UNIVERSITY OF AGDER

Is simple better?

A methodical comparison of monitoring training load in well-trained cyclists

Troels Ravn Pedersen[1]

Supervisor

PhD Student Øystein Sylta[1]

Professor Stephen Seiler[1]

[1] Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway

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Faculty of Health and Sport Sciences

Department of Public Health, Sport and Nutrition

Preface

I am grateful to the subjects for willingness to participate in the study and to University of Agder and Olympiatoppen for providing financial support for the main study producing data for this study as well. It has been a challenging and rewarding journey to be contributing to the planning, preparation and administration of the main study. In addition, I wish to acknowledge the substantial contribution of supervisor PhD Student Øystein Sylta and Professor Stephen Seiler whose leadership made this research possible.

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1. Abstract

Background: Lack of a "gold-standard" for measuring training load (TL) makes it challenging for coaches and athletes to avoid over- or under-reaching during endurance training. **Purpose:** To describe physical and perceptual exertional demands of high intensity training (HIT) and explain variance in quantification of TL with use of *Banister's training impulse* (BanTRIMP), *session rating of perceived exertion* (sRPE) and *individualized training impulse* (iTRIMP). **Method:** During 12 weeks, 12 well-trained male cyclists (VO_{2peak} 60 ± 3 $ml \cdot kg^{-1} \cdot min^{-1}$) completed 879 individual endurance training sessions including HIT-sessions; 4 x 16 min, 4 x 8 min and 4 x 4 min described at their maximal sustainable intensity (*isoeffort*). Training characteristics, in addition to TL were quantified into categories based on the principle of *session goal* (SG) 1-5 (HR zone 1-5). **Results:** sRPE-score was practically identical for HIT in the range of SG3-5-sessions (4 x 16 to 4 x 4 min) respectively 6,8 ± 1,3 to 7,1 ± 1,4 , consistent with the *isoeffort* prescription. Compared to the other TL-methods quantified; BanTRIMP significant higher contribution of total TL from SG1- and 2-sessions and significant lower from SG5-sessions; iTRIMP significant higher from SG3-sessions and sRPE significant higher from SG5-sessions. **Conclusion:** In well-trained cyclists completing an *isoeffort* prescription: 1) the perceived cost (sRPE) of training ≥ LT_2 is practically identical over a 4-fold range of accumulated duration. Appropriate use of TL for the specific cohort and type of training cannot be neglected. Despite its simplicity, sRPE-based-TL appears highly consistent with the training prescription.

Keywords: Training quantification, HIT, training load, TRIMP, session-RPE, individualized, endurance.

2. Introduction

Athletic performance is generally thought to improve with increasing training load (TL), but the syndrome of overtraining suggests that negative adaptations to exercise also can be training-dose related (Foster, Daines et al. 1996). Training load has been defined by Foster as the exertional demand placed upon or experienced by an athlete during a training session or accumulated over a period of time (Foster, Florhaug et al. 2001). Banister defined TL as a dose of work that stresses psychophysiological systems and induces subsequent adaptive responses leading to performance enhancement (Banister, Calvert et al. 1975). Physiological adaptation characteristics are highly individual and depend on many factors, such as psychological parameters, initial training status, recovery potential, non-training stress factors and genetic background (Borresen and Lambert 2009). In order to avoid under- and overtraining, and to achieve optimal performance at specific time-points, it is important for athletes and coaches to know the physical and perceptual exertional demand of training and be able to monitor individual TL so training programs can be tailored to the temporary and cumulative individual responses to training (Seiler 2010, Rønnestad, Ellefsen et al. 2012).

Training charteristica of elite endurance athletes is by describe studies observed as *polarized* with approximately 75% of training performed at intensities below the first lactate threshold (LT_1), relatively little training at the second lactate threshold (LT_2), and approximately 10–20% at intensities clearly above LT_2 (Billat, Demarle et al. 2001, Seiler and Kjerland 2006, Seiler, Haugen et al. 2007). To monitor and describe training organization the *session goal* (SG) approach proposed by Seiler and Kjerland (Seiler and Kjerland 2006), appears to give a realistic pattern of the total training intensity distribution over the long term (Sylta, Tønnessen et al. 2014). The SG approach is a categorical method, where the entire session is assigned to a single intensity zone category based on the intent, and the intensity achieved at the main part of the session (Seiler and Kjerland 2006).

Several methods for quantifying TL have been suggested in the literature. These methods include subjective approaches such as *session rating of perceived exertion* (sRPE) (Foster, Florhaug et al. 2001), and objective approaches based on heart rate (HR) such as *Banister's training impulse* (BanTRIMP) (Banister 1991) and the *individualized training impulse* (iTRIMP) (Manzi, Iellamo et al. 2009). Multiple studies have "validated" the TL methods by correlating them with each other. However, a strong correlation between the methods does not necessary make them valid. A few studies have used change in fitness and/or performance to validate the TL methods (Manzi, Iellamo et al. 2009, Akubat, Patel et al. 2012). Correlations with change in fitness and performance can be less useful in a cohort of well-trained or elite athletes, as the TL-improvement relationship is unlikely to be linear due to their highly trained status and a TL on the edge of the tolerable. However, the lack of a single physiological marker to measure fitness and fatigue response to exercise, and no scientific consensus or “gold standard” of measuring TL makes the validation of the TL-methods challenging.

Another approach is to evaluate the TL-methods is to identify specific characteristics that may explain the variance between the methods of quantifying training load. This has to our knowledge only been done once; Borresen and Lambert (2008) evaluated the two objective methods BanTRIMP and summated heart rate zone score (SHRZ) and the subjective method sRPE in 33 habitually physically active subjects. They suggested that the sRPE method might overestimate training load for athletes spending more time doing low-intensity exercise whereas for athletes participating in proportionally more high-intensity exercise the sRPE method underestimates training load compared with HR-based methods or vice versa.

To evaluate the specific TL-methods and in-between methods difference, it would be advantageous to split the total TL into smaller load-components whereby the constellation contributing to the total TL, and possible weaknesses in the load calculation, may be identified. We propose that quantifining training characteristics and total TL into categories based on the principle of SG (HR zone 1-5), can make evaluation of specifik physical and perceptual exertional demand of high intensity training (HIT) possible, and in addition illuminate the TL-methods in a novel manner.

The purpose of the present study was therefore dual; 1) describe physical and perceptual exertional demand of HIT in well-trained cyclists undergoing a structured training program and 2) identify and discuss possible specific characteristics that may explain variance in quantification of total TL with use of BanTRIMP, sRPE and iTRIMP, three of the most commonly utilized TL-methods.

3. Theory

To enhance performance, it is crucial to balance periods of training stress and recovery in order to achieve a sufficient stimulus for eliciting performance benefits, while avoiding non-functional over- or under-reaching and inappropriate training (Seiler 2010, Rønnestad, Ellefsen et al. 2012). Training load units can be measured as either external or internal. External load (EL) is defined as the work completed by the athlete, measured independently of physiological or perceptual response (Wallace et al. 2009). External load quantification includes, power output, duration, training frequency, and distance. External load is important in understanding work completed, capabilities and capacities of the athlete. Internal load (IL) is the individual physiological and psychological stress imposed by acute or repeated work. Internal load unit measures, include rating of perceived exertion (RPE), sRPE, relative VO_2 consumption, HR, blood lactate concentration ($[La^-]b$), biochemical- and hormonal response as well as TRIMP. Dissociation between EL and IL may reveal the state of fatigue of an athlete (Halson 2014). To help athletes and coaches in designing and monitoring training programs a number of potential markers are available for use, these are described below.

3.1 Banister's Training Impulse

Banister's original TRIMP method was designed to quantify loads in cyclic, endurance-type sports (Banister, Calvert et al. 1975). It combines IL and EL components in one measure (Table 1) considering the average exercise fractional elevation in HR (ΔHR_{ratio}) during exercise to quantify the intensity, which is multiplied by the duration (D) of effort to contribute to dose size of physical effort (Banister 1991).

(Equation 1)

$$\Delta HR_{ratio} = HR_{exercise} - HR_{rest} \; / \; HR_{peak} - HR_{rest}$$

To avoid giving a disproportionate weighting to long duration low intensity exercise compared with intense short duration exercise, the ΔHR_{ratio} is weighted by a multiplying factor (y) to give greater emphasis to effort at high intensity compared to effort at low intensity (Banister 1991).

The *y* factor is based on the classically described exponential rise of [La-]b in relation to the fractional elevation of HR above HR_{rest}. Where y is a nonlinear coefficient given by the equation:

(Equation 2)

$$y = 0{,}64e^{1.92x} \text{ (male)}$$

$$y = 0{,}86e^{1.67x} \text{ (female)}$$

with e = base of the Napierian logarithms (2,712), x = ΔHR_{ratio} during exercise, and the constants b = 0.64, c = 1.92 for males and b = 0,86, c = 1,67 for females. Thus,

(Equation 3)

$$\text{TRIMP (arbitrary units (AU))} = \text{D (min) x } \Delta HR_{ratio} \text{ x y}$$

It is the relative internal physiological stress imposed on the athlete and induced by the external training load that determines the stimulus for physiological adaptation (Wallace, Slattery et al. 2014). Internal training load can be quantified by relative VO_2 consumption, which is highly linearly related to relative HR (r = 0,92-0,96) (Herman, Foster et al. 2006, Wallace, Slattery et al. 2014). While the relationship between HR and external submaximal training load is linear, is the relationship between external training load and time to exhaustion exponential similar the relationship between external training load and $[La^-]b$. Once the external training load exceeds that corresponding to the lactate threshold, very small changes in external load cause large changes in accumulated exercise duration (Seiler and Tønnessen 2009, Seiler 2010). Therefor accurately weighting the effort of exercise relative to the ΔHR_{ratio} is important for accurately quantifying load. The BanTRIMP weighting factor *y* is gender-specific and based on a sample of only five males (VO_{2peak} 3,74 ± 0,73 $l \cdot min^{-1}$, power output at ventilatory anaerobic threshold (W_{VAT}) 196 ± 32 W) and five females (VO_{2peak} 2,54 ± 0,34 $l \cdot min^{-1}$, W_{VAT} 132 ± 34 W), all recreationally active in a variety of physical activities on a non-regular basis (Green, Hughson et al. 1983, Morton, Fitz-Clarke et al. 1990).

Use of standard weighting factor with a fixed lactate-workload relationship can be inappropriate 1) when an athlete’s training status changes over time or 2) when comparing training load of athletes that differ with respect to training status. In addition, the relationship between work load and HR is influenced by day-to-day variation, 6 beats/min or up to 5-6 % of HHR caused by factors like state of training, environmental conditions, diurnal changes, exercise duration, hydration status, altitude and medication (Borresen and Lambert 2009). Overtraining has also been found to decrease HR at the same submaximal intensity (Borresen and Lambert 2008). In spite of this, HR-response to fixed work load shows good levels of

test-retest reliability (3.9% coefficient of variation (CV)) compared to a poor level of test-retest reliability of Banister's TRIMP (15.6% CV) (Wallace, Slattery et al. 2014). Correspondingly, Banister's TRIMP showed a strong positive but significantly lower correlations with the total VO_2 (r = 0,85) than did measures of HR alone (r = 0,92) when compared with $\%VO_{2peak}$. Comprehensive indicating, that the weighting factor harbor an increased potential for error associated with the reliability and validity of the BanTRIMP (Wallace, Slattery et al. 2014). An additional limitation is that BanTRIMP requires steady-state heart rate measurements (Banister 1991), thus limiting the accuracy with which HIT or non-steady-state exercise such as resistance training, high-intensity interval training, or plyometric exercise can be quantified (Foster, Florhaug et al. 2001).
Borresen and Lambert compared the BanTRIMP with the sRPE method and proposed from their results that the BanTRIMP might be giving disproportionate importance to high-intensity exercise for athletes who spent a greater percentage of their total training time at high intensity and underestimating the effect of low-intensity exercise on training load for athletes who spent a greater percentage of their total training time at low intensity compared with the sRPE method (Borresen and Lambert 2008).

3.2 Perception of Effort

Since the introduction of TRIMP (Banister, Calvert et al. 1975), several attempts have been made to improve its accuracy in quantifying TL and the individual responses to a given TL. To monitor training load with lower cost and independent of measurement equipment subjective perceptual methods can be used. The rating of perceived exertion (RPE) is one of the most common methods of assessing *acute* perception of effort associated with a given internal physiological load (Borg 1970). This approach depends on an athlete's ability to intrinsically monitor their physiological stress and judge changes in exercise intensity using RPE scales. Wallace and colleague (2014) found very strong (Hopkins, Marshall et al. 2009) correlations coefficients between RPE (CR10 scale) and $\%VO_{2peak}$ (r = 0,80).
A recent meta-analysis of the literature reported that the validity of RPE may not be as high as described above (Halson 2014). For example, weighted mean validity coefficients for HR, [La-]b and $\%VO_{2peak}$ were 0,62, 0,57, and 0,64, respectively in relation to RPE (Chen, Fan et al. 2002). Evidence suggests that RPE correlates well with heart rate during steady-state exercise and high-intensity interval cycling training, but not as well during short-duration high-intensity soccer drills (Borresen and Lambert 2009). Factors other than VO_2 and HR can affect global training load. The complex interaction of many factors contributing to one's

personal perception of physical effort, might include hormone and substrate concentrations, personality traits, ventilation rate, neurotransmitter levels, environmental conditions, and psychological states (Herman, Foster et al. 2006). RPE scales might not be useful in comparing or prescribing training intensities for different runners, but RPE scales might still be useful within individuals (Borresen and Lambert 2008).

3.3 Session Rating of Perceived Exertion

Training load measured by sRPE is a subjective scale-based method of quantifying the overall training effort associated with a single training session, as experienced by the subject (Foster, Florhaug et al. 2001). The sRPE method was developed to eliminate the need to utilize HR monitors when assessing exercise intensity. The sRPE protocol is a rating of the overall difficulty of the entire exercise bout obtained 30 minutes after the completion of the exercise, by asking the subject “how was your workout?” on a 0-10 scale (CR10) (Foster, Florhaug et al. 2001), with specific verbal descriptors assigned to different scale values. Session LOAD is calculated by multiplying the relative perceived exertion (RPE) of the session (sRPE score) on the CR10-scale by the duration (D) of the exercise in minutes.

