However, it is evident that the prescription of intensity by RPE 13 still leads to a large range of responses around vLT2 between individuals (0.34 ± 1.52 $km\cdot h^{-1}$), and therefore the SRT_{RPE} is still limited in the same way as the LSCT in not being able to directly regulate intensities around this key threshold. However, no direct comparison with those prescribed by $\%HR_{max}$ were made, therefore it remains uncertain which methodology of intensity prescription may most accurately control for this between individuals. In addition, the use of RPE to prescribe intensity may still be preferentially used due to the practical considerations and relative ease of use in comparison to $\%HR_{max}$ (see section 1.7)

As discussed in section 1.1, as well as reliability the validity of a new measure must be considered (Currell and Jeukendrup 2008); referred to as the degree in which the protocol resembles the performance that is being simulated (Hopkins 2000). Chapter 3 used a correlation analysis to assess the agreement between the SRT_{RPE} and a laboratory-based graded exercise test (GXT) to determine the parameters of the SRT_{RPE} were valid markers of aerobic fitness. The results showed the v at RPE 10, 13 and 17 showed large associations with $\text{v}\dot{\text{V}}\text{O}_{2\text{max}}$ (r = 0.50 – 0.66) and vLT2 (r = 0.50 – 0.62); suggesting STR_{RPE} agreeably discriminated between individuals of varying aerobic fitness but was not accurate enough to predict parameters of the GXT from SRT_{RPE} . It was proposed that the associations between vLT2 and v during SRT_{RPE}, in particular at RPE 13, may have been limited by using a fixed criteria of 4 $\text{mmol}\cdot\text{L}^{-1}$ to determine this metabolic thresholds during GXT. The use of this fixed criteria does not take into account the large individual variability in the trajectory of a person's lactate accumulation curve. Alternatively methodologies, which may have more validly reflected individuals vLT2 is to use modelling of the inclination of the lactate curve (Keul et al. 1979) or inflection point (Machado et al. 2006), future research should look to rectify this limitation.

In Chapter 4 the between-participant association between vSRT_{RPE} and v12minTT was assessed using the Bland and Altman (Bland and Altman 1994) method for the correlation of repeated measures. Results showed large correlations for vRPE 10 (r = 0.70, 90%CI ; 0.19 – 0.91) and vRPE 13 (r =0.74, 90% CI; 0.28 – 0.93) with the strongest association of v12minTT being with vRPE17 (r = 0.78, 90% CI; 0.35 – 0.94). To the best of our knowledge this is the first study to compare responses to submaximal intensities with maximal time trial performance over a longitudinal (16-week) observation, adding to literature confirming the validity of submaximal testing in endurance performance.

The main aim of Chapter 4 was to assess the within-individual association between variance in responses to the SRT_{RPE} and endurance performance (v12inTT) over time. Although there has been some previous investigation aimed at assessing the sensitivity of submaximal performance tests to track within-participant longitudinal responses to training using the LSCT (Lamberts et al. 2010) and LSRT (Vesterinen, Nummela, Heikura, et al. 2016), this previous research used only a single case study or assessed only the between-participant correlations between pairs of change scores, pre-post a training intervention which still utilises a between-participant model. To address these limitations Chapter 4 used a linear mixed model to directly assess within-individual associations between vSRT_{RPE} and v12minTT performance over the 16-week period. Results revealed that of the three stages of the $\mathrm{SRT_{RPE}}$ the within-induvial variance in v at RPE 13 shared the strongest association with v12minTT over 16-week training period. This provides additional support for the tentative suggestion made by Capostagno, Lambert and Lamberts (2021) that performance at stage 2 of the LSCT (80%$\mathrm{HR_{max}}$) may be most informative in distinguishing between adaptors and non-adaptors to and endurance-type training intervention. A hypothesis for the superior association between vRPE 13 and v12minTT seen in Chapter 4, is that vRPE 13 represented the performance of individual at their key metabolic threshold vLT2 (as suggested in Chapter 3). Previous research has shown, that of the GXT determinants outlined in section 1.2, vLT2 was reported to be the strongest determinant of variance in 3km performance over a season; which is approximal the distance covered by participants in the 12minTT (2981 ± 282 m). Therefore, the strong association between vRPE 13 and v12minTT could similarly be a response to the beneficial adaptation to individual's performance at LT2 as results of 16-weeks training. However, individual analysis of vLT2 alongside the $\mathrm{SRT_{RPE}}$ would be required to confirm this hypothesis. An alternative hypothesis is that the 24-hour rest period between training and testing sessions was not adequate in allowing training-induced fatigue to dissipate. As shown in Chapter 5, acute fatigue most greatly affects performance at the highest intensity of RPE 17, and thus may have affected the validity of the performance recorded at this stage, and its true association with 12minTT performance.

The primary finding of Chapter 5 was that vRPE 17 showed the most variation in response to an ultra-marathon race. Results showed a meaningful change in vRPE 17 ~48-hours post-race compared to pre-race (-0.78 $\mathrm{km{\cdot}h^{-1}}$, [90% CI; -0.99 – -0.57 $\mathrm{km{\cdot}h^{-1}}$]) p_{MET} = <0.001, followed by a meaningful increase (0.83 $\mathrm{km{\cdot}h^{-1}}$, [0.46 – 1.19 $\mathrm{km{\cdot}h^{-1}}$]) p_{MET} = 0.004 between ~48-hours post-race and 7-days post-race, whereas no meaningful change was found at intensity RPE 10 and RPE 13. This confirms previous findings of an inability to produce the PO necessary to reach an intensity corresponded to 90%$\mathrm{HR_{max}}$ in cyclists following 8-days of intensified training load. In addition, previous research has shown that 2-days following acute eccentrical muscle damage, self-paced time trial performance (30-min TTE on a treadmill) in runners was significantly reduced by 4% resulting from of a significant decrease in performance v (pre-test 13.9 ± 1.7 $\mathrm{km{\cdot}h^{-1}}$, post-test 13.6 ± 1.7 $\mathrm{km{\cdot}h^{-1}}$) with no change in the perceived effort of the test (Marcora and Bosio 2007). However, this is the first study, to our knowledge to quantify the reduction of performance output (v) at RPE prescribed intensities (specifically RPE 17) following fatigue endurance-based exercise in runners.

