Training load quantification in elite swimmers using a modified version of the training impulse method

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Published online: 19 Jun 2014.

To cite this article: Amador García-Ramos, Belén Feriche, Carmen Calderón, Xavier Iglesias, Anna Barrero, Diego Chaverri, Thorsten Schuller & Ferran A. Rodríguez (2015) Training load quantification in elite swimmers using a modified version of the training impulse method, European Journal of Sport Science, 15:2, 85-93, DOI: 10.1080/17461391.2014.922621

To link to this article: http://dx.doi.org/10.1080/17461391.2014.922621

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Training load quantification in elite swimmers using a modified version of the training impulse method

AMADOR GARCÍA-RAMOS1, BELÉN FERICHE1, CARMEN CALDERÓN2, XAVIER IGLESIAS3, ANNA BARRERO3, DIEGO CHAVERRI3, THORSTEN SCHULLER4, & FERRAN A. RODRÍGUEZ3

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Abstract

Prior reports have described the limitations of quantifying internal training loads using heart rate (HR)-based objective methods such as the training impulse (TRIMP) method, especially when high-intensity interval exercises are performed. A weakness of the TRIMP method is that it does not discriminate between exercise and rest periods, expressing both states into a single mean intensity value that could lead to an underestimate of training loads. This study was designed to compare Banister’s original TRIMP method (1991) and a modified calculation procedure (TRIMPc) based on the cumulative sum of partial TRIMP, and to determine how each model relates to the session rating of perceived exertion (s-RPE), a HR-independent training load indicator. Over four weeks, 17 elite swimmers completed 328 pool training sessions. Mean HR for the full duration of a session and partial values for each 50 m of swimming distance and rest period were recorded to calculate the classic TRIMP and the proposed variant (TRIMPc). The s-RPE questionnaire was self-administered 30 minutes after each training session. Both TRIMPc and TRIMP measures strongly correlated with s-RPE scores ($r = 0.724$ and $0.702$, respectively; $P < 0.001$). However, TRIMPc was $\sim 9\%$ higher on average than TRIMP ($117 \pm 53$ vs. $107 \pm 47$; $P < 0.001$), with proportionally greater inter-method difference with increasing workload intensity. Therefore, TRIMPc appears to be a more accurate and appropriate procedure for quantifying training load, particularly when monitoring interval training sessions, since it allows weighting both exercise and recovery intervals separately for the corresponding HR-derived intensity.

Keywords: Interval training, swimming, s-RPE, TRIMP, heart rate

Introduction

The training adaptations are associated with changes in performance. Finding the optimal balance between training load and recovery is crucial for sports performance (Smith, 2003). This principle of training can be reduced to a simple dose–response relationship between the physiological stress associated with the load of exercise training (‘dose’) and the training adaptations (‘response’) (Borresen & Lambert 2009). While the ‘response’ can be measured rather easily, either as a change in performance in the laboratory or field or as a physiological adaptation, the ‘dose’ imposes more difficulty and logistical challenges (Lambert & Borresen, 2010). Even if several methods of quantifying training loads have been proposed (Borresen & Lambert, 2008, 2009), to date no effective method has been described for assessing training loads in swimming that can discriminate between different types of time intervals (Wallace, Coutts, Bell, Simpson, & Slattery, 2008).

In swimming, distance and/or speed are often used to monitor the external training load. Along with training session duration, heart rate (HR) is considered an objective measure of internal training load (Desgorges, Sénéga, Garcia, Decker, & Noirez, 2007; Impellizzeri et al., 2006; Mallo & Navarro, 2008; Stagno, Thatcher, & Van Someren, 2007). The training impulse (TRIMP) method (Banister, 1991), first proposed by Banister and Hamilton (1985), considers three factors: session duration, the mean HR for the session (expressed...
according to resting and maximum HR values) and a sex-dependent exponential coefficient that weights intensity. Two of the main inconsistencies of Banister’s method are 1. the assignment of a single mean intensity value (mean HR) for the entire workout and 2. the generic weighting factor based on a standard lactate curve instead of an individualised one. We believe that an additional weakness of this method is that it does not discriminate between exercise and rest periods, a critical factor in interval training. Instead, these two states are expressed as a single mean intensity value for the total duration of the training session and, most likely, this could lead to underestimate training loads.

