

Hayes & Quinn's TRIMP Concurrent Validity for Cycling

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Abstract

Quantification models aim to accurately reflect the magnitude of the training stress imposed to the athlete, especially in sports with high training volumes, such as road cycling. The aim of this study was to explore the concurrent validity of a new whole-body bioenergetic TRIMP model (Hayes & Quinn, 2009) correlating the obtained training load scores in road cycling with other commonly used models (the Banister TRIMP, the sRPE model and Training Stress Score (TSS)). After three weeks of familiarization with procedures and the performed test to determine $\dot{V}O_{2\max}$, critical power (P_{crit}), anaerobic work capacity (AWC) and Maximal Power Output (P_{max}), 12 well-trained road cyclists performed 8 weeks of individual training to record their individual training data (duration, heart rate, power output and rate of perceived effort (RPE)). Different Pearson's correlation was performed to assess the relationship between models and the changes in fitness. A very large correlation was found between Hayes & Quinn's TRIMP and RPE session ($r = 0.90$; $p < 0.001$) and TSS ($r = 0.88$; $p < 0.01$) and a moderate correlation was found with Banister's TRIMP ($r = 0.64$; $p < 0.05$). No significant correlation was found between changes in fitness and Hayes & Quinn's TRIMP. According to these findings, Hayes & Quinn's TRIMP is a promising mathematical model based on an individual's bioenergetic profile that could be used to quantify training load in road cycling. This research increases our knowledge about training load models that use power output to measure intensity.

Keywords: cycling; training impulse; power output; training load; heart rate

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Introduction

The main goal for coaches is to reach the best performance for their athletes. As such, the ability to achieve peak fitness and performance coinciding with dates of competition is met with varying degrees of success (Borresen & Lambert, 2009). It requires to control the frequency, duration, and intensity of exercise during a long period of time and to predict the athlete's response in order to increase precision during training and to achieve their goals with the best possible guarantees (Borresen & Lambert, 2009). An appropriate use of techniques for monitoring training load is a key factor for many reasons such as adequate and individualised training programmes, which can explain changes in performance and prevent non-functional overreaching or injuries (Halsen, 2014). For this purpose, several models have been developed during the last half-century to obtain a training load value related to these variables (Borresen & Lambert, 2008; Sanders et al., 2016). In this regard, road cycling is a sport with a high volume of training and races and there is a need to plan and control training load to optimize performance. Furthermore, the development of new technologies, like power meters, provides an access to a great quantity of data in every training session (Passfield et al., 2017). The most common quantification models in cycling use duration and intensity of effort. These differ primarily in

the parameter chosen to measure this exercise intensity, being considered internal and external measurements (Bourdon et al., 2017). First, the Session-RPE (sRPE) (Foster et al., 1996), which provides an easy way to quantify training load by using the rated of perceived effort thought the CR-10 scale (Borg, 1998). However, this method have disadvantages such as the moment for collecting the scale information, the subject's experience and the type of training (Day et al., 2004). Second, those models that use heart rate (HR) as intensity. In this regard, the "training impulse" or TRIMP (Banister et al., 1975; Calvert et al., 1976; R. Morton et al., 1990) is one of the most used, and they are very widespread because of their simplicity. The main disadvantages of the use of HR is that it only reflects efforts below maximal oxygen uptake. In addition, HR presents a high variability between days. Finally, those models that use external measurements, such as power output (P) or velocity (V), like Training Stress Score (TSS) (Allen & Coggan, 2010; Sanders et al., 2016) that uses P to calculate the training load metrics. During last years, a great number of devices have appeared to measure power output in road cycling, being many of them, valid and reliable tools to accurately measure power output. For that reason, the use of power output in road cycling it has become popular. And finally there is Hayes & Quinn's TRIMP (Hayes & Quinn, 2009), a new emerging model based on the triparametric bioenergetics model (Hopkins et al., 1989; Morton & Hodgson, 1996), which aims to increase. This model takes three variables into account: Critical power (P_{crit}), Anaerobic Work Capacity (AWC) and Maximum Power Output (P_{max}). (Monod & Scherrer, 1965; Morton, 2006; Morton & Hodgson, 1996) P_{crit} is described as the maximal steady-state power rate that