Chapter 5 used the HR-RS index to calculate the absolute difference in the theoretical and actual HR_{ex} for a given v, results showed no meaningful difference in the group mean HR-RS Index at each stage of the SRT_{RPE} ~48-hours following ultra-marathon race. This conflicts with previous research which showed a significant blunting in HR_{ex} at 70% PTRS (-3 beats·min^{-1}) and 85% PTRS (-2 beats·min^{-1}) 2-days following a 56km Ultra-marathon (Siegl et al. 2017). In addition, a decrease in submaximal HR_{ex} associated with a given external load has also been recorded shortly following (65-hours) (Hammes et al. 2016) and in the 3 – 6 days (ten Haaf et al. 2019; Decroix, Lamberts and Meeusen 2018) following participation in intensive training in cyclists. This discrepancy is likely due to the large individual variability in responses to the 6-hour ultra-marathon. As such, a corelation analysis was used to assess the dose-response relationship between training load (dose) and SRT_{RPE} (response). Results showed that the magnitude of depression of HR_{ex} and time course of recovery is associated to the size of the individual training stress. Results showed an almost mirrored first positive (r = 0.59) to negative (r = -0.68) association between HR-RS Index at RPE 13 and rTSS suggest that those with greater rTSS showed the greatest decrease in HR_{ex} and v at RPE 13 at ~48-hours post-race, which recovered by 7-days post-race. Conversely, for RPE 17 the negative association between rTSS and HR-RS Index at 7-days post, suggests those who experience a lower rTSS maintained a depressed HR_{ex}, despite recovering v.

In Chapter 6, a similar effect of training was translated through analysis of the HR-RS Index. There was no meaningful change in HR-RS Index between normal training (NT) and 3-weeks over-load training, however there was a tendency for HR-RS Index to be elevated at RPE 13 (+0.78 Au [0.12 –1.44 Au]) and RPE 17 (+0.79 Au [0.21 – 1.36 Au]). HR-RS Index shared a moderate correlation with training duration at all stages, with the greatest association between HR-RS Index at RPE 17 and weekly training duration (r= 0.49, 90% CI: 0.08 – 0.76). This suggests that HR-RS Index at RPE 17 may be an important indicator of individual responses to weekly training load. Through individual case studies there was some evidence of agreement between an increase in HR-RS Index and either a decrease or stagnation in 3kmTT performance, however further study is required to ascertain the value at with HR-RS Index becomes an indicator of mal-adaptation to training. The result of both Chapter 5 and 6 make an important contribution to literature supporting the use of multivariate analysis (RPE, HR_{ex} and v) for monitoring responses to training and confirms the sensitivity of the SRT_{RPE} to within-individual responses to and recovery form high training/competition loads.

7.2 General Limitations

Table 7.1 displays that Chapter 6 in particular is limited by a low sample size, which largely increases the chances of a type II error when analysing the main effects, and reduced ability to use correlation and linear regression models as had been planned (Hecksteden et al. 2015).

Table 7. 1 Post-hoc power analysis (calculated in G*power version 3.1)

Chapter	Number of participants	Effect size ($\eta_p{}^{2)}$	Achieved power (1-β)
3	11	0.02	0.86
4	9	0.16	0.72
5	11	0.09	0.97
6	5	0.25	0.51

Abbreviations: ηp2 (partial eta-squared) achieved power (probability of a type II error) calculations using G*power

During recruitment for the research of this thesis, the criteria and methods of distribution of material did not change. A cohort of recreational runners was selected for reasons with are predominantly two fold; firstly, the SRT_{RPE} is most desirable for this group of athletes as they likely do not have the funds to repeatedly use laboratory protocols to monitor performance yet have a requirement for frequent testing driven by an interest to optimise training for improvement of competitive performance. Secondly, this was largely shaped by the local accessibility to recreation athletes and their availability to participate in the research studies. This had its benefits in being able to compare studies within the thesis and use results from Chapter 3 and 4 to set realistic meaningful changes in future studies. However, this limits the ability of the results of this thesis to be translated to other population groups. This was shown in Chapter 3 when the cohort was separated based on gender, female participant's displayed greater associations between SRT_{RPE} responses and GXT results; consequential of lower values of v in SRT_{RPE} and GXT parameters, when compared to males who 'clustered' higher on both. These results highlight the potential constraints in generalising overall correlation results to more homogeneous subset (e.g., elite cohorts).

A specific aim of the thesis, highlighted in Chapters 4 – 6, was to examine the sensitivity of the SRT_{RPE} to track within-individual response to training and competition. In order to precisely assess within-individual responses it is important to use appropriate statistics to ascertain if variation is a result of an inherent physiological response which is a repeatable effect, or, the outcome of within-individual random error. A collection of recent publications has highlighted the limitation in the current thesis in not including a control group (Padilla, Leary and Limberg 2020; Islam and Gurd 2020; Atkinson, Williamson and Batterham 2019; Hopkins 2018) potentially limiting the ability in accurately elucidating the effects in endurance exercise (Chapter 5) and training (Chapter 6) of individual response to the SRT_{RPE} . The current 'gold-standard' approach to appropriately quantifying the typical inter-individual difference in response described by (Atkinson, Williamson and Batterham 2019; Hopkins 2018) involves calculating the difference in standard deviations (SD) of the changes between intervention and control groups. This SD represents the typical true inter-individual variation in response, with accounts for the influence of random error (removal of 'noise'). Unfortunately, by not including a control group it was not possible to account for random error. In an attempt to control for random error, the current thesis used the value for the within-individual SD calculated as the typical error of measurement in Chapter 3. This typical error was then added to the observed value which provides around 68% confidence interval for the true response value (Atkinson and Nevill 1998). A larger 90% confidence interval can be calculated using the TE as described (Hopkins et al. 2009). However, in doing this, the width of values was too large for any effect to be seen within studies, and therefore the TE and adjusted TE for change values was used instead. The practical importance of this change was then defined by ability of the observed value + TE to completely cross the threshold set by either the results of Chapter 3 (change associated with a meaningful variation in TT performance) or 0.2* SD of baseline. This statistical approach to assessing true individual response, goes further than other studies in this field of research (Siegl et al. 2017; Vesterinen, Nummela, Äyrämö, et al. 2016; Nuuttila et al. 2020). However, future research should include a control group and follow the statistical approach outlined by Atkinson, Williamson and Batterham (2019).