(Equation 4)

sRPE (arbitrary units (AU)) = sRPE score x D (min)

The use of sRPE is based on the notion that an athlete can retrospectively provide information regarding their perceived effort 30 min post training or competition. The method is also popular because it is applicability across different training modes and in sports where HR-monitoring is difficult, like swimming. Likewise sRPE might be a more valid load method than HR-based in measuring of training intensity when both aerobic and anaerobic metabolic systems are activated like in intermittent exercise and supramaximal exercise (Impellizzeri, Rampinini et al. 2004, Borresen and Lambert 2008).

The perception of global training load quantified by sRPE may be influenced by other factors than cannot be quantified by measuring HR or VO_2 consumption, for example, the muscle damage caused from a previous training bout may influence perception of effort (Marcora and Bosio 2007). The account of non-physiological factors in sRPE like environmental conditions under which the activity is performed may have important motivational, psychological and physical effects on the person perception of load, but these are not in the same degree accounted for in the HR-based methods.

The limitations of sRPE include the possibility that social factors may encourage reporting bias (Borresen and Lambert 2009) and that some previous studies have failed to detect a significant relationship with change in fitness (Akubat, Patel et al. 2012). sRPE seems to be more influenced by resistance/intensity load than volume (Sweet, Foster et al. 2004) and intermittent-type exercise might contribute to an increase in RPE which can lower the correlations between HR-based load methods and sRPE (Borresen and Lambert 2008).

3.4 Individualized Training Impulse

The need for an individualized approach applicable in high-intensity or non-steady-state exercise led to a further refinement of BanTRIMP by Manzi and colleagues, who introduced an individual weighting factor (y_i) for each subject (Manzi, Iellamo et al. 2009). This led to better individualization but also more methodological complexity. The individual y_i values were calculated for each subject with the best-fitting method for the relationship between ΔHR_{ratio} and [La-]b to increasing exercise intensity using an exponential model.

Individualized TRIMP uses a time-in-zone approach by use of averaged HR values every 5 s, and as exercise intensity increases, as indicated by the HR response, the weighting factor y_i increases exponentially at individual level (Manzi, Iellamo et al. 2009). The TRIMP for each 5 s interval is then calculated and summated to provide a TRIMP for the entire session.

(Equation 5)

$$\text{iTRIMP (arbitrary units (AU))} = \text{D (min)} \times \Delta HR_{ratio} \times y_i$$

The ability of iTRIMP to account for small changes in intensity across time during a training session, and use of individual weighting factor have shown emerging evidence for iTRIMP to be a advancement and more valid than previously available TL-methods, by reflecting the individual physiological effort of each training session (Manzi, Iellamo et al. 2009, Akubat, Patel et al. 2012, Iellamo, Manzi et al. 2013).

Manzi and colleagues studied eight recreational runners (> 50 $km \cdot wk^{-1}$), examining sum of weekly iTRIMP in relation to improvement in running velocity at 2 and 4 $mmol \cdot L^{-1}$ $[La^-]b$. They found significant and very strong correlations of r = 0,87; P = 0,005 and r = 0,74; P = 0,04 respectively (Manzi, Iellamo et al. 2009). The same study found that mean weekly iTRIMP was significantly related to 5.000 m (r = -0,77; P = 0,02) and 10.000 m track performance (r = -0,82; P = 0,01) and there was a significant relationship between BanTRIMP and the four parameters above (Manzi, Iellamo et al. 2009). Akubat and coworkers used nine professional soccer players and both sRPE, BanTRIMP and iTRIMP resulting in only one significant correlation between mean weekly iTRIMP load and change in running velocity at 2 mmol · L^{-1} $[La^-]b$ (r = 0,67; p = 0,04) (Akubat, Patel et al. 2012). Use of velocity at 2 and 4 mmol · L^{-1} $[La^-]b$ as a performance parameter in relationship to iTRIMP itself using blood lactate response to "weight" exercise intensity have been suggested to result in a spurious correlation (Akubat, Patel et al. 2012).

A fundamental assumption in relation to the validity of the TRIMP methods is that the lactate concentration observed in the blood is representative of the overall training 'stress' imposed on the athlete. It can be argued that the relationship between increasing exercise intensity and physiological stress is exponential like increase in lactate concentrations based on the change in hormones concentrations such as catecholamines (Akubat and Abt 2011). The change in catecholamine concentrations are very close related to the intensity of the effort expressed in percent of VO_{2peak} (Zouhal, Jacob et al. 2008). Blood noradrenaline concentration increases non-linearly with the intensity of the exercise and this increase accelerates beyond 75% of the maximal aerobic power (Zouhal, Jacob et al. 2008) supporting the validity of using $[La^-]b$ as a surrogate measure of the sympathetic stress load during exercise. From a resting level (1.18 nmol · L^{-1}) noradrenalline can increase 10-15 fold at maximal aerobic power (MAP) (11.8–17.7 nmol · L^{-1}). However large variability of these results has been suggested (Zouhal, Jacob et al. 2008). When the work does not exceed 20 minutes plasma adrenaline concentration starts to rise at a power corresponding to 50% of the MAP and work duration of 60 minutes at 35% of VO_{2peak} is enough to increase the plasma noradrenaline concentration (Zouhal, Jacob et al. 2008). The increase in catecholamine concentration is even more pronounced for intensities higher than MAP (Zouhal, Jacob et al. 2008).

Potential limitations of iTRIMP can be addressed to the need of regular and valid testing with intent to regular monitoring of blood lactate accumulation for recalculation of y_i. The basis for this need of regular testing is that blood lactate accumulation is the net result of result of a number of interacting physiological and biochemical processes, and those processes can be altered with training (Gladden 2004). The regular testing can be influenced by inter- and intra-individual differences in lactate accumulation depending on ambient temperature, hydration status, diet, glycogen content, previous exercise, as well as sampling procedures and hereby lead to over- or underestimation of training load. In addition, endurance training has an effect on resting, submaximal, and possibly maximal heart rate (Borresen and Lambert 2008) whereby these have to be regular tested as well.

Table 1. External, internal and weighting components in the three load methods for calculating of training load

Load method	External load	Internal load	Internal load weighting coefficient
BanTRIMP	Duration	ΔHR_{ratio}	Standard and gender-specific coefficient based on the exponential rise of $[La^-]b$
sRPE	Duration	sRPE	None
iTRIMP	Duration	ΔHR_{ratio}	Individualized coefficient based on the exponential rise of $[La^-]b$

4. Method

This study was a prospective experimental cohort study and a sub-study of a larger randomized controlled study of different training periodization models. Before the intervention period, there was a six wk preparation period to familiarize subjects with testing protocols and three different HIT-sessions (SG3-5). The six wk “pre-training” period also served to help ensure a steady state training baseline prior to the initiation of the intervention period. The intervention lasted 12 weeks and consisted of three training cycles with a total of 24 supervised HIT-sessions, four test days, plus self-organized LIT (SG1 & 2) ad libitum equal to the subject’s normal LIT volume. All subjects trained the same amount and type of supervised HIT, but the specific sequence of HIT session types varied among subjects (See Figure 1). Physiological tests were conducted pre-intervention and in the last wk of each four wk training cycle.

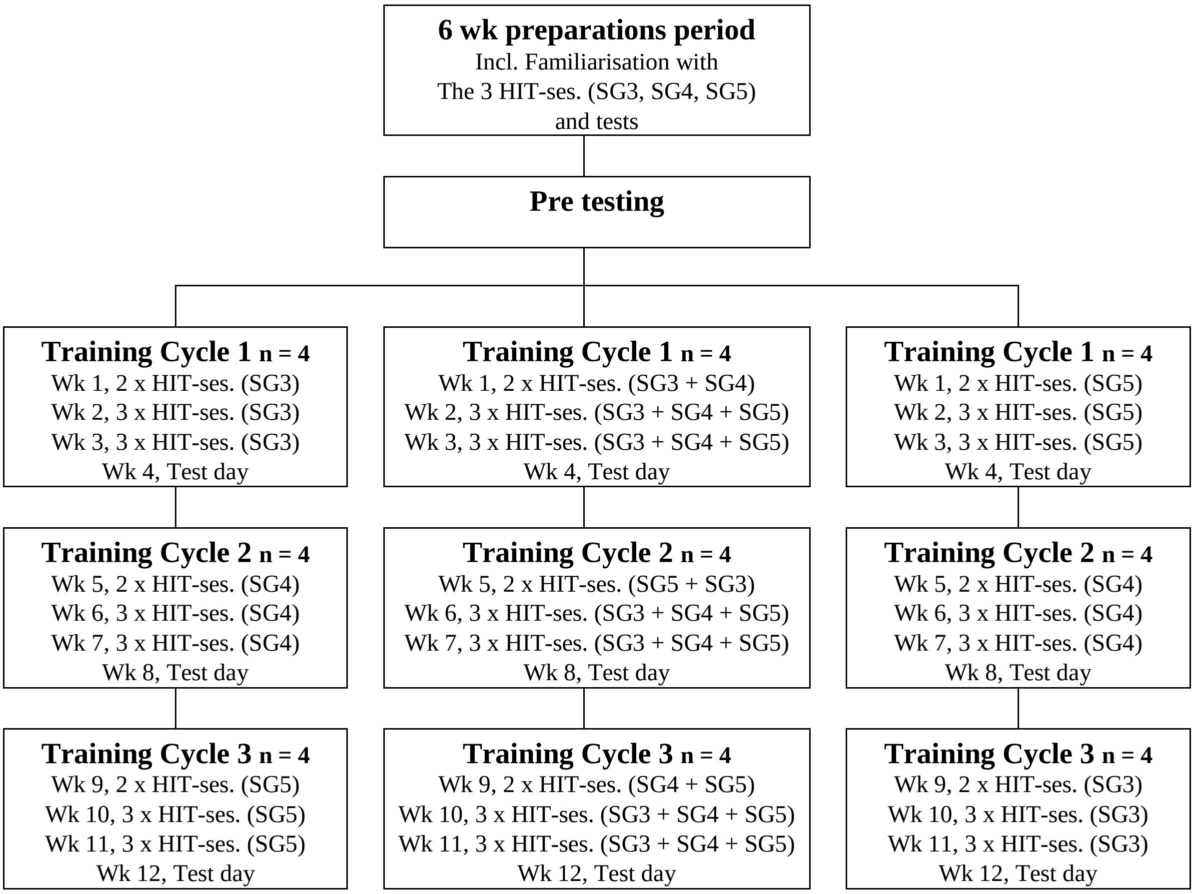

Figure 1. Intervention process. All subjects trained the same amount and type of supervised HIT but the sequence of HIT varied between subjects. The three HIT-sessions were conducted with an “isoeffort approach” and 2 min recovery period between interval bouts. Session goal 3 (SG3); 4 x 16 min, session goal 4 (SG4); 4 x 8 min, session goal 5 (SG5); 4 x 4 min. In addition subjects trained self-organized LIT (SG1 & 2) ad libitum equal to the subject’s normal LIT volume.

4.1 Subjects

Twelve male cyclists, classified as well-trained (De Pauw, Roelands et al. 2013), mean maximal oxygen consumption 4864 ml $O_2 \cdot min^{-1}$ (range 4583–5514 ml $O_2 \cdot min^{-1}$), were recruited to participate in this study, in addition to the main study. Inclusion criteria were: 1) absence of known disease or exercise limitations based on self-report, 2) minimum 5 h $\cdot$ wk^{-1} training volume, and 3) minimum 50 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$. Included in the analysis were subjects with no use of additional, self-organized HIT during the intervention period, a minimum 85 % completed scheduled HIT-sessions, and < 30 % alternative training based on total training hours. All subjects met these requirements and were included in the analysis. Before preliminary testing, all subjects completed a training questionnaire to estimate 1) weekly training hours, and 2) cycling experience. The study was approved by the human subjects review committee of the Faculty for Health and Sport, University of Agder. All subjects provided informed written consent before participation.

4.2 Testing procedures

The main study included two test days with a large amount of test parameters but only test day 1 and the following tests parameters are included in the present study. All testing was performed with a minimum of 36 h recovery from the last HIT-session. All subjects were familiarized with testing procedures in the first 3 wk of the 6 wk preparations period.

The test day consisted of body composition analysis using octapolar impedence (Inbody 720, Biospace Co Ltd., Seoul, South Korea), a lactate profile test on a bicycle ergometer to determine: 1) the aerobic lactate threshold (LT_1) defined as power at 2 mmol $\cdot$ L^{-1} [La-]b, 2) the anaerobic lactate threshold (LT_2) defined as power at 4 mmol $\cdot$ L^{-1} [La-]b, 3) maximal aerobic power (MAP), and 4) the exponential relationship between [La-]b accumulation and fractional elevation ΔHR_{ratio} to determine the y_i coefficient for iTRIMP calculation in the subsequently training cycle. The lactate profile test started with 5-min cycling at 125 W. Cycling continued and power output was increased by 50 W every 5 min until [La-]b of 2,9 mmol $\cdot$ L^{-1} after which power output was increased by 25 W every 5 min. The test was terminated when a [La-]b of 4 mmol $\cdot$ L^{-1} or higher was reached. After 10 min recovery, a continuous incremental test to exhaustion was conducted to determine: 1) peak oxygen consumption (VO_{2peak}), 2) peak power output (PPO) and, 3) peak heart rate (HR_{peak}).

The subjects began cycling at an initial workload of 200 W with a workload increase by 25 W $\cdot$ min^{-1} until voluntary exhaustion or failure to maintain a pedaling rate of 60 rpm. At 60 s post-exhaustion, a blood sample was acquired from finger stick to quantify the peak blood lactate concentration (La^-_{peak}). The highest 60 s $VO_{2average}$, 30 s $RER_{average}$ and 1 s HR were defined as VO_{2peak}, RER_{peak} and HR_{peak}. Following a 15 min recovery from the test to exhaustion, subjects performed a 30 sec Wingate anaerobic power tests with a torque factor of 0,098 Kp · kg^{-1} to determine 1) peak power output ($Wingate_{peak}$), 2) mean power output ($Wingate_{mean}$) and 3) fatigue index.