could be sustained by each individual without reaching fatigue (Hill, 1993) and AWC represents a finite work capacity (in Joules) available to the athlete once he or she attempts a power output above P_{crit} (Skiba et al., 2012). This allows to calculate the training load based on an individual's bioenergetic profile. Hayes & Quinn's TRIMP uses three variables to calculate training load: intensity, concentration, and distance. All quantification models mentioned have been applied to endurance cyclic sports, like road cycling. These models allow a better knowledge of an athlete's adaptation and their response to the training process. Some studies (Sanders et al., 2016; Wallace et al., 2014) compared different models with both external and internal variables in cycling to test its concurrent validity, nevertheless, this comparison has not been performed with Hayes & Quinn's TRIMP.

Some studies have been tested the dose-response relationship between different training load metrics and changes in fitness and performance (Akubat et al., 2012; Malone & Collins, 2016; Manzi et al., 2013; Taylor et al., 2017). In road cycling, it has been suggested that training load metrics that use HR have the strongest dose-response relationships (Sanders et al., 2016). Nevertheless, this comparison has not been tested with the Hayes & Quinn's TRIMP that allows the possibility to quantify the training load based on an individual's bioenergetic profile, which could lead in a more accurately training load calculation.

The aim of this study was to explore the validity of a new whole-body bioenergetic TRIMP model (Hayes & Quinn's TRIMP) correlating the obtained training load scores with changes in fitness. Furthermore, the relationship of this training load metric with other commonly used models was also calculated with the aim of test the concurrent validity.

Methods

Subjects

Twelve well-trained male road cyclists, with more than five years of experience, volunteered to participate in the study in the middle of a competitive season. All participants were members of local teams. In addition, all the cyclists had followed a training programme in the previous two years. Cyclists characteristics were (mean $\pm$ SD) an age of 27.1 ± 11.7 years, VO_{2peak} of 64.6 ± 7.7 ml·kg⁻¹·min⁻¹ and a peak power output (PPO) of 424.0 ± 23.9 W. The study was approved by University Ethic Committee. All participants provided informed written consent prior to participation.

Study Design

The training variables were registered during a eleven-week period. This period was divided into three parts: one familiarization week (FW), eight registered training weeks (RTW) and two testing weeks (TW), before (PRE) and after (POST) RTW

FW was conducted with protocols, data logging, and instrument handling to avoid mistakes in records. During this week, participants learned to record their HRV, calibrate their powermeters before each training

session and save training data (duration, HR, power output). In addition, they familiarized themselves with the subjective scales explained below. Training sessions were collected with the same device (Garmin 500, Garmin Inc, Kansas, United States), HR was measured with a Garmin strap. A rear wheel hub powermeter (Powertap G3, CycleOps, Madison, USA) was fitted to the bike of participants to record power output during training. During the FW, cyclists maintained their training schedule.

In RTW, subjects trained with a homogeneous training load, with a similar volume and intensity across the 8 weeks. Training data were collected every day. Morning training sessions were performed between 10:00 A.M. and 14:00 P.M, while evening sessions were performed between 15:00 P.M. and 19:00 P.M. Duration of effort, HR and power output of all the sessions were registered. A CR-10 scale was completed 30 minutes after each training session. During this period, the cyclists performed their individual training programme, maintaining volume (12.3 ± 4.1 hours) and intensity of training ($73\% \pm 4\%$, expressed as the percentage of watts obtained at the second ventilatory threshold (VT2). Intensity distribution during the eight weeks of RTW was $71\% \pm 3$ under the first ventilatory threshold (VT1), $11\% \pm 4$ between VT1 and VT2 and $18\% \pm 6$ above VT2. No significant differences between cyclists were found for volume and intensity values along RTW. All training sessions were performed on the bikes they normally used.