Lastly, the measurement error within each study will be affected in part by the HR monitor and GPS devices. The Polar H7 heart rate monitor was used constantly through the thesis and has a reported reliability of < 4% error (Polar Research and Technology, 2019). However, in Chapter 3 and 4 the GPS device used was the Polar V800, while in Chapters 5 and 6 the Garmin forerunner 45 was used. As the reliability test was performed in the Polar

V800, the measurement error will have been included in the typical error assessed, however the error in the Garmin forerunner 45 was not specifically accounted for. Future research would be advised to complete their own reliability analyse on the equipment used in order to account for this error in analysis.

7.3 Future Directions

A future direction would be to assess the transferability of the SRT_{RPE} across different exercise modalities. Since it's conception the LSCT (Lamberts et al. 2011) has been adapted for running (Vesterinen, Nummela, Äyrämö, et al. 2016; Nuuttila et al. 2020) and rowing (Otter et al. 2015), showing the utility of submaximal testing within a range of sports. The use of RPE prescribed intensities has largely focused on cycling and running (Foster et al. 2001; Eston 2012; Scherr et al. 2013). Edwards and Lander (2012) compared the responses to RPE clamped exercise in the same individual completing running and rowing. The results showed that for the 20-min exercise at the same RPE clamped intensity (RPE 15) the relative work intensity (%$\dot{V}O_{2max}$) was greater in treadmill running than rowing ergometry (86.1% vs. 83.7%; respectively $P<0.05$), with a higher heart rate (174.7 ± 5.9 vs. 165.5 ± 6.6; respectively $P<0.01$) and larger pre- to post-test change in blood lactate concentration from rest (Δ La: 4.0 ± 0.8 $mmol \cdot l^{-1}$ vs. 3.3 ± 1.2 $mmol \cdot l^{-1}$). This difference was thought to result in part from a lower placement of the ventilatory threshold as a % $\dot{V}O_{2max}$ in rowing than running (73% vs. 78% respectively) causing participants to pace RPE 15 at a lower relative intensity when rowing. The monitoring of relative workload (%HR_{max}; %Peak PO /v) during the SRT_{RPE} may be an insightful between-modalities tool to compare aerobic fitness levels across sports, while external load (v/PO) and HR-RS Index may be useful indicators of within-induvial responses over a range of modalities.

It would be interesting to explore the use of the SRT_{RPE} to monitor response to training in a greater range of population groups (youth, masters and elite). Children have shown to be able to reliably use the RPE scale (Mahon and Marsh 1992) and in a comparison of youth and older endurance athletes Borg 6-20 rating at a given a given %HR_{max} and %$\dot{V}O_{2max}$ was not significantly different between age groups (Perez-Landaluce et al. 2002). However, children's lactate threshold is shown to occur at a higher % of their VO_{2max} when compared with adult counterparts (Pfitzinger and Freedson 1997). It would therefore be insightful to assess the utility of the SRT_{RPE} to assess aerobic fitness between age groups and its ability to assess within-individual responses to training. Finally, the use to the SRT_{RPE} in elite athletes should be explored. The proposal of the central regulatory theory states that prior experience and familiarity of task requirements are key determinants of pacing judgments (Tucker 2009). Therefore, it could be hypothesised that elite athletes would produce greater test-retest reliability within the SRT_{RPE}. However, their success within competitions also relies upon more marginal differences, requiring testing methodologies to be highly sensitive to small changes in performance. The time efficient, non-invasive nature of the SRT$_{\text{RPE}}$ could help gain athlete and coach buy in (Thorpe et al. 2017), as such, the use of the SRT$_{\text{RPE}}$ in elite sport would be interesting to investigate.

Furthermore, the non-invasive, time efficient nature of the SRT$_{\text{RPE}}$ could advocate for its use in clinical populations. The beneficial use of perceptually regulated exercises tests in clinical populations is well recognised as they have been shown to be more ‘pleasant’ and practical for patients (Parfitt, Evans and Eston 2012). In addition, the use of the SRT$_{\text{RPE}}$ in particular, which uses RPE to prescribe intensity and v as a main outcome, may be beneficial as HR$_{\text{ex}}$ is highly affected by a number of medical conditions medical conditions (e.g., hypertension; Schultz et al. 2016) or medication (e.g. beta blockade; Eston and Connolly 1996) and subsequently increasing error in its measurement and inaccuracy in its use to prescribe intensities. Previous research has shown that even inactive participants are able to validly use self-paced efforts corresponding to RPE (Coquart et al. 2014). Therefore, future research may be interested in the use of the SRT$_{\text{RPE}}$ to repeatably monitor responses within training interventions for clinical/inactive populations.

7.4 Practical Application and Conclusions

Practical Application

The current thesis describes the application of the SRT_{RPE} as three-fold, Firstly, the SRT_{RPE} can be validly used within a group of athletes to infer aerobic fitness or endurance performance, which may be beneficial in grouping athletes for training. Secondly the SRT_{RPE} can use used for a short-term period of monitoring, for example monitoring within-individual responses around a competition load. Lastly, the SRT_{RPE} can be used to track within-individual longitudinal responses to endurance training, useful for the personal prescription of training within a season.