Testing was performed on a factory-calibrated Velotron ergometer (Racermate, Seattle, WA, USA). The ergometer was PC controlled and electromagnetically braked. Subjects were instructed to remain seated on the ergometer during tests. Seat height, seat to handlebar distance, and handlebar height were adjusted by each subject as desired. Testing was performed with the ergometer in the pedal frequency-independent workload mode. Before each test, the Velotron ergometer was calibrated using a roll-down resistance procedure as described by the manufacturer.

Oxygen consumption was quantified continuously in a mixing chamber using an Oxycon Pro open circuit metabolic cart calibrated before each test (Oxycon, Jaeger BeNeLux Bv, Breda, the Nederlands). Gas sensors and delay time were calibrated via an automated process deriving three gas concentrations using a certified calibration mixture (5.93% CO2, 15.00% O2, AGA Gas, Oslo, Norway), room air (20.93% O2, 0.03%CO2), and a 50–50 admixture of the test gas and room air. Ventilatory volume was calibrated using a 3 L syringe (Hans Rudolph, Kansas City,MO, USA). Calibration procedures were repeated before each test.

The power output at 2 and 4 mmol · L^{-1} $[La^-]$b was calculated for each subject using an excel sheet with algorithms introduced by J. Newell and colleagues (Newell, Higgins et al. 2007). Subjects were blinded to oxygen consumption, but were provided elapsed time, HR, pedaling frequency and vigorous verbal encouragement throughout the three cycling tests. Testing was performed at an ambient temperature between 17 and 20°C. An electric fan was used to ensure sufficient evaporative cooling. All blood lactate measurements were from finger stick (LactatePro LT-1710, Arkay KDK, Kyoto, Japan). Rating of perceived exertion was determined at the end of each bout in the lactate profile test and at the end of the exhaustive protocol. Borg's 6–20 RPE scale (Borg 1970) was used after providing subjects with written and verbal instructions regarding its use. Test days were categorized as SG5-sessions but excluded from analysis when describing the average physical and perceptual response to different SG-intensity for exclusively to describe the demands and TL of 4 x 4 min sessions.

Resting HR (HR_{rest}) was measured on Saturday and Sunday morning of the second wk of every training cycle. Subjects were supine in a resting state (i.e. immediately after awakening, quiet room). The HR_{rest} was assumed as the lowest 1 s value within a 5 min monitoring period.

4.3 Training intervention

In addition to the HIT-sessions, subjects were instructed to perform LIT ab libitum. Subjects were instructed to perform all additional endurance training sessions exclusively at a low intensity (HR zone 1 & 2) and self-categorize the LIT into SG1 or SG2.

Individualized HR-zones were calculated based on HR_{peak} from pre-testing and with a typical intensity zone scale used for endurance training prescription and monitoring; Z1 55-75, Z2 75-85, Z3 85-90, Z4 90-95, and Z5 95-100 %HR_{peak} (Seiler and Tønnessen 2009, Seiler 2010) A minority of the subjects did a few sessions of resistance training, alpine skiing and hiking which were excluded from all analysis. All HIT-sessions was supervised and began with a self-selected warm-up. A roll-down resistance calibrations was conducted after ≈ 2 and 15 min as prescribed by the manufacturer to quantify and adjust wheel-ergometer rolling resistance to 3,5 ± 0,1 lbs. For all interval prescriptions, subjects were instructed to perform the entire interval session at their maximal sustainable intensity ("isoeffort") (Seiler and Hetlelid 2005, Seiler, Joranson et al. 2011). Interval sessions were designed with the intent of the main part of the session to elicit a physiological stimuli corresponding to HR Z3, Z4 or Z5 for 4 x 16 min, 4 x 8 min or 4 x 4 min respective, and was categorized with SG according to the intent of the session. Heart rate and power output were quantified continuously during each work period. RPE was quantified at the last min of each interval for every HIT-session. Blood samples were taken from two random selected subjects in the main study for each HIT-session. The blood samples were taken at the end of interval 3 or 4 to determine lactate concentration. High intensity training sessions were performed in groups of 10 persons on their own road racing bicycle connected to the same Computrainer Lab™ ergometer (Race Mate, Seattle, WA, USA) during all HIT-sessions. Interval training sessions were performed at the same time of the day throughout the intervention period. Subjects manipulated cycling load by individually adjusting the electromagnetic brake of their ergometer. Subjects were provided feedback regarding their cycling power, pedaling frequents, HR and cycling time continuously on a large screen. Room temperature was maintained at 17–20° C for all training sessions. An electric fan was used to ensure sufficient convective cooling.

4.4 Quantification of training load

All the training data analyzed were endurance sessions related activity > 20 min, including cycling to and from work, was recorded as training. Training load was calculated with the use of BanTRIMP (equation 3), sRPE (equation 4) and iTRIMP (equation 5). Subjects were provided a heart rate watch (V800, Polar Elektro Oy, Kempele, Finland) and training diary (Polar Flow and Olympiatoppen's electronic training diary). Records for each training session performed were 1) training form, 2) HR-data, 3) SG and 4) sRPE. If sRPE-score was missing, the subject was contacted as soon as possible to rank demands of the session (> 30 min post training). Where HR-data were not recorded or incorrect (e.g. short sections with HR records over HR_{peak}) due to user errors or equipment malfunction, HR-data were estimated on the basis of previous and subsequent HR-data to obtain the most valid estimation of total load. Physiological adaptions were taken as the average of absolute change in VO_{2peak}, PPO, $Wingate_{mean}$, MAP and $W_{4mmol} \cdot L^{-1}$ for each subject, to generate a measure of the overall response to training.

4.5 Statistics

Training load was estimated by the original methods of BanTRIMP, sRPE and iTRIMP (equation 3, 4 & 5) in Excel (Microsoft, Redmond, WA, USA) using a customized spreadsheet. All HR-data were initially processed in Polar Flow (Polar Elektro Oy, Kempele, Finland), then exported to Excel for further data processing.

Descriptive data are reported as mean ± standard deviation (SD). Exploratory data analysis and skewness revealed whether the data sets were non-normally distributed and heteroscedastic. Non-parametric Spearman's rank correlation coefficients (rho) were calculated to examine the relationship between the load-methods (Figure 2). Correlation coefficients are discussed as very strong (rho ≥ ± 0.7), strong (0.70 > rho ≥ ± 0.5), moderate (± 0.5 > rho ≥ ± 0.3) and small (± 0.3 > rho ≥ ± 0.1) based on Hopkins and colleagues (Hopkins, Marshall et al. 2009). TL estimated by the three load-methods and grouped for SG (Figure 4) as well as training characteristics of a mean session (Table 5) and weekly training characteristics (Table 4) were compared using one-way repeated measures ANOVA with Bonferroni correction, significantly difference were assessed by pairwise comparisons. Statistical analyses were conducted using SPSS 21.0 (SPSS Inc, Chicago, IL, USA). The alpha level was set at $P < 0,05$.

5. Results

Descriptive data for the participants are presented in Table 2. The training related data analyzed were obtained from a total of 879 individual endurance training sessions and tests (789 cycling, 39 cross country skiing, 36 running, 4 swimming, and 12 other endurance type sport activities (e.g. rowing, elliptical trainer)). The largest individual distribution of alternative training was 20,2% (range 0 – 20,2 %) The mean session duration was 101,6 ± 52,1 min (range 22,7 – 389,0 min), and total duration analyzed was 1488 h. Completed was 282 out of 288 scheduled HIT-sessions, with the largest individual failure rate of 12,5 % (3 out of 24 HIT-sessions).

Tabel 2. Physiological and performance status at baseline (n=12).

	Pre intervention
Age (y)	37 ± 9
Cycling experience (y)	4,5 ± 4,1
Weight (kg)	81,7 ± 4,9
Body fat (%)	14,2 ± 1,7
HR_{rest} (bpm)	43 ± 5,5
HR_{peak} (bmp)	189 ± 6,3
VO_{2peak} (ml $O_2 \cdot min^{-1}$)	4864 ± 292
La^-_{peak} (mmol · L^{-1})	13,1 ± 2,5
Respiratory exchange rate (RER_{peak})	1,19 ± 0,05
Peak power output (W)	437 ± 25,6
Maximal aerobic power (W)	383 ± 26,0
$Wingate_{peak}$ (W)	1354 ± 134,5
$Wingate_{mean}$ (W)	880 ± 45,5
Wingate fatigue index (W/s)	24,3 ± 5,7
$W_{2mmol \cdot L-1}$ (W)	236 ± 43,3
$HR_{2mmol \cdot L-1}$ (%ΔHR)	67 ± 8
$W_{4mmol \cdot L-1}$ (W)	285 ± 32,9
$HR_{4mmol \cdot L-1}$ (%ΔHR)	81 ± 5

HRrest is measured in the end of wk 2 in training cycle 1. Cycling experience was self-reported.

Mean weekly TL based on the first three weeks in each training cycle was 925 AU, 3035 AU and 827 AU for respectively iTRIMP, sRPE and BanTRIMP (Table 3). Load reduction in wk 4, 8 and 12 relative to mean of the two previous weeks was respective iTRIMP 59, 55 and 66%, sRPE 52, 54 and 65%, BanTRIMP 48, 48 and 61% and total duration 39, 44 and 55%. Mean weekly training duration from heart rate data was 10,3 ± 4,0 $h \cdot wk^{-1}$.

Table 3. Mean weekly estimated internal training load and training duration from the 12 subjects during 879 individual endurance training sessions across the intervention.

	Wk 1	Wk 2	Wk 3	Wk 4	Mean load wk 1-3
iTRIMP (AU)	787 ± 328	1024 ± 456	945 ± 417	400 ± 125	919 ± 405
sRPE (AU)	2108 ± 564	3121 ± 758	3206 ± 957	1529 ± 543	2811 ± 908
BanTRIMP (AU)	709 ± 221	898 ± 254	857 ± 276	455 ± 147	821 ± 258
Duration (h)	9,2 ± 3,1	11,9 ± 3,7	11,7 ± 4,2	7,2 ± 2,6	10,9 ± 3,8
	Wk 5	Wk 6	Wk 7	Wk 8	Mean load wk 5-7
iTRIMP (AU)	851 ± 206	992 ± 186	847 ± 191	410 ± 132	896 ± 201
sRPE (AU)	2683 ± 569	3334 ± 861	3171 ± 828	1481 ± 437	3063 ± 793
BanTRIMP (AU)	751 ± 210	893 ± 244	761 ± 234	427 ± 139	802 ± 232
Duration (h)	10,4 ± 3,4	12,9 ± 4,3	11,6 ± 4,2	6,8 ± 2,1	11,6 ± 4,0
	Wk 9	Wk 10	Wk 11	Wk 12	Mean load wk 9-11
iTRIMP (AU)	907 ± 250	1044 ± 227	929 ± 258	337 ± 131	960 ± 246
sRPE (AU)	3070 ± 636	3575 ± 1151	3048 ± 660	1144 ± 338	3231 ± 861
BanTRIMP (AU)	827 ± 204	929 ± 221	818 ± 187	342 ± 129	858 ± 205
Duration (h)	12,0 ± 3,2	13,2 ± 3,0	11,5 ± 2,5	5,5 ± 2,5	12,3 ± 2,9

Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Duration, mean weekly duration of training.

The pooled TL-scores for all 879 sessions and test days showed very strong correlations of r = 0,72 between sRPE and iTRIMP, r = 0,79 between iTRIMP and BanTRIMP, and r = 0,82 between sRPE and BanTRIMP.

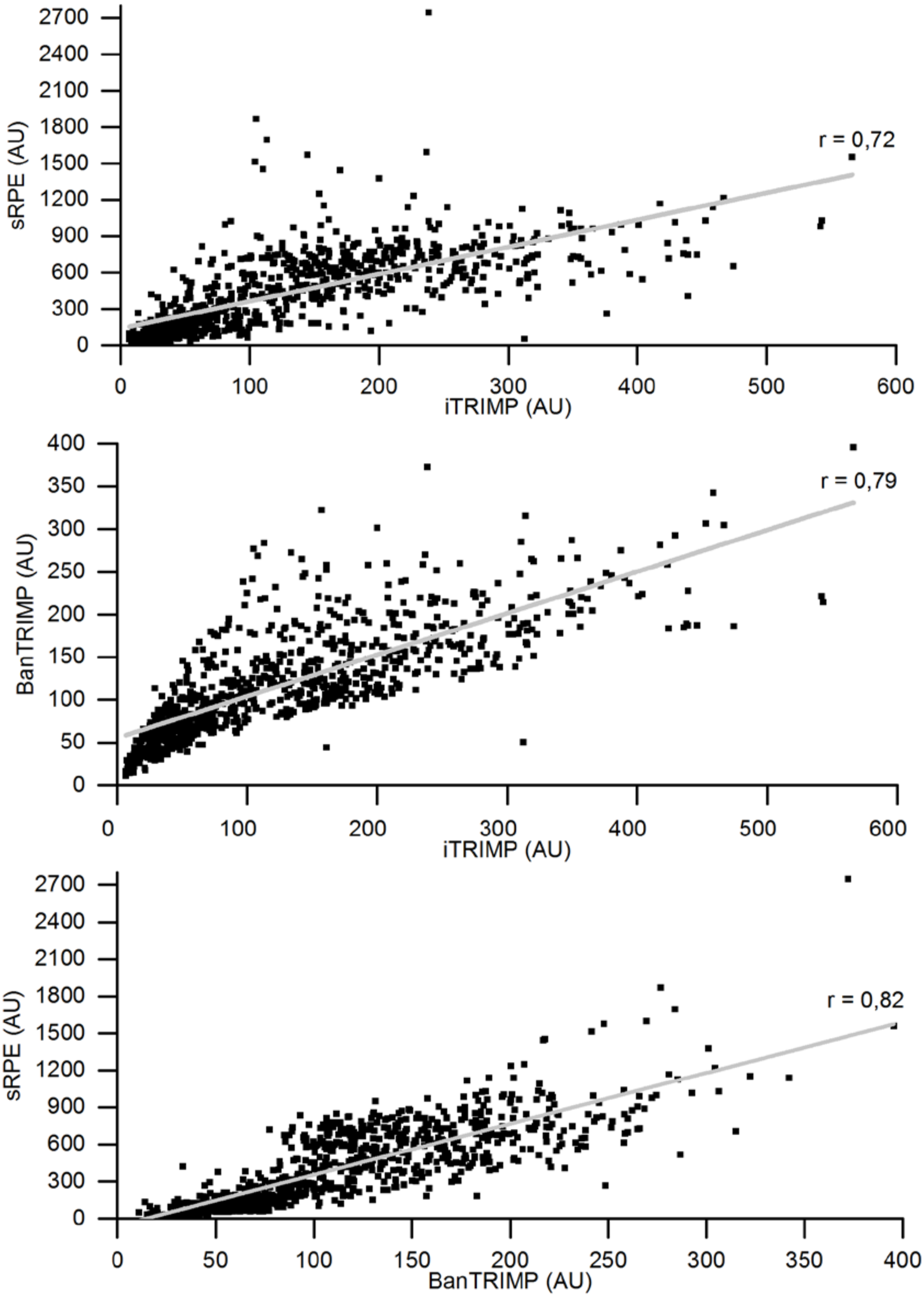

Figure 2. Plots of estimated training load of 879 training sessions calculated by use of, iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Linear fit and associated Pearson's are shown.