During the first TW (PRE), participants performed the tests to obtain the training variables used to calculate the training load with the different models, with at least 48 hours between tests. The first day, participants performed a graded exercise test (Pettitt et al., 2013) to obtain VO_{2peak} and ventilatory thresholds and a Wingate test (Bar-Or, 1987) to obtain the maximal power output (P_{max}). The second day, at 9:00 A.M., participants performed a 3-min all-out test to calculate P_{crit} and AWC. For testing, participants were encouraged not to do any vigorous physical activity 24 hours prior to each test. After RTW, participants performed another TW (POST) to assess the changes. During POST, participants performed a graded exercise test with the same protocol described above.

Methodology

Wingate Test

All tests were conducted using a Monark 839-E cycle ergometer (Monark Exercise, Vansbro, Sweden). The cycle ergometer seat and handlebars were adjusted for comfort, with the cyclist's own pedals fitted if required, and with the same settings replicated for the subsequent test.

A Wingate Test (Bar-Or, 1987) was performed to obtain P_{max} . The protocol requires pedalling for 30 seconds at maximal speed and against a constant force in a seated position. A constant force was established by adding a 0.075 kg per kg of the subject's body mass with an electrical brake.

Determination of VO_{2peak} , $VT1$ and $VT2$

A graded exercise test was performed to obtain VO_{2peak} and ventilatory thresholds. It started with 3 min of unloaded baseline, followed by an increase of $30 \text{ W} \cdot \text{min}^{-1}$ until volitional exhaustion, starting with an initial power output of 100 W (Pettitt et al., 2013). Participants were instructed to maintain their preferred cadence for as long as possible. The test finished when the pedal rate fell to more than 10 rpm below the chosen cadence for more than 10 s, despite strong verbal encouragement. VO_{2peak} was determined as the highest VO_2 average during a 30-s period. Data were reduced to 15-s averages for the estimation of $VT1$ and $VT2$ using direct observation in CO_2 and O_2 equivalents (Caiozzo et al., 1982). Respiratory gas exchange was measured MasterScreen CPX (Jaeger Leibniztrasse 7, 97204 Hoechberg, Germany) on a breath-by-breath basis and after the device was calibrated. Peak power output (PPO), Power at $VT1$ (WVT1) and Power output at $VT2$ (WVT2) were also calculated derived from this test.

3-Min All-Out Test

Subjects first performed a warm-up at 100 W, followed by a 5-min rest. The test started with 3 min of unloaded baseline pedalling at each subject's preferred cadence, followed by a 3-min all-out effort. Subjects were asked to increase their cadence to approximately 110 rpm during the last 5 s of the baseline period. The resistance on the pedals during the 3-min effort was set using the linear mode of the ergometer so that the subjects would attain the power output halfway between the GET and the VO_{2peak} (i.e., $GET + 50\% \Delta$, with Δ being the magnitude of the interval between the GET and VO_{2peak}) on reaching their preferred cadence (linear factor = power/cadence^2) (Vanhatalo et al., 2007). Strong verbal encouragement was provided throughout the test, although the subjects were not informed of the elapsed time to prevent pacing. Subjects were instructed to maintain their cadence as high as possible at all times throughout the test. P_{crit} was calculated as the average power output during the final 30-s and AWC was calculated as the power-time integral above end power (Vanhatalo et al., 2007). This test was performed to determine P_{crit} and AWC.

Subjective perception of effort.

The CR-10 scale (Borg, 1998) was used to measure the subjective effort perception 30 min after training.

Training load quantification

Training load was calculated with four different models to quantify training load. These models are based in the rating of perceived effort (Session RPE), heart rate (Bannister's TRIMP) and power output (TSS and Hayes & Quinn's TRIMP)

The Session RPE is a rating of the overall difficulty of the exercise bout obtained 30 minutes after the completion of the exercise (Borresen & Lambert, 2009). Session load was calculated multiplying session RPE (using Borg's CR-10 scale) by session duration of aerobic exercise (in minutes) (Foster et al., 1996).