The utility of the SRT_{RPE} of each of these functions has been explored within this thesis using the following set of criteria which should be similarly attended to in future use of the protocol in an applied setting:

- The SRT_{RPE} has been validated using the standardised set of instructions created for the Borg 6-20 scale (Appendix VI). Directions given to participants when implementing an RPE scale, could influence the response given and as a result may have considerable implications in the control of pace around the three stages (RPE 10, 13 and 17) of the SRT_{RPE} (Abbiss et al. 2015). Future users are therefore advised to only use the validated set of instructions throughout testing.
- Criteria for acceptable weather conditions were outlined in section 2.2. If external variables cannot be similarly controlled, each should be recorded for retrospective analysis of their influence. Furthermore, validated psychological questionnaires such as those used in the current thesis will provide useful supporting evidence for the variation in $SRT_{RPE,}$ attributable to training or life stressors.
- Throughout all testing, individuals completed the SRT_{RPE} without any feedback or influence from other runners around them. Previous research has shown that pacing behaviour of runners varies when exercising in a group (Renfree et al. 2015). For best practice, future users would be advised to test individuals separately.
- In all experimental chapters, participants were provided with one familiarisation trial before baseline recordings. This was based on the results of Chapter 3, which showed no significant difference between repeated trials 1 - 2 and 2 - 3. Future research should be similarly confident in the use of one familiarisation trail of the SRT_{RPE}.
- The raw typical errors for v; RPE 10 = 0.60 $km\cdot h^{-1}$, RPE 13 = 0.55 $km\cdot h^{-1}$, RPE 17 = 0.55 $km\cdot h^{-1}$, HR_{ex}; RPE 10 = 7.3 $beats\cdot min^{-1}$, RPE 13 = 6.3 $beats\cdot min^{-1}$, RPE 17

= 4.1 beats·min^{-1}, HR-RS Index: RPE 10 =1.24 Au, RPE 13= 0.73 Au and RPE 17 =0.71 Au, can be used as an estimate measurement error when a separate reliability study is not possible.

- The change in v associated with a meaningful change in 12minTT; vRPE 10 = 0.26 km·h^{-1} (-2.97 – 3.49 km·h^{-1}), vRPE 13 = 0.14 km·h^{-1} (-1.65 – 1.93 km·h^{-1}), v RPE 17 = 0.17 km·h^{-1} (-2.02 – 2.38 km·h^{-1}), can be used to set thresholds of meaningful changes in future studies.

Conclusions.

The SRT$_{RPE}$ can be used as a time-efficient and accessible monitoring tool in a field-based setting. This thesis provides evidence that v monitored at each RPE stage can be reliability and validly used to assess the construct of endurance fitness (Chapter 3) and endurance performance (Chapter 4) between-individuals. The v, particularly at RPE 13 and 17 can be reliably used to track longitudinal responses to training within-individuals and provide inference about endurance performance ability (Chapter 4). Furthermore, the v and HR-RS index can be used to monitor short-term responses to intensified training or competition loads as well as recovery periods (Chapter 4, 5 and 6). The typical errors displayed in Chapter 3 and meaningful changes quantified in Chapter 4 can be used to guide and evidence-based approach to decision by defining thresholds for meaningful changes in within-individual responses.

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Appendices

Appendix I
Study Proposal for Research not conducted due to COVID-19

Study Proposal: A comparison of submaximal running tests for use in athlete monitoring.

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Research Context

Individual athlete monitoring is considered a fundamental component of a successful training programme (Taylor et al. 2012; Gabbett 2016). Maximal performance tests such as time trials are commonly used within research to evaluate sport specific performance following a training intervention (Meeusen et al. 2013; Heidari et al. 2018). However, maximal exertions are thought to be unsuitable for the regular assessment of athlete's in an applied setting (Taylor et al. 2012).

Lamberts Submaximal Cycle/Run Test (Lamberts et al. 2011), has been shown as a valid and reliable submaximal exercise test, which monitors external performance output (Power output/running velocity) and perceived exertion (Rating of Perceived Exertion [RPE]) at 60%, 80% and 90% of their heart rate maximum (HR_{max}). Vesterinen et al (2016) used a modification of this three stage protocol to monitor runners' responses to an 18-week endurance training intervention. Results displayed an increased velocity (v) at stage 2 (80% HR_{max}) and stage 3 (90% HR_{max}) which correlated with improved maximal oxygen uptake ($\dot{V}O_{2max}$) and v at lactate threshold.

The use of %HR_{max} to standardise submaximal exercise stages for athlete monitoring assumes that the physiological demand of the exercise stage is equivalent across individuals. Contrariwise, there is strong evidence that prescribing intensity in this manner leads to large inter-individual differences in metabolic responses to exercise (Katch et al. 1978; McLellan 2011). Meyer et al (1999) compared the physiological responses of regional level male cyclists and triathletes (62.2 ± 5.0 $mL\cdot kg^{-1}\cdot min^{-1}$) to exercise at 70% and 85% of their $HR_{max.}$ The physiological response, calculated as a percentage of individual anaerobic threshold (IAT); which was determined using the Stegmann et al (1981) method using the lactate turn point, ranged from 53 – 85% IAT at 70% HR_{max}, and 87-116% IAT at 85% HR_{max}. This shows that, even within a homogenous group of athletes, there is large variation in responses to exercise prescribed by % HR_{max}. With reference to a submaximal exercise test, this would lead to each individual being monitored under very different exercise domain, which would have considerable implications in how the results of such could be interpreted.

An alternative method could be the use of rating of perceived exertion (RPE) for the prescription of light, moderate and vigorous exercise intensities within the submaximal run test (ACSM). Research has shown that the rating of perceived exertion is closely related to metabolic responses (lactate concentration) and cardiac responses ($r = 0.74$, $r = 0.83$, respectively) (Scherr et al. 2013). Furthermore, the RPE at blood lactate (B[La]) derived thresholds (LT1, LT2) is independent of gender, age and training status (Demello et al. 1987; Scherr et al. 2013). Therefore, prescription of submaximal intensities using RPE may narrow the individual variability in response; whilst also alleviating the need for expensive and exerting tests to exhaustion, which are currently required in order to prescribe intensity by an individuals' maximal exercise capacity. However, research has highlighted that the relationship between B[La] and RPE is highly dependent on the duration of the exercise interval (Scherr et al. 2013; Zinoubi et al. 2018).