The weekly training frequency and duration over the 12-wk intervention period divided into SG categories 1 through 5 are presented in Table 4.

Table 4. Weekly training characteristics divided into session goal (SG) from the 12 subjects during 843 training sessions during the intervention.

	SG1 (n = 516)	SG2 (n = 45)	SG3 (n = 91)	SG4 (n = 95)	SG5 (n = 96)
Training freq. (sessions/wk)	3,6 ± 1,3[1]	0,3 ± 0,3[2]	0,6 ± 0,1[3]	0,7 ± 0,3[3]	0,7 ± 0,0[3]
Training freq. distribution (%)	59,1 ± 14,0[1]	5,8 ± 6,2[2]	11,6 ± 4,0[3]	11,8 ± 2,7[3]	11,8 ± 2,7[3]
Training duration (h/wk)	6,2	0,6	1,2	1,1	1,0
Training duration distribution (%)	61,9	5,6	12,1	10,7	9,8

Superscript values denote $P < 0,05$ vs mean values with non-identical superscripts.
n = number of sessions analyzed in each SG-category (SG5 is without Test days). SD-data was not available for training duration.

Significant differences were found in mean HR (%ΔHR, $\%HR_{peak}$), power output ($\%W_{4mmol}$), $[La^-]b$ and acute RPE ($RPE_{all\ bouts}$, $RPE_{last\ bout}$) for SG3-, 4- and 5- sessions (4 x 16 min, 4 x 8 min and 4 x 4 min interval sessions respectively) (Table 5).

Table 5. Training characteristics of a mean session for each session goal category from the 12 subjects during 843 training sessions throughout the intervention.

	SG1 (n = 516)	SG2 (n = 45)	SG3 (n = 91)	SG4 (n = 95)	SG5 (n = 96)
Duration (min)	103,5 ± 63,9	111,7 ± 57,0	111,8 ± 14,7	96,9 ± 18,0	87,1 ± 20,3
Load iTRIMP (AU)	70 ± 59,8	147 ± 102,1	315 ± 78,6	221 ± 49,6	162 ± 37,9
Load sRPE (AU)	272 ± 290,4	423 ± 272,6	755 ± 173,2	685 ± 168,8	624 ± 163,3
Load BanTRIMP (AU)	96 ± 62,0	130 ± 77,5	200 ± 34,6	149 ± 30,2	126 ± 31,0
Mean heart rate ($\%HR_{peak}$)	-	-	86,8 ± 2,7[1]	89,0 ± 2,4[2]	90,3 ± 2,2[3]
Mean heart rate (%ΔHR)	-	-	82,8 ± 3,5[1]	85,7 ± 3,3[2]	87,4 ± 2,8[3]
Power output ($\%W_{4mmol}$)	-	-	99,6 ± 9,1[1]	108,2 ± 8,1[2]	120,3 ± 8,8[3]
Blood lactate ($mmol \cdot L^{-1}$)	-	-	5,6 ± 1,7[1]	9,4 ± 2,5[2]	11,5 ± 2,2[3]
sRPE	2,3 ± 1,0[1]	3,6 ± 1,2[2]	6,8 ± 1,3[3]	7,1 ± 1,2[4]	7,1 ± 1,4[3,4]
$RPE_{all\ bouts}$	-	-	15,2 ± 1,7[1]	16,0 ± 1,7[2]	16,5 ± 1,7[3]
$RPE_{last\ bout}$	-	-	16,9 ± 1,1[1]	17,8 ± 0,9[2]	18,4 ± 0,8[3]

Superscript values denote $P < 0,05$ vs mean values with non-identical superscripts.
n = number of sessions analyzed in each SG-category (SG5 is without Test days). Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Heart rate ($\%HR_{peak}$), mean heart rate is based on average HR of all four interval bouts. Heart rate ($\%\Delta HR_{ratio}$), fractional elevation of heart rate (equation 1) based on average HR of all four interval bouts. Watt, average watt of all four interval bouts relative to watt at 4mmol blood lactate concentration. Blood lactate, average of measurements taken after third and fourth bout (Sample size, SG3 n = 43, SG4 n = 35, SG5 = 25). sRPE, perceived exertion for the entire training session. $RPE_{all\ bouts}$, Borg scale, average value for all interval bouts performed. $RPE_{last\ bout}$, Borg scale, average value for the last interval bout.

Mean values for sRPE for each athlete based on all the sessions they performed in each SG-category and at fitted line for the mean group sRPE are shown in Figure 3.

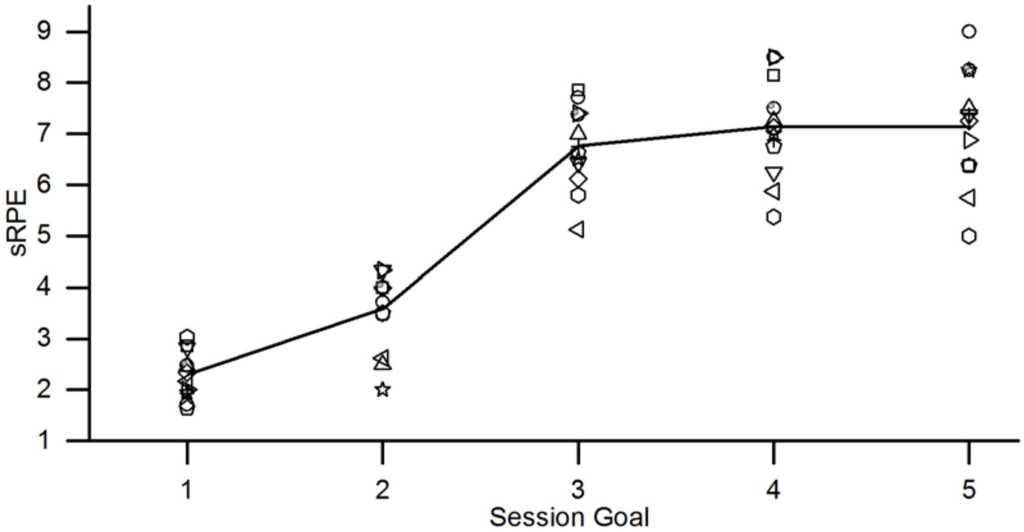

Figure 3. Mean session rating of perceived exertion (sRPE) based on session goal (SG1-5). The sRPE protocol is rating of the overall difficulty of the entire exercise bout obtained 30 minutes after the completion of the exercise on a 0-10 scale (CR10). Number of sessions SG1 n = 516, SG2 n = 45, SG3 n = 91, SG4 n = 95, SG5 n = 96. SG5 is without test days.

Individualized TRIMP elicited a significantly higher contribution of total TL from SG3-sessions than both sRPE and BanTRIMP. Total TL calculated by sRPE had a significant higher contribution from SG5-sessions than both iTRIMP and BanTRIMP and finally was the contribution of total TL quantified by BanTRIMP significant lower from SG4- and SG5-sessions and significant higher from SG1-sessions than both iTRIMP and sRPE (Figure 4).

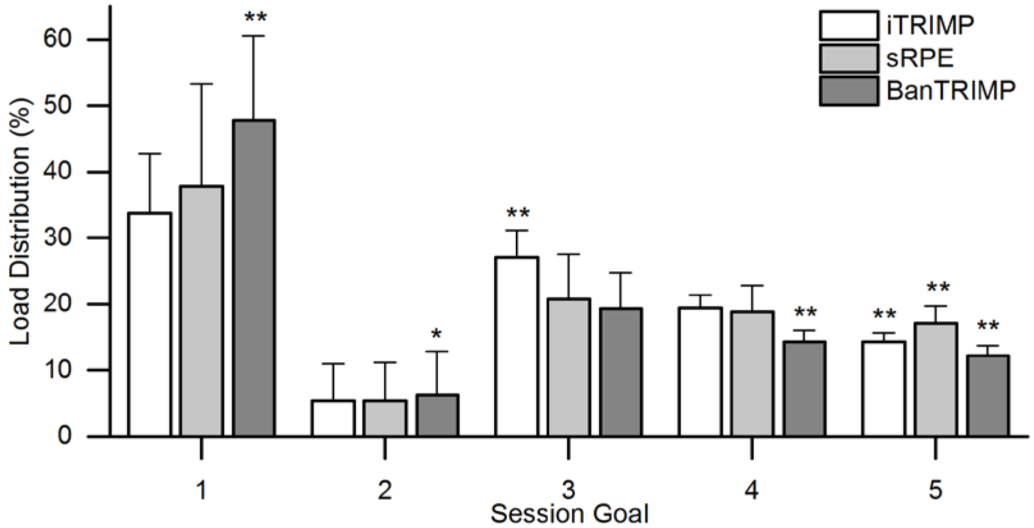

Figure 4. The distribution of total intervention training load estimated by each load-method and categorized by session goal 1-5. Number of sessions SG1 n = 516, SG2 n = 45, SG3 n = 91, SG4 n = 95, SG5 n = 96. SG5 is without the test days. Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3).
* P < 0,05 relative to sRPE. ** P < 0,05 relative to the other load-methods.

The exponential function for this cohort is presented in figure 5 (A) and is comparable to the function used in BanTRIMP (epuation 3). The theoretical Y-intercept is < 0,1 mmol/L blood lactate concentration for both the mean (A) and the individual (B) exponential function. The fitted exponential line is strongly correlated with the actual blood lactate concentration response to increased fractional elevation in HR (A, r = 0,97 & B, r = 0,93).

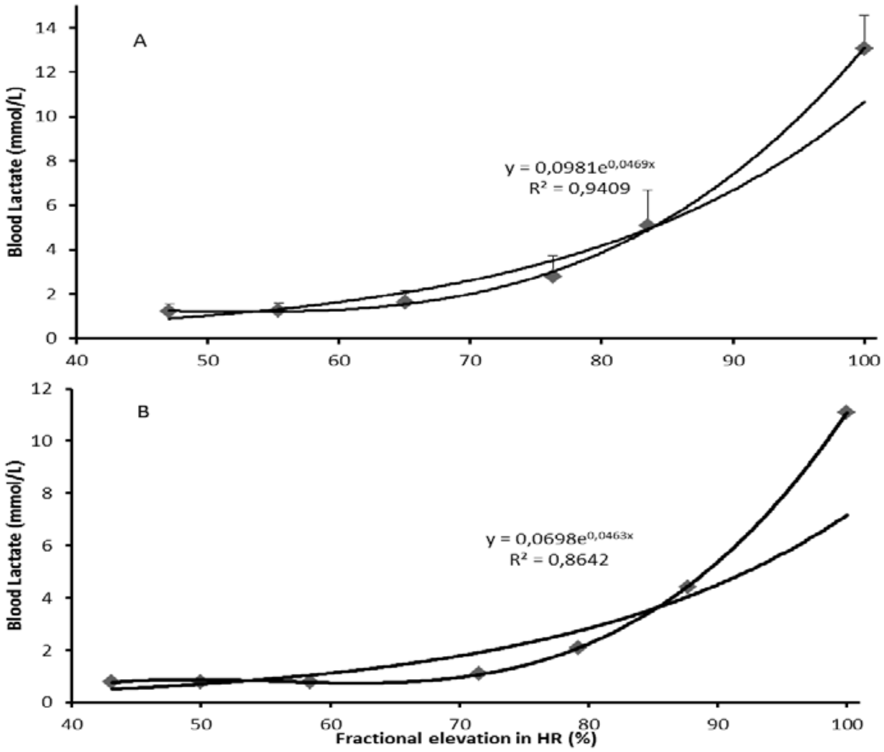

Figure 5. Blood lactate concentration plotted against the fractional elevation in HR. (A) the pooled values from all subjects (n = 12) post cycle 2. (B) result from one subject from the study post cycle 2. The exponential line and function are shown in addition to a polynomial line with three degrees of freedom.

Percentage overall response to training relative to pre-testing was post cycle 1; 3,7 ± 3,2 %, post cycle 2; 5,4 ± 2,7 %, and post cycle 3; 3,3 ± 4,5 % (Figure 6).