Banister's TRIMP is an objective model to calculate training bouts (Banister et al., 1975), using HR response as a measure of intensity. TRIMP was calculated using

training duration, maximal heart rate (HR_{max}), resting heart rate (HR_{rest}) and average HR during the exercise session (equation 1). The original formula uses ΔHR (equation 2) and a different correction factor (Y) for males and females: $0.46e^{1.92x}$ for males and $0.86e^{1.67x}$ for females, in which $e = 2.712$ y $x = \Delta HR$.

$$TRIMP = \text{volume}(\text{min}) \times \Delta HR \times Y \quad (\text{Eq. 1})$$

$$\Delta HR = \frac{HR_{ex} - HR_{rest}}{HR_{max} - HR_{rest}} \quad (\text{Eq. 2})$$

TSS was originally developed by Allen & Coggan (Allen & Coggan, 2010) and adapted to other sports, like running (Wallace et al., 2014). Power output is the variable used to measure intensity. To calculate it, (eq.3 and 4) training duration (t), normalized power of the session (NP^{TM}) and the functional threshold power (FTP) of cyclist are needed. For its calculation, FTP was replaced by P_{crit} in order to avoid additional tests. The reason for this change was that they refer to the same point or at least very close to each other, although at present there are no studies that compare both. This calculation also takes the impact factor (IF^{TM}) defined as the ratio between the NP^{TM} of training session and FTP (Equation 4) into account.

$$TSS = \frac{(t \times NP^{TM} \times IF^{TM})}{P_{crit} \times 3600} \times 100 \quad (\text{Eq. 3})$$

$$IF^{TM} = \frac{NP^{TM}}{P_{crit}} \quad (\text{Eq. 4})$$

The bioenergetic model proposed by Hayes and Quinn (2009) involves the use of a critical power three-parameter model (Hopkins et al., 1989; Morton & Hodgson, 1996) to quantify training load. The most relevant and innovative part of this model is the use of an individualized bioenergetic approach to quantify the training load. The TRIMP score depends on an individual's P_{crit} , AWC and P_{max} . This model consider the repetitions, recovery time, and mode of recovery into the TRIMP calculation. To calculate training bouts, the type of session (intervallic, continuous, etc.), intensity and recovery if any, were registered. The formula (eq. 5) to calculate TRIMP (W) has intensity (eq. 6), concentration (eq. 7) and volume (eq. 8) as main parameters. For a more extensive explanation of the model, see Hayes and Quinn (2009).

$$W = I \times C \times V$$

$$(\text{Eq. 5})$$

Where I is the relative intensity, C is the concentration of session, and D is the volume of session.

$$I = \frac{P_{act}}{P_{opt}} + \frac{P_{act} - P_{crit}}{P_{max} - P_{crit}}$$

$$(\text{Eq. 6})$$

Where P_{act} is the average of power output during session, P_{opt} is the optimal power based on the three-parameter model, P_{max} is the maximal power output and P_{crit} is the critical power.

$$C = 1 + \frac{I(nT_{act}) - I(T_{act})}{I(T_{act})} e^{-\sigma_1 \frac{\tau_{rec}}{\tau_{effort}}} \quad (\text{Eq. 7})$$

Where $I(T_{act})$ is the intensity for one repetition of the session (in case of an intervallic session), n is the number of repetitions, σ_1 reflects the type of recovery (from standing recovery ($\sigma_1 = 1$) to recovery at P_{crit} ($\sigma_1 = 0$), τ_{rec} is the recovery time between repetitions and τ_{effort} is the time of one repetition.

$$V = nT_{act}(q_D + (q_{nD} - q_D)e^{-\frac{\tau_{rec}}{\tau_{effort}}}) \quad (\text{Eq. 8})$$

Where q_D is the quality of repetition.