Therefore, the current research aims to examine if the submaximal run test, anchored by RPE (SRT_{RPE}) can provide a simple and valid alternative to the original submaximal run test used by Vesterinen (2016) anchored by %HR_{max}. Secondly, the study aims to examine if a shorter version of the submaximal run test; of total duration 9-mins, is still able to reliably and validly monitor athlete's submaximal performance.

Aim

The aim of the study is two-fold:

Firstly, the study will investigate the hypothesis that the SRT_{RPE} can provide a simple and valid alternative to the original submaximal run test used by Vesterinen et al (2016) anchored by %HR_{max}. Therefore, the study will compare the reliability of the original 15-min protocol used by Vesterinen et al (2016) (SRT_{HRmax}): 6-mins a 60% HR_{max}, 6-mins at 80% HR_{max} and 3-min at 90% HR_{max}, with a modified protocol (SRT_{RPE}) using 6-min at RPE 10, 6-mins as RPE 13 and 3-min at RPE 17.

The physiological demand of each protocol will be compared using a range of internal load variables. In particular, the % of LT1 and 2 threshold reached during each stage will be compared across protocols. Furthermore, the study will compare the test-retest reliability of both protocols, to validate the use of SRT_{RPE} as a reliable monitoring tool.

Secondly, the study aims to compare the utility of a shorter, 9-min, testing protocol using 3, 3-min intervals, to increase convenience of the test.

Hypothesis

Previous research has shown that intensity prescribed using $\%HR_{max}$ can lead to large inter-individual variability in responses, due to differences in the point at which the key metabolic thresholds (LT1 and 2 for example) occurs between individuals. However, there is evidence that an individuals' perception of effort is closely related to the accumulation of lactate. Therefore, we hypothesis that the use of RPE based intensities may reduce the inter-individual variability in the physiological demands of exercise during the submaximal run test.

However, it is hypothesised that the SRT_{RPE} will have a lower test-reset reliability that when exercise is prescribed by $\%HR_{max}$. This is based on unpublished work by the current research group on the reliability of the SRT_{RPE} on an outdoor track.

Lastly, we hypothesise that parameters measured during each increment of the SRT_{HRmax} and SRT_{RPE} will reach stabilisation by 3-mins, which would allow for a quicker, more convenient test time (Cerretelli, Di Prampero,1971).

Research design

The study will follow a randomised repeated measure, crossover design. Participants will complete 5 visits to the laboratory in total, separated by a minimum of 48-hours and spread across a maximum of 4-weeks. During their first visit, participants will complete an initial incremental exercise test to exhaustion for the assessment of maximal oxygen consumption rate ($\dot{V}O_{2max}$) Heart rate max (HR_{max}) and velocities associated with B[La] concentration 2 mmol (Lactate threshold 1) and 4 mmol (Lactate Threshold 2). During visits 2,3 and 4, participants will complete both the 15-min SRT_{HRmax} an SRT_{RPE} protocols on a treadmill, separated by a 20 -min rest period. The order of each protocol will be randomly assigned upon arrival using a block randomisation. Upon their final visit to the laboratory, participants will complete to trials of the shortened 10-min SRT_{RPE} protocol consisting of 3 x 3-min intervals, separate by a 20-min rest.

All 5 visits must be completed within a maximum of 4-weeks of the original $\dot{V}O_{2max}$ to limit the effect of any changes in physiological condition of individual participants. Total time commitment for participants will be 7-hours 30-mins.

Study participants

With reference to Hopkins (2000), we believe 16 participants tested over three trials, will give an acceptable likely range for the true typical error within each SRT.

Male and female endurance athletes ages 18 – 50 years, of performance level 3 (De Peuw, Decroix): Males 55.0 – 64.9 $mL \cdot kg^{-1} \cdot min^{-1}$, females 48 – 52 $mL \cdot kg^{-1} \cdot min^{-1}$, regular training 3 running session per week for > 2 years' experience. Free of any history of cardiovascular problems (e.g., high blood pressure or any kind of heart problems), respiratory disorders (e.g., asthma, bronchitis), and neurological conditions (e.g.

Epilepsy), metabolic diseases (e.g. Diabetes), or have suffered a trunk or lower-limb, soft tissue (e.g., muscles, ligaments) or bone, injury or surgery in the last 3 months, Participants must also be non-smokers.

Participants will be subjected to an initial screening consisting of a PAR-Q questionnaire. Participants with pulmonary, cardiovascular or metabolic disease and those unable to perform the required exercises will be excluded.

Recruitment

Participants will be recruited via word of mouth, emails to local clubs, posters on social media and flyers handed out at local events.

Methods

Visit 1: 1-hour 45-mins

Upon arrival, participants will complete a consent form, giving their consent to the below procedures for the duration of the expected study, and will complete the PAR-Q questionnaire for health screening.

Graded Exercise Test with verification phase.

Participants will be instructed to refrain from heavy exercise 2 days prior to Visit 1. In addition, participants will be instructed to arrive in a fasted state and having refrained from caffeine in the 12 hours prior to arrival.

Before commencement, it is important that participants understand the correct use of the RPE scale which they will use to rate their exertion during the maximal incremental test and to select exercise intensity in subsequent tests. Instruction will be verbally communicated to participants. Particular emphasis will be given to the concept that the rating relates to overall exertion and not exertion of a particular body part, giving clear instruction to provide a rating of overall ‘effort, strain, discomfort and fatigue’ (Ritchie 2012)

The maximal exercise test will be used for the determination of maximal oxygen uptake ($\dot{V}O_{2max}$), maximal heart rate (HR_{max}) and ventilatory thresholds (VT1 and VT2); the determination of each is given in detail below. For consistency with previous literature, the procedure follows that used by Vesterinen (2013). Prior to commencement participants will complete a 5-min warm up at their walk to jog pace, followed by 3-mins passive rest. The initial velocity will be 8 $km.h^{-1}$ for females and 9 $km.h^{-1}$ for males, it will increase by 1 $km.h^{-1}$ each 3-mins until exhaustion. The incline will be kept at 1%. After each 3-min stage the treadmill will be stopped for 60-s for fingertip blood lactate samples (5ul) and blood lactate analysis. Participants will be asked to give a rating of perceived exertion

(RPE) using the Borg 6-20 scale (Borg, 1985) in the final 30-s of each interval and immediately after termination of the test. Expired gases will be measured on a breath-by-breath basis (MetaLyzer; Cortex Biophysik GmbH, Leipzig, Germany) calibrated before the test according to the manufacturer's specifications. Heart rate will be monitored by beat-by-beat analysis from the Polar chest band and monitor (Polar Instruments, Kempele, Finland).