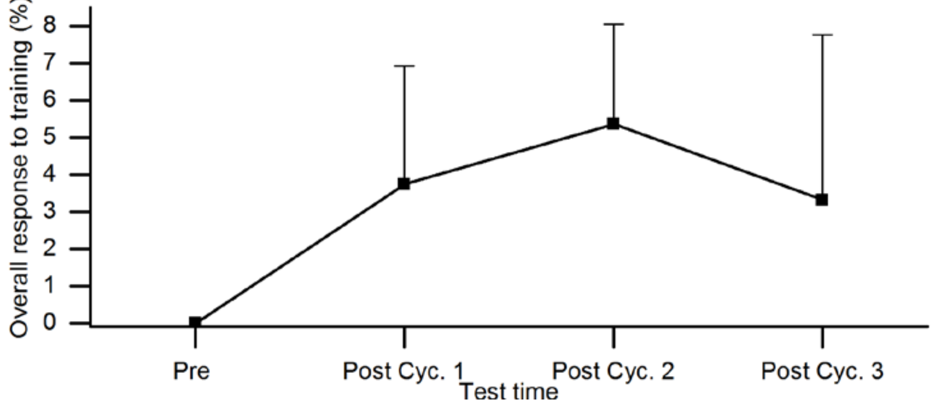

Figure 6. Overall response to training relative to pre-testing (% change). Overall response to training were taken as the average of absolute change in VO_{2peak}, PPO, $Wingate_{mean}$, MAP and $W_{4mmol \cdot L-1}$ for each subject.

6. Discussion

In the present study, well-trained cyclists were prescribed interval training sessions designed to correspond to intensity zones 3, 4, or 5 on a commonly adopted 5-zone aerobic intensity scale (Seiler 2010). The interval sessions varied 4-fold in work bout duration (4, 8, 16 min), and accumulated duration (16, 32, 64 min). However, athletes were instructed to perform each training session with maximal tolerable average intensity i.e. isoeffort (Seiler and Hetlelid 2005, Seiler, Joranson et al. 2011).

We report two novel findings in the present study. The first key finding is that sRPE results across this range of intensity x duration prescriptions were practically identical (Figure 3), despite significant differences in mean HR (%ΔHR, $\%HR_{peak}$), power output ($\%W_{4mmol}$), $[La^-]b$ and acute RPE for the different bouts (Table 5). This finding is consistent with what would be predicted by the *isoeffort* prescription. Thus, in well trained subjects, the 30 min post exercise perception of exertion for the entire training session (sRPE) does indeed integrate accumulated work duration and work intensity in a manner independent of acute physiological measures such as $[La^-]b$ and RPE. The second finding was that comparing the training load contribution to sessions performed in different training intensity zones, as calculated by the methods of iTRIMP, sRPE and BanTRIMP reveals differences among these commonly used training load methods. Despite its simplicity, the sRPE based TL method appears to provide training load data that is highly consistent with prescription, and more internally consistent than the iTRIMP and BanTRIMP methods.

Examining physical and perceptual demands, and in-between methods differences in quantifying TL over a 12 wk, highly controlled training period can provide some important insights regarding the manipulation of training duration and intensity variables. That is the mean sRPE-score was practically identical between long duration zone 3 sessions (4 x 16 min at 100 $\%W_{4mmol \cdot L-1}$, 5,6 mmol · L^{-1}[La-]b, RPE 17) and short duration high intensity zone 5 sessions (4 x 4 min at 120 $\%W_{4mmol \cdot L-1}$, 11,5 mmol · L^{-1}[La-]b, RPE 18,4) is potentially important. This finding is in accordance with Seiler and colleagues (Seiler, Haugen et al. 2007) who found no differences in post-exercise recovery of autonomic nervous system (ANS) balance in highly trained men when interval training (6 x 3 min) at 95% HR_{peak} was performed, compared with "LT-training" (1 x 30 min) at 88% HR_{peak}. This was despite a shorter duration at LT_2 (30 Vs 64 min) compared with the present study and a significant lower sRPE-score at LT-training (5 ± 0,5) compart with interval training at 95% HR_{peak} (8,1 ± 1) (Seiler, Haugen et al. 2007). Compared with the results of Seiler et al. (2007), increasing training duration (30 Vs 64 min) at identical intensity (88 Vs 89 % HR_{peak}) was associated with a substantially increased sRPE-score (5 vs 6,8) in well-trained athletes. It appears at the present study that sRPE scale is not more sensitive to intensity than "overall effort", which integrates both intensity and duration in this cohort.

The present findings differ from those of a recent study using the exact same HIT-session protocol and isoeffort approach but three independent groups training only HIT as 4 x 16, 4 x 8 or 4 x 4 min intervals, and a cohort of less well-trained subjects (PPO 361 Vs 437) (Seiler, Joranson et al. 2011). In these cyclists, the 4 x 4 min HIT prescription resulted in significantly greater sRPE compared with the 4 x 8 min and 4 x 16 min isoeffort prescriptions (7,9; 7,3; 6,8 vs. 7,1; 7,1; 6,8 in this study). One plausible explanation for this difference is that the athletes in the present study were prescribed more frequent HIT during the peak periods of each training cycle (3 Vs 2 HIT session · wk^{-1}) and did a larger mean intervention training volume (10,3 Vs 6,3 h · wk^{-1}). We speculate that the athletes "self-paced" at a slightly lower work intensity at 4 x 4 min (120% W_{4mmol}) compared with the study of Seiler et al. (131% VT_2) and thereby experienced a lower sRPE. This was despite the fact that intensity was relatively identical between to two studies at 4 x 16 min (100% W_{4mmol} vs 100% VT_2) and 4 x 8 min (108% W_{4mmol} Vs 113% VT_2). That the HIT prescription in the present study was near their limits is supported by a decrease in the overall response to training after training cycle 3 (Figure 6) despite an increase in mean TL for the first three weeks of training cycle 3 relative to training cycles 1 and 2 (Table 3). A prolonged average weekly TL higher than iTRIMP = 900 AU, sRPE = 3000 AU and BanTRIMP = 800 AU may have induced a modest overreached state in this cohort (Table 3).

A high TL close to the tolerable can be assumed crucial to achieve peak performance in highly trained endurance athletes. Therefore, careful quantification and feedback regarding athlete management of training load and distribution of training intensity probably becomes critical. Descriptive data of how high level endurance athletes organize training intensity suggest a polarized training model with approximately 75% of their training at intensities below LT_1 (60–70% VO_{2peak}), relatively little trainings at LT_2 (75–85% VO_{2peak}), and approximately 10–20% of their training at intensities clearly above LT_2 (88–95% VO_{2peak}) (Billat, Demarle et al. 2001, Seiler and Kjerland 2006, Seiler, Haugen et al. 2007). From the results of the present study, some practical interpretations can be made of how exercise intensity and duration interact. The subjects in the present study were prescribed a polarized training regime, where all sessions not performed as interval sessions were performed at low intensity. The athletes appeared to largely adhere to this prescription, with mean sRPE for the prescribed LIT training sessions averaging < 3 arbitrary sRPE units. However, in keeping with a contemporary understanding of training intensity distribution and adaptation (Seiler 2010), this training component accounted for much of the total TL. SG1-sessions represented 62 % of the total duration and 48; 34 and 38 % of total TL estimated by respectively BanTRIMP, iTRIMP and sRPE. When SG corresponded to LT_2 or above, the sRPE rose significantly and plateaued in spite of a significant increase in mean HR (%ΔHR, $\%HR_{peak}$), power output ($\%W_{4mmol}$), $[La^-]$b and acute RPE resulting in a larger physical stimulus per unit of interval time. This suggests that the athletes "self-paced" their effort in a manner that was consistent with the maximal overall effort prescription that was identical for all HIT sessions. The demanding nature of HIT in the present study highlights the importance of exact monitoring of TL to avoid non-functional over- or under-reaching and inappropriate training.

The pooled TL-scores for all 879 sessions showed all very strong correlations of r = 0,72 between sRPE and iTRIMP, r = 0,79 between iTRIMP and BanTRIMP, and r = 0,82 between sRPE and BanTRIMP. The present study is the first to examine the variance in TL contribution not accounted for by correlations among the three most acknowledged TL-methods, BanTRIMP, iTRIMP and sRPE. By splitting the total TL into smaller load components based on the SG-distribution of training sessions, we have demonstrated thereby that BanTRIMP quantified a significant higher percent of total load deriving from SG1- and SG2-sessions and a significant lower distribution of TL from SG5 than iTRIMP and sRPE (Figure 4). A fundamental assumption in relation to the validity of the TRIMP methods is that the lactate concentration observed in the blood is representative of the overall training 'stress' imposed on the athlete. Accepting this assumption, we can examine the weighting factor *y* for BanTRIMP that is gender-specific and based on only 5 male and 5 female subjects (male VO_{2peak} 3,74 ± 0,73 $L \cdot min^{-1}$, W_{VAT} 196 ± 32 W) (Green, Hughson et al. 1983, Morton, Fitz-Clarke et al. 1990). This recreationally active cohort resulted in an exponential coefficient given by the equation $y = 0.64e^{1.92x}$. In comparison, calculation of y for the present well trained sample (n=12) was $y = 0{,}0981e^{4{,}69x}$ (Figure 5 A). The theoretical $[La^-]$b at rest is 6,5 fold larger in the group generating Banister's y-coefficient relative to this well-trained cohort in addition to a lower proportional change given by the exponent (1,92x vs 4,6883x). This can lead to overestimation of TL imposed on the athlete at low intensities and can be the reason for a significant higher percent of total load deriving from longer sessions performed in intensity zone 1, compared with the methods of iTRIMP and sRPE. The significantly lower contribution of TL from SG5 calculated with use of BanTRIMP relative to iTRIMP and sRPE can be caused by the use of HR_{mean} for the entire high-intensity interval training session. This interpretation is in accordance with Foster et al (2001) who suggested that the accuracy of the TRIMP equation might be limited by the inability of heart-rate data to quantify high-intensity or non-steady-state exercise. García-Ramos and colleagues introduced a modified TRIMP calculations based on the cumulative sum of partial TRIMP values for each 50 m swimming and rest periods, resulting in a ≈ 9 % higher average load compared with use of mean HR for the full duration of a session with proportionally greater inter-method difference with increasing workload intensity (Garcia-Ramos, Feriche et al. 2014). Results from the present study shows that LT calculated by BanTRIMP with use of the standardized y-coefficient and HR_{mean} not seems appropriate in a cohort of well-trained endurance athletes.

Individualized TRIMP is seen as a refinement of the original TRIMP proposed by Banister, and iTRIMP based TL has been shown to be strongly correlated with running velocity at 2 and 4 $mmol \cdot L^{-1}$ $[La^-]b$ and 5.000 m and 10.000 m track performance (Manzi, Iellamo et al. 2009, Akubat, Patel et al. 2012). But the fractional distribution of total load estimated by iTRIMP had not been analyzed prior to this study. Here we observed that iTRIMP estimated a significant higher percentage of total training load derived from SG3 (lactate threshold) sessions relative to sRPE and BanTRIMP. As for BanTRIMP, ΔHR_{ratio} is weighted by a multiplying factor (y) to give greater emphasis to effort at high intensity compared to effort at low intensity by assuming that the $[La^-]b$ reflects the overall training stress. Deviation between actual $[La^-]b$ and the predicted value in terms of the individual weighting factor y_i can therefore be important. As seen in figure 5 B, a mismatch is apparent through the ΔHR-spectrum at the individual level with a tendency to an overestimation of actual $[La^-]b$ between ≈ 55 and 85% ΔHR_{ratio} and underestimation under ≈ 55% ΔHR_{ratio} and over ≈ 85% ΔHR_{ratio}. Training between LT_1 and LT_2, in this cohort 67–81% ΔHR_{ratio} (Table 1), can thus be estimated with a too high TL and training above LT_2 and below LT_1 with a too low TL. The blood lactate curve and derived weighting factor may be the source of discrepancy in TL component contribution observed.

The last TL-method evaluated is sRPE which estimating a significant higher percent of total TL from SG5-sessions than both iTRIMP and BanTRIMP. In addition estimated sRPE compared with iTRIMP a relative identical (37,8 Vs 33,7 & 5,4 Vs 5,5%), but significant lower than BanTRIMP distribution of total TL from SG1- and SG2-sessions. This is contrary to the findings of Borresen and Lambert (2008) as suggested that the sRPE method might

overestimate TL for athletes spending more time doing low-intensity exercise whereas for athletes participating in proportionally more high-intensity exercise the sRPE method underestimates TL compared with BanTRIMP or vice versa. The reason for the different between the present findings and the results of Borresen & Lambert may be due to activities completed, were the 33 subjects (men n = 15, women n = 18) trained ad libitum for 2 weeks in a wide variety of sports including running (n = 19), running + gym training (mainly interval-type training) (n = 4), only gym training (n = 5), running + cycling (n = 4) and only cycling (n = 1). In addition varied numbers of subjects in each of the group used (n = 6, 4 & 23) increasing the risk of a type 1 error. It appears in the present study that sRPE does not overestimate the distribution of TL derived from LIT (SG1-2-sessions) or underestimate the distribution of TL derived from HIT (SG3-5-sessions) compared with HR-based methods (BanTRIMP & iTRIMP). But sRPE did overestimate the distribution of TL derived from SG5-sessions relative to BanTRIMP and iTRIMP. This deviation between the TRIMP-methods and the sRPE-method may be caused by TL quantified by sRPE being a more global indication of physical effort and a complex interaction of many factors not accounted for to the same degree in heart-rate-based TL-methods. These factors might include hormone and substrate concentrations, personality traits, ventilation rate, neurotransmitter levels, environmental conditions, and psychological states (Herman, Foster et al. 2006).
In all three present TL-methods comparison of load in-between subjects might not be useful because of individual difference in use of the sRPE-scale and in the individualized y-coefficient. The individual use of the sRPE-scale can be visualized in figure 3 showing a lower intersubject than in-between subject variation in sRPE-score across SG3-5-sessions, showing that the subjects tend to be internal consistent.
There are limitations to the study including use of HR_{mean} for all single sessions including high-intensity interval training to estimate TL by BanTRIMP, which may have limited the accuracy. The high TL close to the tolerable cannot be refused to influence the TL measured and thereby the in-between TL-methods difference.
The present study is to our knowledge the first study comparing three of the most recognized LT-methods in an unprecedented manner and discus of variance not accounted for by correlations. The use of both objective and subjective TL-methods at the same subjects over a prolonged training period with a large number of sessions varying in duration and intensity and a polarized training intensity distribution, can be viewed as strength of the study. We believe these findings are meaningful for understanding the physical and perceptual exertional demand of HIT in well-trained cyclist and to gain a better understanding of possible specific

characteristics that may explain variance in quantification of total training load with use of iTRIMP, sRPE and BanTRIMP. Future studies assessing the validity and difference between TL-monitoring methods should aim to include measures of training adaptation or fatigue by use of biochemical markers such as plasma catecholamines and cortisol as well as measures of heart rate variability (HRV) or ANS recovery time which might add a new dimension to the differences between TL methods.