In addition, HR-based methods have certain limitations for non-aerobic modes of exercise, such as resistance training (Busso et al., 1990) or interval exercises (Borresen & Lambert, 2009), very common in swimming training (Foster et al., 2001; Stagno et al., 2007). Hellard et al. (2006) argued that this indicator has limitations when monitoring starts and turns. Indeed, these actions generally represent 30% of training session duration for sprint swimmers (Thompson, Haljand, & MacLaren, 2000). These shortcomings have been addressed, and modifications have been proposed (see Borresen & Lambert, 2009, for a review). A proposal presented as a TRIMP variant multiplies the cumulative time spent in a given HR zone by a weighting factor (Foster et al., 2001; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003), computing total exercise demands by adding the loads within each HR zone. However, in contrast to classical TRIMP, only exercise periods are computed. Additionally, the weighting factor increases linearly, instead of exponentially as in the TRIMP method, and therefore does not seem to adequately represent the training load of exercises performed at intensities exceeding the anaerobic threshold (Stagno et al., 2007). In interval workouts, these procedures could lead to underestimated training loads as suggested by Borresen and Lambert (2008).

Subjective methods such as the rating of perceived exertion (RPE) are gaining popularity to monitor and control training because of their practicality and usability (Borresen & Lambert, 2009; Lamberts & Borresen, 2010; Psycharakis, 2011; Raffaelli, Galvani, Lanza, & Zamparo, 2012; Wallace, Slattery, & Coutts, 2009). RPE was found to be closely associated with different physiological variables (e.g., HR, oxygen consumption and lactate concentration) and training zones (Bonitch, Ramirez, Femina, Feriche, & Padial, 2005; Coutts, Rampinini, Marcara, Castagna, & Impellizzeri, 2009; Feriche, Chicharro, Vaquero, Perez, & Lucia, 1998; Mendez-Villanueva, Fernandez-Fernández, Bishop, & Fernandez-Garcia, 2010; Steed, Gaesser, & Weltman, 1994). The session RPE (s-RPE) proposed by Foster (Foster, 1998; Foster et al., 1995) intends to circumvent the problems associated with measuring HR during training and is currently one of the most used methods in sport. Recent reports have established good agreement between objective and subjective methods of exertion quantification such as the TRIMP and s-RPE methods in endurance training (Wallace, Slattery, & Coutts, 2014) and its ecological validity for training load evaluation in elite swimmers has been established (Wallace et al., 2009).

Therefore, a quantification method for sessions eliciting substantial HR changes across exercise intervals interspersed with recovery periods of different duration is needed. Such a method would make it possible to determine the swimmer’s level of exercise and more precisely reflect the physiological stress imposed by the training session.

This study was designed to propose a modification to the calculation of training impulses (cumulative TRIMP or TRIMPc) based on the summation of partial values weighted by the time duration of the exercise and recovery intervals, and to correlate both of them with an independent quantification method (s-RPE) in elite swimmers. Our starting hypothesis was that considering each repetition and recovery periods separately would represent more accurately the training load, and that this would be reflected by an improved relationship with the subjective (RPE-based) load indicator.

Methods

Participants

The study participants were 17 elite swimmers, 11 women (aged 19 ± 2.6 years, height 175 ± 6 cm, body mass 64.7 ± 5.1 kg) and 6 men (aged 19.8 ± 1.9 years, height 186 ± 5 cm, body mass 78.5 ± 6.6 kg). They were members of the Spanish and Dutch national teams and elite swimming clubs. Selection criteria were to have competed internationally during the previous season and/or being pre-selected as member of their National and/or Olympic teams. To quantify the competitive level of the participants, the FINA Point Scoring (FPS) system was used (data from 2011), and a point score (range 0–1100) was ascribed to each swimmer according to her/his best time in her/his main event, scaled up or down from 1000 points based on the global 2012 fastest performance in each event. The FPS of the study sample was 766.6 ± 59.5. Subjects were invited to voluntarily participate in the study and provided written informed consent. For swimmers under 18 years old, consent was obtained from their legal guardians. The study protocol adhered to the tenets of the Declaration of Helsinki and was
approved by the Ethics Committee for Clinical Sport Research of Catalonia.