After the incremental phase participants will complete a 10-min active rest (treadmill walk) before performing a verification phase. The verification phase will consist of running to volitional exhaustion at a speed 0.5 km.h^{-1} higher than the final stage reached in the last completed stage of the incremental phase. Expired gases will be measured on a breath-by-breath basis (MetaLyzer; Cortex Biophysik GmbH, Leipzig, Germany) calibrated before the test according to the manufacturer's specifications. Heart rate will be monitored by beat-by-beat analysis from the Polar chest band and monitor (Polar Instruments, Kempele, Finland). Participants will be asked to give their RPE at termination of the test.

Determination of $\dot{V}O_{2max}$, HR_{max} and threshold zones

Determination of $\dot{V}O_{2max}$

The $\dot{V}O_{2max}$ will be taken as the highest 30-s mean value attained prior to the participant's volitional exhaustion during the incremental exercise test. Secondary criteria for achieving $\dot{V}O_{2max}$ will be when two of the following criteria are attained, Heart rate within 10 beats·min^{-1} of age-predicted maximum; RER ≥ 1.10; RPE ≥ 17; and B [La] ≥ 8 mmol·L^{-1} Finally, $\dot{V}O_{2max}$ will be verified as no greater than a 2% differences between the greatest VO_2 reached during the verification phase.

Determination of HR_{max}

The highest 5-second average from the incremental exercise test. This will be verified by a no greater than 2 beat difference with that from the verification test.

Should participants fail to meet the criteria for the verification of $\dot{V}O_{2max}$ and HR_{max}, they will be asked to repeat the test at least 48-hours later.

Determination of blood lactate reference values

Lactate measured in blood samples obtained at the end of each 3-min stage will be analysed for the subsequent determination of velocity equivalent to B [La] 2 mmol·L^{-1} , representing Lactate Threshold 1 and 4 mmol·L^{-1} representing Lactate Threshold 2 (Aunola and Rusko 1986).

Determination of gas exchange threshold reference values

The gas exchange threshold was determined from a cluster of measurements, including: 1) the first disproportionate increase in CO_2 production ($\dot{V}CO_2$) from visual inspection of individual plots of Vs $\dot{V}CO_2$ vs $\dot{V}O_2$; 2) an increase in expired ventilation (VE)/ $\dot{V}O_2$ with no increase in VE/$\dot{V}CO_2$ and 3) and increase in end tidal O_2 tension with no fall in end-tidal CO_2 tension. (McLellan 2011)

Familiarisation

Following 10-mins of passive rest, participants will complete a familiarisation for visits 2,3 and 4. The familiarisation will allow participants to practice self-adjustment of the treadmill to reach a target RPE level.

The researcher will re-read the instruction for correct use of the RPE scale as before (Borge 1985, Ritchie 2012). Participants will be instructed to run for three -mins at an intensity associated with RPE 10, 3-mins at RPE 13 and 3-mins at RPE 17. Participants will be instructed to adjust the speed accordingly to reach and maintain the target RPE level throughout, however being blinded to the absolute treadmill speed and time elapsed. The researcher will ask participants to review their RPE level every 30-s. Heart rate will be monitored by beat-by-beat analysis from the Polar chest band and monitor (Polar Instruments, Kempele, Finland).

Familiarisation will be successful if participants are confident in having reach the target RPE level by the final -min of each interval and if the heart rate recorded in the final -min of each increment is within 2 beats·min^{-1} of that associated with the RPE's given during the maximal exercise test.

Visit 2,3 and 4 : 1 hour 30-mins each

Each visit will take place in a controlled laboratory environment, standardised at room temperature of 18 – 22°C. Each participant will complete the visits at the same time of day. Participants will be informed to refrain from any exercise 24-hour prior to test, avoid consumption of caffeine 12 hour before. Food consumption will be limited to 3-hours before testing and any consumption of food prior to testing must be weighed/ measured and replicated prior to each visit.

Readiness to perform questionnaires

Upon arrival to the laboratory, participants will be asked to complete 2 questionnaires:

A daily analyses of life demands for athlete's questionnaire (DALDA) (Rushall 1990). The DALDA questionnaire is divided into two parts, namely Part A and Part B which represent the sources of life stress and symptoms of stress, respectively. It has previously shown to be a sensitive indicator of training induced fatigue (Coutts, Slattery and Wallace 2007; Capostagno, Lambert and Lamberts 2014)

Should participants give ≥ 50% 'worse than normal' for symptoms of stress, they will not be able to participate in testing on that given day.

In addition, participants will be asked the following question 'Please mark along the line below with a single downward stroke to indicate how physically/mentally ready you are to invest effort in….' . They will be asked once in reference to a 6-min effort at 80% HR_{max}, and another for 3-mins at 90% HR_{max} as these will be the most exerting efforts required from participants. Participants will mark along a 100mm line their readiness from 'not ready at all' too 'complete readiness to perform'

Results from the readiness questionnaire will not be used to exclude participant from future testing but will be used retrospectively to assess changes in data.

Lastly participants will be re-read the instructions for using the RPE scale.

Submaximal running tests

Random allocation

Participants will complete both SRT protocols in the same visit separated by 20-mins. The order in which the SRT protocols are performed will be randomly allocated using the software: http://www.randomization.com. In order to control for any effects of prior exercise on the second SRT. This will follow a block randomisation such that groups of 4 participants will be randomly assigned to either group A: Complete SRT_{HRmax} first on 2 occasions and SRT_{RPE} first on one occasion. Or Group B: Complete SRT_{RPE} first on 2 occasions and SRT_{HRmax} on one occasion. This will allow for a randomisation, while ensuring equal incidences of each protocol being performed first.