7. Conclusion

The present study showed a practically identical sRPE response across a range high intensity interval sessions varying in intensity x duration prescriptions, despite significant differences in mean HR (%ΔHR, ΔHR_{ratio}), power output (%W_{4mmol}), $[La^-]$b and acute RPE results. That may indicate that the cost of training at or above LT_2 is practically identical, using an "isoeffort" prescription in well-trained cyclist. The sRPE-score does thereby integrate accumulated work duration and work intensity in a manner independent of acute physiological measures. The demanding nature of HIT showed in the present study highlight the importance of exact monitoring of TL to avoid non-functional over- or under-reaching and inappropriate training. Comparing TL contribution to sessions performed in different training intensity zones, as calculated by the methods of iTRIMP, sRPE and BanTRIMP reveal differences between these commonly used training load methods. The importance for appropriate and valid coefficients applicable for the specific cohort and type of training cannot be neglected. Despite its simplicity, the sRPE based TL method appears to provide training load data that is highly consistent with prescription.

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Is simple better?

A methodical comparison of monitoring training load in cyclists

This is an original investigation with 3 tables and 5 figures. The abstract consists of 229 words and the text 3491 words.

Troels Ravn[1], Øystein Sylta[1], & Stephen Seiler[1]

[1] Faculty of Health and Sport Sciences, University of Agder, Kristiansand, Norway

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Address for correspondence:
Troels Ravn
Universitetet i Agder, Fakultet for Helse og Idrettsvitenskap,
Postboks 442, 4604 Kristiansand
Norway
E-mail: Troelp13@uia.no
Telephone 0047 40525369

Running head:
Monitoring training load in cyclists

Abstract

Purpose: To describe physical and perceptual exertional demands of high intensity training (HIT) and explain variance in quantification of training load (TL) with use of *Banister's training impulse* (BanTRIMP), *session rating of perceived exertion* (sRPE) and *individualized training impulse* (iTRIMP). **Method:** During 12 weeks, 12 well-trained male cyclists (VO_{2peak} 60 ± 3 ml · kg^{-1} · min^{-1}) completed 879 individual endurance training sessions including 24 HIT-sessions; 4 x 16 min, 4 x 8 min and 4 x 4 min described at their maximal sustainable intensity (*isoeffort*). Training characteristics, in addition to TL were quantified into categories based on the principle of *session goal* (SG) 1-5 (HR zone 1-5). **Results:** sRPE-score was practically identical for HIT in the range of SG3-5-sessions (4 x 16 to 4 x 4 min) respectively 6,8 ± 1,3 to 7,1 ± 1,4 , consistent with the *isoeffort* prescription. Compared to the other TL-methods quantified; BanTRIMP significant higher contribution of total TL from SG1- and 2-sessions and significant lower from SG5-sessions; iTRIMP significant higher from SG3-sessions and sRPE significant higher from SG5-sessions. **Conclusion:** In well-trained cyclists completing an *isoeffort* prescription: 1) the perceived cost (sRPE) of training ≥ LT_2 is practically identical over a 4-fold range of accumulated duration. Appropriate use of TL for the specific cohort and type of training cannot be neglected. Despite its simplicity, sRPE-based TL appears highly consistent with the training prescription.

Keywords: Training quantification, TRIMP, session-RPE, individualized, endurance.

Introduction

Training load (TL) can be defined as a dose of work that stresses psychophysiological systems and induces subsequent adaptive responses leading to performance enhancement [1]. In order to avoid under- and overtraining, and to achieve peak performance at specific time-points, it is important for athletes and coaches to know the physical and perceptual exertional demand of training, and be able to monitor individual TL, so training programs can be tailored to the temporary and cumulative individual responses to training [2, 3].

Training charteristica of elite endurance athletes is by describe studies observed as *polarized* with approximately 75% of training performed at intensities below the first lactate threshold (LT_1), relatively little training at the second lactate threshold (LT_2), and approximately 10–20% at intensities clearly above LT_2 [4-6]. To monitor and describe training organization the *session goal* (SG) approach proposed by Seiler and Kjerland [5], appears to give a realistic pattern of the total training intensity distribution over the long term [7]. The SG approach is a categorical method, where the entire session is assigned to a single intensity zone category based on the intent, and the intensity achieved at the main part of the session [5].

Training load can be measured as either external or internal. External load is the work completed by the athlete (power output, duration, and distance etc.), measured independently of physiological or perceptual response. Internal load is the individual physiological stress imposed by acute or repeated work. Several methods for quantifying internal TL have been suggested in the literature including objective approaches based on HR such as *Banister's training impulse* (BanTRIMP) [8] and the *individualized training impulse* (iTRIMP) [9] and subjective approaches such as *session rating of perceived exertion* (sRPE) [10]. Multiple studies have "validated" the TL-methods by correlating them with each other; although it does not necessary make them valid. A few studies have used change in fitness and/or performance to validate the TL-methods [9, 11]. Another approach to evaluate the TL-methods is to explain the variance not accounted for by correlations between the TL-methods. This has to our knowledge only been done once by Borresen and Lambert [12] suggesting that the sRPE method might overestimate TL for athletes spending more time doing low-intensity exercise whereas for athletes participating in proportionally more high-intensity exercise the sRPE method underestimates TL compared with HR-based methods (BanTRIMP and summated heart rate zone score) or vice versa.

We propose that quantifining training characteristics and total TL into categories based on the principle of SG (HR zone 1-5), can make evaluation of specifik physical and perceptual exertional demand of high intensity training (HIT) possible, and in addition illuminate the TL-methods in a novel manner.

The purpose of the present study was therefore dual; 1) describe physical and perceptual exertional demand of HIT in well-trained cyclists undergoing a structured training program and 2) identify and discuss possible specific characteristics that may explain variance in quantification of total TL with use of BanTRIMP, sRPE and iTRIMP, three of the most commonly utilized TL-methods.

Method

This study was a prospective experimental cohort study. Before intervention, there was a 6 wk preparation period to familiarize subjects with testing protocols and 3 different HIT-sessions. All subjects trained the same amount and type of supervised HIT, but the specific sequence of HIT-session types varied among subjects (Figure 1).

[Figure 1]

Subjects

Twelve well-trained male cyclists (VO_{2peak} 60 ± 3 ml · kg^{-1} · min^{-1}, age 37 ± 8 y) volunteered to participate in the study. Inclusion criteria: 1) absence of disease or exercise limitations based on self-report, 2) minimum 5 h · wk^{-1} training volume, and 3) minimum 50 ml · kg^{-1} · min^{-1}. The study was approved by the human subjects review committee of the Faculty for Health and Sport, University of Agder. All subjects provided informed written consent before participation.

Testing procedures

Subjects avoided any strenuous exercise in 36 h prior tests. Test days consisted of body composition analysis (Inbody 720, Biospace Co Ltd., Seoul, South Korea), a lactate profile test to determine the exponential relationship between blood lactate accumulation and the exercise fractional elevation in HR (ΔHR_{ratio}) to determine the y_i coefficient for iTRIMP calculation in the subsequently training cycle. The lactate profile test started at 125 W. Power output increased 50 W every 5 min until a blood lactate concentration ($[La^-]b$) of 2,9 mmol · L^{-1} after which power output increased 25 W every 5 min. The test was terminated at $[La^-]b$ of 4 mmol · L^{-1} or higher. After 10 min recovery, a continuous incremental test to exhaustion starting at 200 W with a workload increase of 25 W · min^{-1} until voluntary exhaustion or failure to maintain a pedaling rate of 60 rpm. At 60 s post-exhaustion, a blood sample was acquired to quantify peak $[La^-]b$ (La^-_{peak}). The highest 60 s $VO_{2average,}$ and 1 s HR were defined as VO_{2peak}, and HR_{peak}. Testing was performed on a Velotron ergometer (Racermate, Seattle, WA, USA). Oxygen consumption was quantified in a mixing chamber (Oxycon, Jaeger BeNeLux Bv, Breda, Nederland). All blood lactate measurements were from finger stick (LactatePro LT-1710, Arkay KDK, Kyoto, Japan) Power output and HR at 2 and 4 mmol · L^{-1} $[La^-]b$ was calculated using an excel sheet with algorithms introduced by J. Newell and colleagues [13]. Test days were categorized as SG5-sessions, but excluded from analysis when describing the average physical and perceptual response to different interval sessions (SG3-5). Resting HR (HR_{rest}) was measured within a 5 min monitoring period with subjects supine in a resting state on Saturday and Sunday morning of the second wk of every training cycle.

Training intervention

In addition to the HIT-session, subjects were instructed to perform all additional endurance training exclusively at low intensity (HR zone 1 & 2) and self-categorize the low intensity training (LIT) into SG1 or SG2. Individualized HR-zones were calculated based on HR_{peak} from pre-testing with a typical intensity zone scale; Z1 55-75; Z2 75-85; Z3 85-90; Z4 90-95, and Z5 95-100 $\%HR_{peak}$ [14]. A minority of the subjects did a few sessions of resistance training, alpine skiing or hiking which were excluded from all analysis cause very low intensity and limitations in use of HR-based TL-methods at resistance training. All HIT-sessions began with a self-selected warm-up and calibration after ≈ 2 and 15 min. Subjects were instructed to perform all interval sessions at their maximal sustainable intensity ("*isoeffort*") [15, 16]. Rating of perceived exertion (RPE) [17] was quantified at the last min of each interval. Blood samples were taken at the end of interval 3 or 4 for to determine $[La^-]b$. All HIT-sessions were performed in groups of 10 persons on their own road racing bicycle connected to the same Computrainer Lab™ ergometer (Race Mate, Seattle, WA, USA). Subjects were provided feedback regarding power output, pedaling frequents, HR and duration continuously.

Quantification of training load

Training load was calculated by BanTRIMP using ΔHR_{ratio} multiplied by the duration (D) of effort to contribute to dose size of physical effort [8].

(Equation 1)

$$\Delta HR_{ratio} = HR_{exercise} - HR_{rest} \; / \; HR_{peak} - HR_{rest}$$

To avoid giving a disproportionate weighting to long duration low intensity exercise compared with intense short duration exercise, the ΔHR_{ratio} was weighted by a multiplying factor (y) based on the classically described exponential rise of $[La^-]b$ in relation to increased intensity [8].

(Equation 2)

$$y = 0{,}64e^{1.92x} \text{ (male)}$$

$$y = 0{,}86e^{1.67x} \text{ (female)}$$

with e = base of the Napierian logarithms (2,712), $x = \Delta HR_{ratio}$. Thus,

(Equation 3)

$$\text{TRIMP (arbitrary units (AU))} = D \text{ (min)} \times \Delta HRratio \times y$$

Session-RPE TL was calculated by rating of the overall difficulty of the entire exercise bout obtained 30 min post exercise (sRPE-score), by asking the subject “how was your workout?” on a 0-10 scale (CR10) and multiplied by the duration (D) of the training session [10]

(Equation 4)

$$\text{sRPE (arbitrary units (AU))} = \text{sRPE score} \times \text{D (min)}$$

Individualized TRIMP is a further refinement of BanTRIMP leading to a better individualization but also more methodological complexity. Individualized TRIMP uses averaged HR values for each 5 s interval and an individual weighting factor (y_i) for each subject [9].

(Equation 5)

$$\text{iTRIMP (arbitrary units (AU))} = \text{D (min)} \times \Delta HR_{ratio} \times y_i$$

Records for each training session were, 1) training form, 2) HR-data, 3) SG and 4) sRPE-score. If sRPE-score was missing, the subject was contacted to rank demands of the session (> 30 min post training). Where HR-data were not recorded or incorrect due to user errors or equipment malfunction, HR-data were estimated on the basis of previous and subsequent HR-data.

Statistics

Training load was calculated (equation 3, 4, 5) in Excel (Microsoft, Redmond, WA, USA) using a customized spreadsheet. Descriptive data are reported as mean ± standard deviation (SD). Non-parametric Spearman’s rank correlation coefficients (rho) which were used, are discussed as very strong (rho ≥ ± 0.7), strong (0.70 > rho ≥ ± 0.5), moderate (± 0.5 > rho ≥ ± 0.3) and small (± 0.3 > rho ≥ ± 0.1) [18]. Training load distribution (Figure 4) as well as training characteristics of a mean session (Table 3) and was compared using one-way repeated measures ANOVA with Bonferroni correction. Statistical analyses were conducted using SPSS 21.0 (SPSS Inc, Chicago, IL, USA). The alpha level was set at $P < 0,05$.

Results

Table 1 shows descriptive data for the participants. 879 individual endurance training sessions and tests (789 cycling, 39 cross country skiing, 36 running, 4 swimming, and 12 other endurance type sport activities) were analyzed. Mean session duration was 102 ± 52 min (range 23 – 389 min). Largest individual failure rate of the 24 scheduled HIT-sessions was 12,5 %. The largest individual distribution of alternative training based on duration was 20 % (range 0 – 20 %).

[Tabel 1]

Mean weekly TL based on the first three weeks in each training cycle was 925 AU, 3035 AU and 827 AU for respectively iTRIMP, sRPE and BanTRIMP (Table 2).

[Tabel 2]

Significant differences were found in mean HR (%ΔHR, $\%HR_{peak}$), power output ($\%W_{4mM}$), [La$^-$]b and acute RPE ($RPE_{all\ bouts,}$ $RPE_{last\ bout}$) for SG3-, 4- and 5- sessions (4 x 16 min, 4 x 8 min and 4 x 4 min interval sessions respectively) (Table 3).

[Tabel 3]

Mean values for sRPE-score for each athlete based on all the sessions performed in each SG-category and a fitted line for the mean group sRPE-score are shown in figure 2.

[Figure 2]

The pooled TL-scores for all 879 training sessions and test days showed in between the LT-methods all very strong correlations and are presented in figure 3.

[Figure 3]

Difference in contribution to total TL was found between TL-methods when splitting the total TL into categories based on SG (Figure 4).