**Experimental design**

A correlation study was designed with multiple longitudinal observations. The participants took part in a training camp and were monitored daily over four consecutive weeks of training at the High Performance Centre of Madrid (CAR de Madrid, Consejo Superior de Deportes), or at the Club Natació Sabadell (50-m indoor swimming pools), located at 655 m and 190 m above sea level, respectively. The swimmers completed the training programmes prescribed by their coaches. On average, they trained six days/week, three sessions/day (two in the pool and one on dry land) and usually rested on Sunday. Data from the pool sessions only were used in the analysis. Three different methods for quantifying training load were used and compared.

**Materials**

In each session, HR was recorded beat-by-beat, and averaged every 5 seconds using waterproof monitors (CardioSwim, Freelap, Fleurier and Switzerland). The HR monitors’ belt contains two chest electrodes wired to a monitoring device that was downloaded on a computer at the end of each session using an interface configuration and ancillary software (Frelap Manager, Fleurier, Switzerland, 2007) and then transferred to Microsoft Excel spreadsheet software (Microsoft, USA) for further analysis. Beacon transmitters for electronic timekeeping (TX H2O, Free- lap, Switzerland) were placed at each end of the 50-m pool. These units sent a signal to the monitors’ microprocessor, which was registered as 50-m lap time. Previous to the study period, the baseline and maximum HR were recorded, which were maintained as such throughout the study. Baseline HR was obtained after waking up with beat-by-beat monitors (Polar RS800, Polar Electro Oy, Kempele, Finland). While subjects remained in supine position, time between adjacent R-waves (R-R intervals) were recorded during 8 minutes, and the last 5 minutes were averaged. Maximum HR was the maximal value obtained during a previous maximum 200-m freestyle test. As a subjective indicator of training load, the self-administered Category Ratio scale (CR-10) questionnaire was used according to the procedure proposed by Foster et al. (2001).

**Quantification of training load**

HR and lap time intervals were recorded in all pool training sessions to compute training impulse units using two different calculation procedures: the classic TRIMP method and the modified, so designated ‘cumulative TRIMP’ method or TRIMPc. The classic TRIMP method (Banister & Hamilton, 1985) estimates the internal training load from the exercise duration and HR-based intensity, determined by the increase in HR (ΔHR_{ratio}) weighed by a sex-dependent exponential factor (Banister, 1991) according to the following equation:

\[
\text{TRIMP} = t \cdot k_1 \cdot x
\]

where $\text{TRIMP} = \text{‘training impulse’ (arbitrary units, a.u.)}$; $t = \text{duration of training (minute)}$; $k_1 = \text{sex-dependent intensity factor}$; $e = \text{base of the natural logarithm (2.712)}$; and $x = \text{fractional elevation of the maximum HR range (ΔHR_{ratio})}$ or in other terms:

\[
x = \frac{\Delta \text{HR}_{ratio}}{\text{HR}_{exercise} - \text{HR}_{rest}}
\]

Since HR and time lap intervals were recorded in each pool training session, the TRIMPc quantified the training impulse as the summation of all partial TRIMP values registered during the session. Thus, each exercise and recovery time intervals ($t_{int}$) were individually quantified, and then summed to obtain the TRIMPc value corresponding to the entire training session:

\[
\text{TRIMPc} = \sum_{int=1}^{N} t_{int} \cdot k_1 \cdot x
\]

where TRIMPc = cumulative TRIMP (a.u.) and $N = \text{total (cumulative) number of exercise/recovery time intervals during the training session (N_{int})}$, each with its corresponding ΔHR_{ratio}.