Warm up protocol

Participants will then be instructed to complete a 5-min warm up at RPE 9. Participants will be able to change the speed throughout to ensure an RPE of 9 is maintained, with the treadmill set to increase velocity in increments of 0.2 km.h^{-1}. An RPE of 9 has been selected as it is of lower physical exertion that the initial intensity of the SRT, whilst allowing for a sufficient warm up. Participants will be blinded to the absolute treadmill speed. Heart rate will be monitored by beat-by-beat analysis from the Polar chest band and monitor (Polar Instruments, Kempele, Finland). 5ul of capillary blood will be sampled from the fingertip before and immediately following completion of the warm-up for the analysis of blood lactate concentration. Participants will then complete 3-mins of passive rest before beginning the randomly allocated SRT protocol.

SRT_{HRmax}

The SRT_{HRmax} was originally modified from the Lamberts and Lambert Submaximal Cycle Test, and uses the same protocol implemented by Vesterinen (2016). The 15-min continuous SRT consist of 3 stages: 6 -mins a 60% HR_{max}, 6-mins at 80% HR_{max}, 3-mins at 90% HR_{max}. The treadmill speed will be initially set at a velocity corresponding to 60% HR_{max} as calculated during the incremental exercise test. The researcher will adjust and record the velocity of the treadmill every 30-s to ensure the target heart rate is reached and maintained; The treadmill velocity will be adjustable by increments of 0.2km.h^{-1}. The participants will be blinded to the absolute speed of the treadmill and the time elapsed.

SRT$_{RPE}$

The 15-min SRT is composed of the following stages: 6-mins at RPE 10 , 6-mins as RPE 13 and 3 -mins at RPE 17. Participants will be able to adjust the velocity of the treadmill throughout the test to reach and maintain the target RPE based intensity. The treadmill velocity will be adjustable by increments of 0.2 km.h^{-1}. Participants will be blinded to the absolute velocity of the treadmill and the time elapsed. The researcher will prompt participants by asking for their RPE each -min throughout the test.

Data collection and analysis

Throughout each submaximal run test VO_2, VCO_2, VE, and RER will be continuously monitored using a breath-by-breath basis (MetaLyzer; Cortex Biophysik GmbH, Leipzig, Germany) .Participants will be asked to rate their RPE each -min using the Borg 6-20 Scale (Borg 1985). A 5ul capillary blood sample will be drawn from the finger in the final 30 s of each stage to record lactate concentration. Heart rate will be monitored by beat-by-beat analysis from the Polar chest band and monitor (Polar Instruments, Kempele, Finland). The data collected from the first -min of each stage of the SRT will be excluded from analysis allowing for this time as an adjustment period to reach the specified intensity. Therefore, mean and SD for each parameter will be calculated from time point 1:00-6:00 of stages 1 and 2 and 1:00-3:00 for stage 3. The researcher will record any adjustment in treadmill velocity.

Visit 5: 1 hour 15-mins.

The purpose of this visit is to analyse responses to a shortened 9 -min $SRT_{rpe.}$ Therefore, all procedure will follow the exactly the same design as outlined above for visit 2,3 and 4, however, participants will complete two repeats of the 9-mins SRT_{RPE}.

10-min SRT$_{RPE}$

The 9-min SRT is composed of the following stages: 3-min at RPE 10, 3-mins as RPE 13 and 3-mins at RPE 17.

Data analysis

Analysis will follow the same procedure as outlined for the 15-min SRT's, excluding the first -min of data collection from each interval from the analysis.

Statistical analysis.

To assess the inter-individual variability on the responses to exercise using the SRT_{HRmax} and SRT_{RPE} the standard deviation around the means and the coefficient of variation will be calculated. Bland and Altman Plots will be used to make comparisons between study protocols. To compare the reliability of each of the protocols, parameters recorded over the three trials for each protocol will be log transformed and assessed using a customised spreadsheet (Hopkins, 2016). The Interclass correlation coefficient (ICC), typical error of measurement (TEM) and the TEM expressed as a coefficient of variation ($CV_{TEM\%}$) were calculated with (90% confidence intervals (CI). The typical error assessed between all three trials will be first be analyses in two groups based on gender (male, female), and assessed for a significant difference between groups before results can be pooled.

Appendix II:
Ethical Approval Letter Chapter 3 and 4

University of Kent

School of Sport & Exercise Sciences
Research Ethics and Advisory Group (REAG)
University of Kent at Medway
Chatham Maritime
Kent
ME4 4AG

Ethics Reference:

Prop 71_2017_18

Date: 31st January 2018

Dear Hannah Sangan,

Re: The utility of a submaximal warm up for routinely monitoring individual responses to training in endurance athletes.

I am delighted to confirm that SSES REAG has approved your research study (REF No. Prop 71_2017_18) and you are now permitted to recruit participants and commence your research.

If you need to amend any aspect of your research, please ensure you inform SSES REAG by completing a request for amendment form and submitting all revised paperwork (e.g. participant information sheet, questionnaires).

If there should happen to be any adverse event during your study, please also ensure SSES REAG is kept informed.

I hope your study is successful.

With kind regards,

Louis Passfield

Louis Passfield

(Chair SSES REAG)

Appendix III
Ethical Approval Letter for Chapter 5

University of Kent

School of Sport & Exercise Sciences
Research Ethics and Advisory Group (REAG)
University of Kent at Medway
Chatham Maritime
Kent
ME4 4AG

Ethics Reference:

Prop 107_2017_18

Date: 30th October 2018

Dear Hannah Sangan,

Re: The utility of a self-paced submaximal run test for the monitoring of recovery following an ultra-marathon event.

I am delighted to confirm that SSES REAG has approved your research study (REF No. Prop 107_2017_18) and you are now permitted to recruit participants and commence your research.

If you need to amend any aspect of your research, please ensure you inform SSES REAG by completing a request for amendment form and submitting all revised paperwork (e.g. participant information sheet, questionnaires).