[Figure 4]

The exponential function for rise of [La-]b in relation to increased ΔHR_{ratio} for this cohort is presented in figure 5 (A). The fitted exponential line is strongly correlated with the actual [La-]b response to increased ΔHR_{ratio} (A, r = 0,97 & B, r = 0,93).

[Figure 5]

Discussion

We report two novel findings in the present study. The first key finding is that sRPE-score across a range of intensity (HR zone 3-5) x accumulated duration (16, 32, 64 min) using an "isoeffort" prescription in well-trained cyclist were practically identical (Figure 2). This was despite significant differences in mean HR (%ΔHR, $\%HR_{peak}$), power output ($\%W_{4mM}$), [La$^-$]b and acute RPE for the different bouts (Table 3). Thus, in well trained subjects, the 30 min post exercise perception of exertion for the entire training session (sRPE) does indeed integrate accumulated work duration and work intensity in a manner independent of acute physiological measures. The second finding is that comparing the TL contribution quantified into categories based on SG, as calculated by the methods of BanTRIMP, sRPE and iTRIMP reveals differences among these commonly used TL-methods. Despite its simplicity, the sRPE-based TL-method appears to provide TL data that is highly consistent with prescription, and more internally consistent than the BanTRIMP and iTRIMP methods.

That the mean sRPE-score was practically identical between long duration zone 3 sessions (4 x 16 min at 100 %W_{4mM}, 5,6 mmol · L^{-1}, RPE 17) and short duration high intensity zone 5 sessions (4 x 4 min at 120 %$W_{4mM,}$ 11,5 mmol · L^{-1}, RPE 18,4) is potentially important. This finding is in accordance with Seiler and colleagues [6] who found no differences in post-exercise recovery of autonomic nervous system (ANS) balance in highly trained men when interval training (6 x 3 min) at 95% HR_{peak} was performed, compared with "LT-training" (1 x 30 min) at 88% HR_{peak}. It appears in the present study that in this cohort sRPE-scale is not more sensitive to intensity than "overall effort", which integrates both intensity and duration.

The present findings differ from those of a recent study using the exact same HIT-session protocol and *isoeffort* approach in three independent groups, and a cohort of less well-trained subjects (PPO 361 Vs 437 W) [16]. In those cyclists, the 4 x 4 min HIT prescription resulted in significantly greater sRPE compared with the 4 x 8 min and 4 x 16 min isoeffort prescriptions (7,9; 7,3; 6,8 Vs. 7,1; 7,1; 6,8 in this study). One plausible explanation for this difference is that the athletes in the present study were prescribed more frequent HIT during the peak periods of each training cycle (3 Vs 2 HIT-session · wk^{-1}) and did a larger mean intervention training volume (10,3 Vs 6,3 h · wk^{-1}). We speculate that the athletes "self-paced" at a slightly lower work intensity at 4 x 4 min (120% W_{4mM}) compared with the study of Seiler et al. (131% second ventilatory threshold (VT_2)) and thereby experienced a lower sRPE. This was despite the fact that intensity was relatively identical between to two studies at 4 x 16 min (100% W_{4mM} vs 100% VT_2) and 4 x 8 min (108% W_{4mM} Vs 113% VT_2).

From the results of the present study, some practical interpretations can be made of how exercise intensity and duration interact. The subjects in the present study were prescribed a *polarized* training regime, where all sessions not performed as interval sessions were performed at low intensity. The athletes appeared to largely adhere to this prescription, with mean sRPE for the prescribed LIT sessions averaging < 3 arbitrary sRPE units. However, in keeping with a contemporary understanding of training intensity distribution and adaptation [3], this training component accounted for much of the total TL. SG1-sessions represented 62 % of the total duration and 48; 34 and 38 % of total TL estimated by respectively BanTRIMP, iTRIMP and sRPE. When SG corresponded ≥ LT_2, the sRPE rose significantly and plateaued in spite of a significant increase in mean HR (%ΔHR, %HR_{peak}), power output (%W_{4mM}), $[La^-]$b and acute RPE inducing large physical stimulus per unit of interval time. This suggests that the athletes "self-paced" their effort in a manner that was consistent with the *isoeffort* prescription that were identical for all HIT sessions. The demanding nature of HIT in the present study highlights the importance of exact monitoring of TL to avoid non-functional over- or under-reaching.

The pooled TL-scores for all 879 sessions showed very strong correlations between TL-methods (r = 0,72-0,82). By quantifing the total TL into categories based on the principle of SG it was shown that BanTRIMP quantified a significant higher percent of total TL deriving from SG1- and SG2-sessions and a significant lower distribution of TL from SG5 than iTRIMP and sRPE (Figure 4). A fundamental assumption in relation to the validity of the TRIMP methods is that the $[La^-]b$ is representative of the overall training 'stress' imposed on the athlete. According to this assumption, we can examine the weighting factor *y* for BanTRIMP that is gender-specific and based on only 5 male and 5 female subjects (male VO_{2peak} 3,7 ± 0,7 $L{\cdot}min^{-1}$, W_{VT2} 196 ± 32 W) [19, 20]. This recreationally active cohort resulted in an exponential y-coefficient given by the equation $y = 0.64e^{1.92x}$. In comparison, the y-coefficient for the present well-trained sample (n=12) was $y = 0{,}098e^{4{,}69x}$ (Figure 5 A). The theoretical $[La^-]b$ at rest is 6,5 fold larger in the group generating Banister's y-coefficient relative to this well-trained cohort in addition to a lower proportional change given by the exponent (1,92x vs 4,69x). This can lead to overestimation of TL imposed on the athlete at LIT (SG1 & 2) in the present study. The significantly lower contribution of TL from SG5-sessions calculated with use of BanTRIMP relative to iTRIMP and sRPE can be caused by the use of HR_{mean} for the entire high-intensity interval training session. This interpretation is in accordance with Foster et al [10] who suggested that the accuracy of the TRIMP equation might be limited by the inability of HR-data to quantify high-intensity or non-steady-state exercise. Results from the present study shows that LT calculated by BanTRIMP with use of the standardized y-coefficient and HR_{mean} not seems appropriate in a cohort of well-trained endurance athletes.

Individualized TRIMP is seen as a refinement of the original BanTRIMP, and iTRIMP based TL has shown strongly correlating with running velocity at 2 and 4 $mmol{\cdot}L^{-1}$ $[La^-]b$ and 5.000 m and 10.000 m track performance [9, 11]. But the fractional distribution of total TL estimated by iTRIMP had not been analyzed prior to this study. We observed that iTRIMP estimated a significant higher percentage of total TL derived from SG3-sessions ("*LT-training*") relative to sRPE and BanTRIMP. Deviation between actual $[La^-]b$ and the predicted value in terms of the individual weighting factor y_i can be crucial. As seen in figure 5 B, a mismatch is apparent through the ΔHR_{ratio}-spectrum at the individual level with a tendency to an overestimation of actual $[La^-]b$ between ≈ 55-85% ΔHR_{ratio} and underestimation under ≈ 55% ΔHR_{ratio} and over ≈ 85% ΔHR_{ratio}. Training between LT_1 and LT_2, in this cohort 67–81% ΔHR_{ratio} (Table 1), can thus be estimated with a too high TL, and training above LT_2 and below LT_1 with a too low TL. The blood lactate curve and derived weighting factor may be the source of discrepancy in TL component contribution observed.

The last TL-method evaluated is sRPE which estimating a significant higher percent of total TL from SG5-sessions relative to the two HR-based TL-methods. In addition estimated sRPE compared with iTRIMP a relative identical (37,8 Vs 33,7 & 5,4 Vs 5,5%), but significant lower than BanTRIMP distribution of total TL from SG1- and SG2-sessions. This is contrary to the findings of Borresen and Lambert [12] as suggested that the sRPE-method might overestimate TL for athletes spending more time doing low-intensity exercise whereas for athletes participating in proportionally more high-intensity exercise the sRPE method underestimates TL compared with BanTRIMP or vice versa. The reason for the difference between the present findings and the results of Borresen & Lambert may be due to activities completed, were the 33 subjects (men n = 15, women n = 18) trained in a wide variety of sports. In addition varied numbers of subjects in each of the group used (n = 6, 4 & 23) increasing the risk of a type 1 error. The deviation in TL deriving from SG5-sessions between the TRIMP-methods and the sRPE-method may be caused by sRPE being a more global indication of physical effort and thereby infused by a complex interaction of many factors not accounted for to the same degree in HR-based TL-methods [21]. It appears in the present study that sRPE does not overestimate the distribution of TL derived from LIT (SG1-2-sessions) or underestimate the distribution of TL derived from HIT (SG3-5-sessions) compared with HR-based methods (BanTRIMP & iTRIMP).

Practical applications

We believe these findings are meaningful for understanding the physical and perceptual exertional demand of HIT in well-trained cyclist and to gain a better understanding of specific characteristics that may explain variance in quantification of total TL with use of iTRIMP, sRPE and BanTRIMP. There are limitations to the study including use of HR_{mean} for all single sessions including high-intensity interval training to estimate TL by BanTRIMP, which may have limited the accuracy. A high TL close to the tolerable cannot be refused to influence the TL measured and thereby the in-between TL-methods difference. Future studies assessing the validity and difference between TL-monitoring methods should aim to include measures of training adaptation or fatigue by use of biochemical markers such as plasma catecholamines and cortisol as well as measures of heart rate variability (HRV) or ANS recovery time which might add a new dimension to the differences between TL methods.

Conclusion

The present study showed the perceived cost (sRPE) of training $\geq LT_2$ to be practically identical over a 4-fold range of accumulated duration using an “isoeffort” prescription in well-trained cyclist. Comparing the TL contribution quantified into categories based on the principle of SG (HR zone 1-5) reveal differences between the commonly used TL methods, BanTRIMP, iTRIMP and sRPE. The importance for appropriate and valid coefficients applicable for the specific cohort and type of training cannot be neglected. Despite its simplicity, the sRPE-based TL-method appears to provide a TL that is highly consistent with prescription.

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Table captions

Tabel 1. Physiological and performance status at baseline (n=12).

Table 2. Mean weekly estimated internal training load and training duration from the 12 subjects during 879 individual endurance training sessions across the intervention.

Table 3. Training characteristics of a mean session for each session goal category from the 12 subjects during 843 training sessions throughout the intervention.

Figure captions

Figure 1. Intervention process. All subjects trained the same amount and type of supervised HIT but the sequence of HIT varied between subjects. The three HIT-sessions were conducted with an “isoeffort approach” and 2 min recovery period between interval bouts. Session goal 3 (SG3); 4 x 16 min, session goal 4 (SG4); 4 x 8 min, session goal 5 (SG5); 4 x 4 min. In addition subjects trained self-organized LIT (SG1 & 2) ad libitum equal to the subject’s normal LIT volume.

Figure 2. Mean session rating of perceived exertion (sRPE) based on session goal (SG1-5). The sRPE protocol is rating of the overall difficulty of the entire exercise bout obtained 30 minutes after the completion of the exercise on a 0-10 scale (CR10). Number of sessions SG1 n = 516, SG2 n = 45, SG3 n = 91, SG4 n = 95, SG5 n = 96. SG5 is without test days.

Figure 3. Plots of estimated training load of 879 training sessions calculated by use of, iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Linear fit and associated Pearson's are shown.

Figure 4. The distribution of total intervention training load estimated by each load-method and categorized by session goal 1-5. Number of sessions SG1 n = 516, SG2 n = 45, SG3 n = 91, SG4 n = 95, SG5 n = 96. SG5 is without the test days. Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3).
* P < 0,05 relative to sRPE. ** P < 0,05 relative to the other load-methods.

Figure 5. Blood lactate concentration plotted against the fractional elevation in HR. (A) the pooled values from all subjects (n = 12) post cycle 2. (B) result from one subject from the study post cycle 2. The exponential line and function are shown in addition to a polynomial line with three degrees of freedom.

Table 1

	Pre intervention
Age (y)	37 ± 9
Cycling experience (y)	4,5 ± 4,1
Weight (kg)	81,7 ± 4,9
Body fat (%)	14,2 ± 1,7
HR_{rest} (bpm)	43 ± 5,5
HR_{peak} (bmp)	189 ± 6,3
VO_{2peak} ($ml \cdot min^{-1}$)	4864 ± 292
La^{-}_{peak} ($mmol \cdot L^{-1}$)	13,1 ± 2,5
Peak power output (W)	437 ± 25,6
Maximal aerobic power (W)	383 ± 26,0
W_{2mM} (W)	236 ± 43,3
HR_{2mM} (%ΔHR)	67 ± 8
W_{4mM} (W)	285 ± 32,9
HR_{4mM} (%ΔHR)	81 ± 5

HR_{rest} is measured in the end of wk 2 in training cycle 1. Cycling experience was self-reported.

Table 2

	Wk 1	Wk 2	Wk 3	Wk 4	Mean wk 1-3
iTRIMP (AU)	787 ± 328	1024 ± 456	945 ± 417	400 ± 125	919 ± 405
sRPE (AU)	2108 ± 564	3121 ± 758	3206 ± 957	1529 ± 543	2811 ± 908
BanTRIMP (AU)	709 ± 221	898 ± 254	857 ± 276	455 ± 147	821 ± 258
Duration (h)	9,2 ± 3,1	11,9 ± 3,7	11,7 ± 4,2	7,2 ± 2,6	10,9 ± 3,8
	Wk 5	Wk 6	Wk 7	Wk 8	Mean wk 5-7
iTRIMP (AU)	851 ± 206	992 ± 186	847 ± 191	410 ± 132	896 ± 201
sRPE (AU)	2683 ± 569	3334 ± 861	3171 ± 828	1481 ± 437	3063 ± 793
BanTRIMP (AU)	751 ± 210	893 ± 244	761 ± 234	427 ± 139	802 ± 232
Duration (h)	10,4 ± 3,4	12,9 ± 4,3	11,6 ± 4,2	6,8 ± 2,1	11,6 ± 4,0
	Wk 9	Wk 10	Wk 11	Wk 12	Mean wk 9-11
iTRIMP (AU)	907 ± 250	1044 ± 227	929 ± 258	337 ± 131	960 ± 246
sRPE (AU)	3070 ± 636	3575 ± 1151	3048 ± 660	1144 ± 338	3231 ± 861
BanTRIMP (AU)	827 ± 204	929 ± 221	818 ± 187	342 ± 129	858 ± 205
Duration (h)	12,0 ± 3,2	13,2 ± 3,0	11,5 ± 2,5	5,5 ± 2,5	12,3 ± 2,9

Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Duration, mean weekly duration of training.