Statistical Analysis

All data were analysed using the SPSS 22.0 statistical package (SPSS Inc., Chicago, IL, USA). Separate one-way analyses of variance with repeated measures were used to evaluate between-model (sRPE, Bannister's TRIMP, TSS and Hayes & Quinn's TRIMP) differences in volume, intensity and training load, for this comparison, data were normalized using the natural logarithm and averaged by weeks. In case of obtaining significant differences, a Bonferroni *post hoc* test was performed. Pearson's product moment correlation coefficients (r) were computed to assess relationships between calculated training load of the four models. In addition, the change (%) between PRE and POST was correlated to the four models, in order to discern their relationship between the dose of training load and its response. The following criterion was adopted to interpret the magnitude of the correlation (r) between test measures: < 0.1 trivial, .1-.3 small, .3-.5 moderate, .5-.7 large, .7-.9 very large, and .9-1.0 almost perfect. Statistical significance was set at $p < .05$.

Results

A total number of 445 training sessions and 96 weeks were analysed during RTW. There were no statistical differences in RTW (Figure 1) in volume ($p = .19$) and intensity ($p = .27$) between weeks. Furthermore, there were no statistical differences (figure 2) between training load models.

A very large correlation was found between Hayes & Quinn's TRIMP and Session-RPE ($r = .83$; $p < .01$) and an almost perfect with TSS ($r = .96$; $p < .01$). Furthermore, we obtained moderate correlation with Bannister's TRIMP ($r = .38$; $p < .05$). Results are displayed in figure 3.

Four participants drop out due to incompatibilities of the TW schedule with their competitive calendar. As a

consequence, eight participants performed POST TW. The correlation between changes in fitness and the Hayes & Quinn's TRIMP were not statistically significant: VO_2max ($r = .07$; $p = .87$), WVT1 ($r = .15$; $p = .72$), WVT2 ($r = .54$; $p = .17$) and PPO ($r = .39$; $p = .34$).

Figure 1. Volume and intensity distribution in RTW

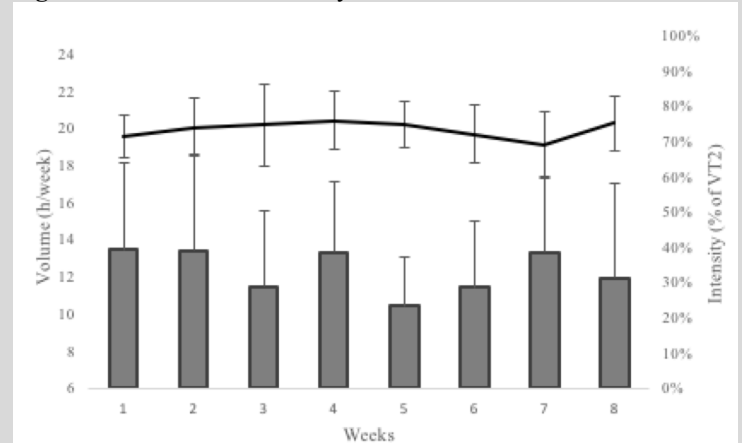
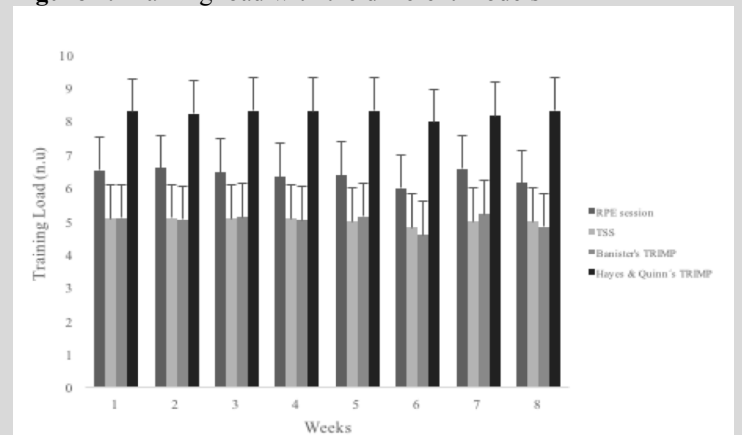