If there should happen to be any adverse event during your study, please also ensure SSES REAG is kept informed.

I hope your study is successful.

With kind regards,

Louis Passfield

Louis Passfield

(Chair SSES REAG)

Appendix IV
Ethical Approval Letter for Chapter 6

University of Kent

School of Sport & Exercise Sciences
Research Ethics and Advisory Group (REAG)
University of Kent at Medway
Chatham Maritime
Kent
ME4 4AG

Ethics Reference:

Prop 83_2018_19

Date: 25th June 2019

Dear Hannah Sangan,

Re: Individual responses to a submaximal self-paced test during acute periods of increased training load.

I am delighted to confirm that SSES REAG has approved your research study (REF No. Prop 83_2018_19) and you are now permitted to recruit participants and commence your research.

If you need to amend any aspect of your research, please ensure you inform SSES REAG by completing a request for amendment form and submitting all revised paperwork (e.g. participant information sheet, questionnaires).

If there should happen to be any adverse event during your study, please also ensure SSES REAG is kept informed.

I hope your study is successful.

With kind regards,

Louis Passfield

Louis Passfield

(Chair SSES REAG)

Appendix V

Ethical Approval Letter for Research not conducted due to COVID-19

School of Sport & Exercise Sciences
Research Ethics and Advisory Group (REAG)
University of Kent at Medway
Chatham Maritime
Kent
ME4 4AG

Ethics Reference: Prop 45_2019_20 A comparison of two methods for standardising exercise intensity during a submaximal running test

Date: 12.03.20

Dear Hannah and James,

Re: A comparison of two methods for standardising exercise intensity during a submaximal running test

I am delighted to confirm that SSES REAG has approved your research study (REF No.45_2019_20) and you are now permitted to recruit participants and commence your research.

If you need to amend any aspect of your research, please ensure you inform SSES REAG by completing a request for amendment form and submitting all revised paperwork (e.g. participant information sheet, questionnaires).

If there should happen to be any adverse event during your study, please also ensure SSES REAG is kept informed.

I hope your study is successful.

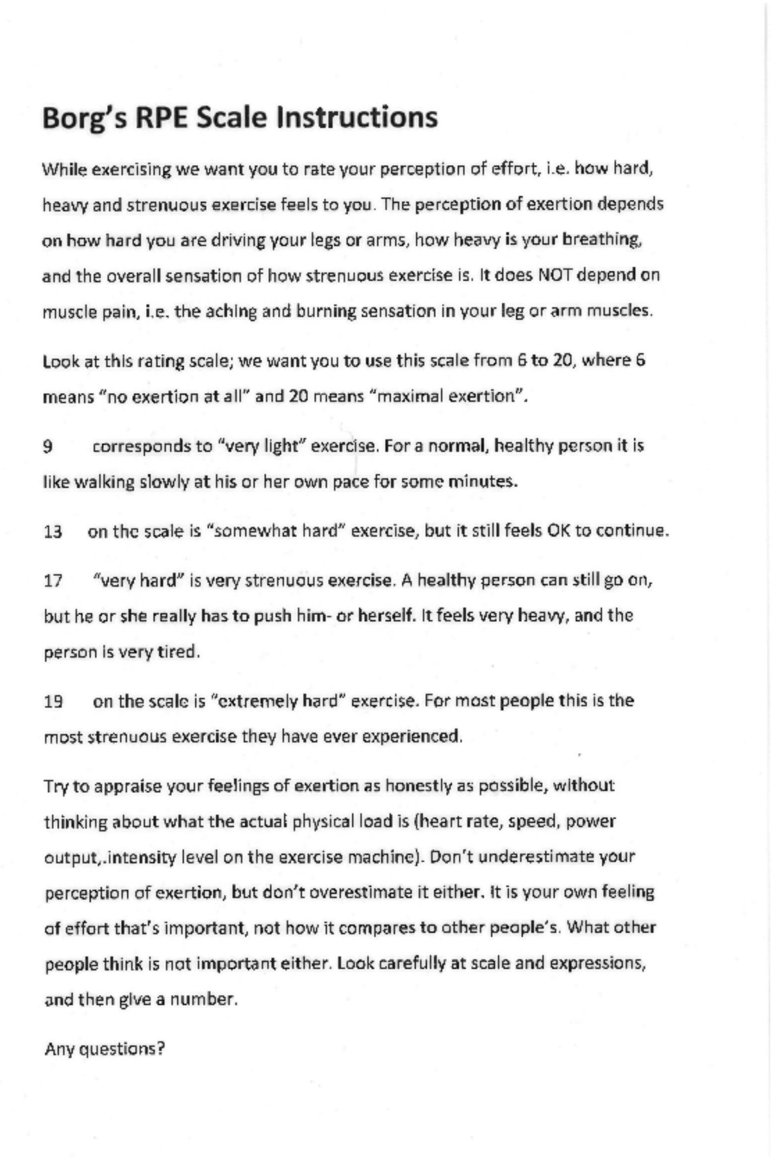
With kind regards,

K. Hambly

Karen Hambly
(Chair SSES REAG)

Appendix VI

Standardised instructions for Borg (1985) 6 – 20 RPE Scale



Borg's RPE Scale Instructions

While exercising we want you to rate your perception of effort, i.e. how hard, heavy and strenuous exercise feels to you. The perception of exertion depends on how hard you are driving your legs or arms, how heavy is your breathing, and the overall sensation of how strenuous exercise is. It does NOT depend on muscle pain, i.e. the aching and burning sensation in your leg or arm muscles.

Look at this rating scale; we want you to use this scale from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion".

9 corresponds to "very light" exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous exercise. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is "extremely hard" exercise. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feelings of exertion as honestly as possible, without thinking about what the actual physical load is (heart rate, speed, power output,.intensity level on the exercise machine). Don't underestimate your perception of exertion, but don't overestimate it either. It is your own feeling of effort that's important, not how it compares to other people's. What other people think is not important either. Look carefully at scale and expressions, and then give a number.

Any questions?