Table 3

	SG1 (n = 516)	SG2 (n = 45)	SG3 (n = 91)	SG4 (n = 95)	SG5 (n = 96)
Duration (min)	104 ± 63,9	112 ± 57,0	112 ± 14,7	97 ± 18,0	87 ± 20,3
Load iTRIMP (AU)	70 ± 59,8	147 ± 102,1	315 ± 78,6	221 ± 49,6	162 ± 37,9
Load sRPE (AU)	272 ± 290,4	423 ± 272,6	755 ± 173,2	685 ± 168,8	624 ± 163,3
Load BanTRIMP (AU)	96 ± 62,0	130 ± 77,5	200 ± 34,6	149 ± 30,2	126 ± 31,0
Mean heart rate (%HR_{peak})	-	-	86,8 ± 2,7^{1}	89,0 ± 2,4^{2}	90,3 ± 2,2^{3}
Mean heart rate (%ΔHR)	-	-	82,8 ± 3,5^{1}	85,7 ± 3,3^{2}	87,4 ± 2,8^{3}
Power output (%W_{4mM})	-	-	99,6 ± 9,1^{1}	108,2 ± 8,1^{2}	120,3 ± 8,8^{3}
Blood lactate (mmol · L^{-1})	-	-	5,6 ± 1,7^{1}	9,4 ± 2,5^{2}	11,5 ± 2,2^{3}
sRPE	2,3 ± 1,0^{1}	3,6 ± 1,2^{2}	6,8 ± 1,3^{3}	7,1 ± 1,2^{4}	7,1 ± 1,4^{3,4}
$RPE_{all\ bouts}$	-	-	15,2 ± 1,7^{1}	16,0 ± 1,7^{2}	16,5 ± 1,7^{3}
$RPE_{last\ bout}$	-	-	16,9 ± 1,1^{1}	17,8 ± 0,9^{2}	18,4 ± 0,8^{3}

Superscript values denote P < 0,05 vs mean values with non-identical superscripts. n = number of sessions analyzed in each SG-category (SG5 is without Test days). Estimated training load scores are: iTRIMP, individual training impulse (equation 5), sRPE, session rating of perceived exertion (equation 4); BanTRIMP, Banister's training impulse (equation 3). Heart rate (%HR_{peak}), mean heart rate is based on average HR of all four interval bouts. Heart rate (%ΔHR_{ratio}), fractional elevation of heart rate (equation 1) based on average HR of all four interval bouts. Watt, average watt of all four interval bouts relative to watt at 4mmol blood lactate concentration. Blood lactate, average of measurements taken after third and fourth bout (Sample size, SG3 n = 43, SG4 n = 35, SG5 = 25). sRPE, perceived exertion for the entire training session. $RPE_{all\ bouts}$, Borg scale, average value for all interval bouts performed. $RPE_{last\ bout}$, Borg scale, average value for the last interval bout.

Figure 1

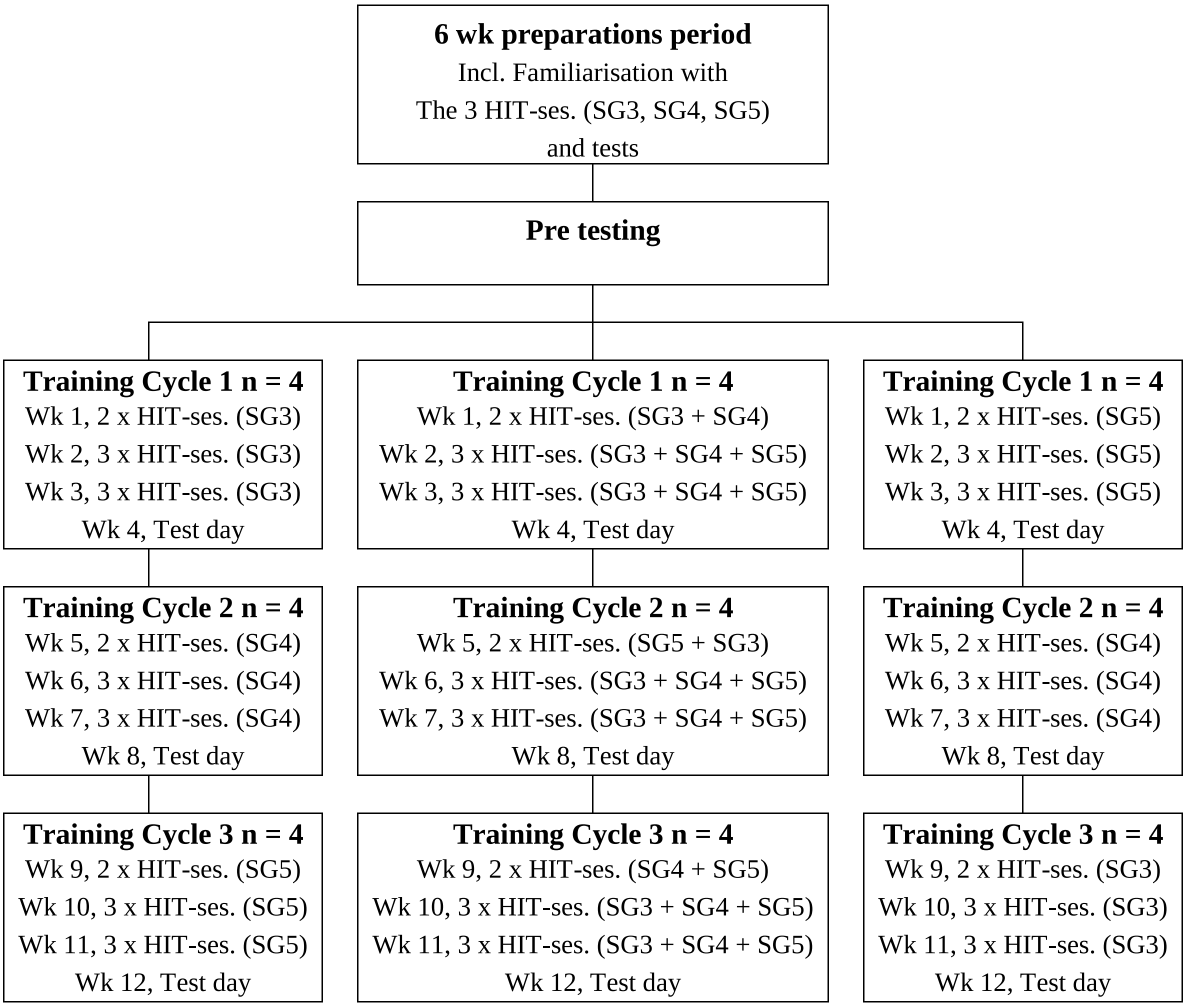


Figure 2

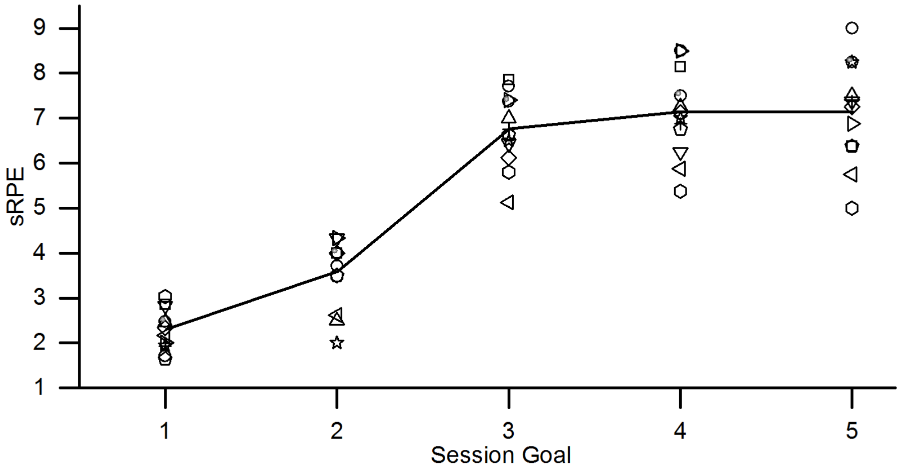
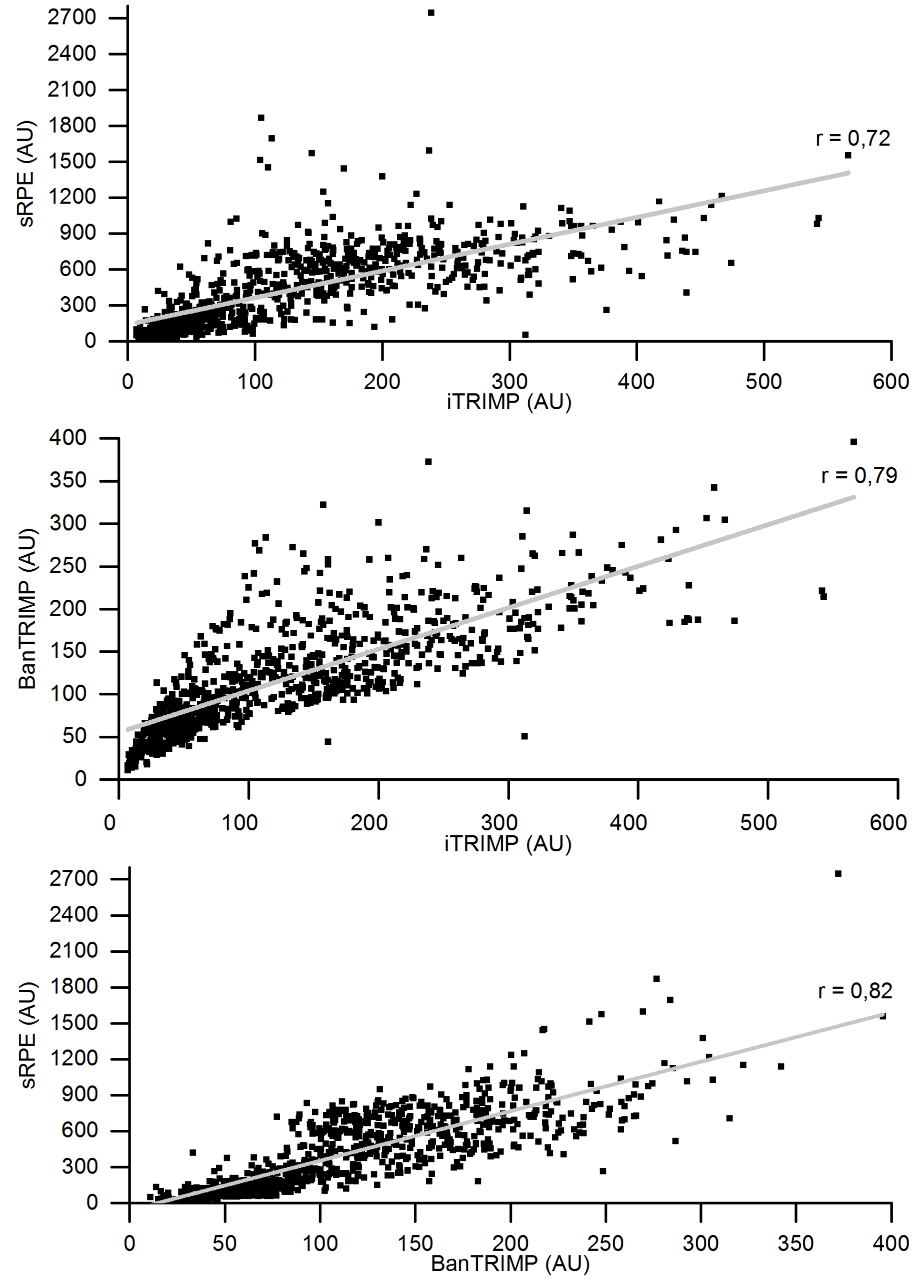


Figure 3



sRPE (AU)
2700
2400
2100
1800
1500
1200
900
600
300
0
r = 0,72
0
100
200
300
400
500
600
iTRIMP (AU)
BanTRIMP (AU)
400
350
300
250
200
150
100
50
0
r = 0,79
0
100
200
300
400
500
600
iTRIMP (AU)
sRPE (AU)
2700
2400
2100
1800
1500
1200
900
600
300
0
r = 0,82
0
50
100
150
200
250
300
350
400
BanTRIMP (AU)

Figure 4

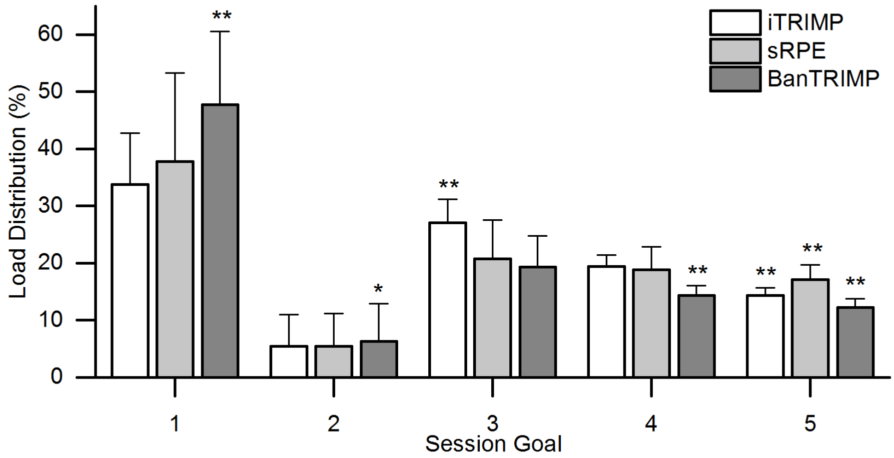


Figure 5