Figure 2. Training load with the different models



Discussion

The purpose of this study was to test concurrent validity of a new theoretical quantifying training load model with other previous models and to evaluate the relationship of this training load metric with changes in fitness in well-trained cyclists. The main finding of the current study was that there were significant correlations (from moderate to very near perfect) among quantifying models. Furthermore, no significant correlation was obtained between changes in performance and the Hayes & Quinn's TRIMP. The high correlations found between models suggest that training load scores evolve similarly among them. These results agree with findings in other studies with internal (Alexiou & Coutts, 2008; Borresen & Lambert, 2008; Impellizzeri et al., 2004) and external models (Scott et al., 2013). However, to the best of our knowledge, concurrent validity has not been tested in Hayes & Quinn's TRIMP to quantify training load in road cycling. In this regard, the highest correlation was obtained with TSS. Both models take the

power output to calculate training load. In running, Wallace et al. (2014) compare a variation of the TSS with changes in performance during a training period, finding that this model is suitable to monitor training load. Despite the use of power output to measure intensity, Hayes & Quinn's TRIMP calculation is based on the triparametric model, taking three parameters into account (P_{crit} , AWC and P_{max}) instead of TSS that only uses one (P_{crit}). This fact could result in a more accurate calculation of the training load due to the use of a bioenergetics approach. Nevertheless, this result also reflects that the TSS reported similar training load values with a most simple calculation. sRPE presents a very large correlation with Hayes & Quinn's TRIMP ($r = .83$). This fact suggests that both external and internal (subjective) intensity variables are related. To the best of our knowledge, this is the first study that compares the sRPE with a quantification model that uses power output in road cycling. The validity of sRPE has been proved in a great number of studies (Day et al., 2004; Herman et al., 2006; Impellizzeri et al., 2004; Wallace et al., 2009). For this reason, the correlation obtained between sRPE and Hayes & Quinn's TRIMP reflected that training load evolves similar between them. Regarding Banister's TRIMP, a moderate correlation ($r = .44$) was found when comparing it with Hayes & Quinn's TRIMP. This result could be due to the differences of HR and power output to measure training intensity and its distribution. Sanders et al. (2017) found different intensity distribution in HR and power output in road cyclists. Furthermore, the use of HR could be limited in road cycling because it only reflects efforts up to the VO_{2max} and its associate HR_{max} and road cycling is made up by both aerobic and anaerobic efforts due the stochastic nature of the sport (Passfield et al., 2017). Halson (2014) reported that there is not a single tool for monitoring training load and an appropriate monitoring of the training load is a key factor in enhancing performance. For this purpose, a combination of internal subjective and external load quantification could be the best option to calculate the training load scores in road cycling. This study has limitations that must be mentioned. First, training load was recorded with similar distribution of volume and intensity during the period and perhaps, a more variation in training load would be an important point to assess the relationship between two models. Second, the dose-response relationship did not support the results of previous studies, however, this could be due to the small sample size that complete POST (eight subjects), thus, this study probably fails to reflect this relationship. Finally, recent studies have shown that the 3-Min All-Out test appears to overestimate the determination of P_{crit} (Bartram et al., 2017; Nicolò et al., 2017). Nevertheless, this test was standardized for all the subjects.

Practical applications

This study has shown an almost correlation between Hayes & Quinn's TRIMP and TSS and sRPE. The evidence from this study suggests that Hayes & Quinn's TRIMP is a promising mathematical model based on an individual's bioenergetic model that could be used to quantify training load in road cycling. However, due to the limited sample size included in the analysis between changes in fitness and the training load metrics, there is a need to implement further research focused in the dose-response relationship. A good point in favour of Hayes & Quinn's TRIMP when compared to the other three quantification models is the possibility to unify many training variables which were not taken into account previously. One of these is the possibility to include recovery periods and their intensities. This research increases our knowledge about training load quantification using external variables to measure intensity (e.g. power output). However, due to the limitations in the method provided, these results must be interpreted with caution and further research is required.

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None

Conflict of Interest

The authors declare that they have no conflict of interest.

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