Additionally, the variability in HR during the training session was expressed as the standard deviation of the time-weighted HR (HRs):

\[
\text{HRs} = \sqrt{\frac{\sum_{int=1}^{N} \text{HR}_{int}^2 \cdot t_{int} - \text{HR}_{mean}^2 \cdot t_{session}}{N_{int}}}
\]

where $N_{int} = \text{number of HR intervals monitored during the session; } \text{HR}_{int} = \text{mean HR for each time interval; } t_{int} = \text{time duration of each time interval (minute); } \text{HR}_{mean} = \text{mean HR for the entire training session; and } t_{session} = \text{time duration of the training session (minute).}$

Separately, within 30 minutes after each training session all swimmers completed a RPE questionnaire based on the CR-10 RPE scale (Borg, Ljunggren, & Ceci, 1985), adapted for the overall assessment of training sessions by Foster (Foster et al., 1995; Foster, 1998), and recently validated for swimmers (Wallace...
et al., 2009). The subjects were required to score from 0 to 10 on how hard they perceived their training session to be, and s-RPE was then calculated using the following equation:

\[ \text{s-RPE} = \text{RPE score} \times \text{t}_{\text{session}} \]  

where RPE score is the rating of perceived exertion score (from 0 to 10) for the whole training session and \( t \) = duration of the training session (minute).

**Statistical analysis**

Data are summarised as means and standard deviations (s). s-RPE was used as an independent (i.e., not HR based) training load indicator to which both TRIMP calculation methods were compared by assessing the level of correlation and inter-method agreement. Correlations between both objective (TRIMP and TRIMPc) and subjective (s-RPE) methods were quantified through Pearson’s linear correlation coefficient (\( r \)). The two TRIMP calculation procedures were also compared using a \( t \) test for paired data. Qualitative interpretations of the \( r \) coefficients as defined by Hopkins (2002; 0–0.09 trivial; 0.1–0.29 small; 0.3–0.49 moderate; 0.5–0.69 large; 0.7–0.89 very large; 0.9–0.99 nearly perfect; 1 perfect) are provided for all significant correlations.

Workload indicators recorded across the four weeks of study were compared by one-way analysis of variance. In addition, algorithmic multiple linear regression (MLR) analysis was used to individuate factors showing an effect on s-RPE, TRIMP and TRIMPc. The best-fit model was generated through stepwise regression (\( F_{\text{in}} \leq 0.05; F_{\text{out}} \geq 1.0 \)) using the three estimated workload scores as the dependent variable, and the objective training load indicators during the training session (duration, \( \Delta \text{HR}_{\text{ratio}} \), \( N_{\text{int}} \), and \( \text{HR}_{\text{rest}} \)) as predictor variables. The adjusted Pearson’s multivariate coefficient of determination (adjusted \( r^2 \)), the standard error of the estimate (\( SE_\beta \)), the regression constant (\( a \)), the raw score (\( b \)) and standardised coefficients (\( \beta \)-weights) are reported. Also a predictive linear regression model for estimating the training impulse with anyone of both calculation methods was developed, and a Bland–Altman mean difference plot with 95% limits of agreement was drawn. Significance was set at \( P < 0.05 \) and the confidence interval at 95% is indicated when appropriate (95% CI). All analyses were performed using PASW Statistics for Windows, version 18.0, SPSS Inc., Chicago, USA.

**Results**

The data analysed were obtained from a total of 328 individual swimming training sessions. The mean duration of each session was 90.2 (22.3) minutes. Table I shows the descriptive results for the training load indicators, and both objective (TRIMP and TRIMPc) and subjective (s-RPE) estimated the internal workload scores across the study. The pooled TRIMPc mean scores during the four-week period were 9.0% higher (95% CI = 8.2–9.7) than TRIMP (\( P < 0.001 \)). No significant differences were observed among scores across the four-week training period in any of the training load variables.

The pooled scores obtained using both calculation methods (TRIMP and TRIMPc) were nearly perfectly correlated (\( r = 0.996; P < 0.001 \); Figure 1), and showed a large to very large correlation with s-RPE across the study (TRIMP; \( r = 0.70, 95\% \text{ CI} = 0.64–0.75 \); TRIMPc: \( r = 0.72, 95\% \text{ CI} = 0.67–0.77 \); \( P < 0.001 \); Table II). The within-subjects correlation coefficients were very large in both cases, although it

<table>
<thead>
<tr>
<th>Table I. Workload indicators and estimated internal training load scores during individual sessions (n = 328) across the study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weighs of training</strong></td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td><strong>Duration (minute)</strong></td>
</tr>
<tr>
<td><strong>HR_{rest} (bpm)</strong></td>
</tr>
<tr>
<td><strong>HR_{max} (bpm)</strong></td>
</tr>
<tr>
<td><strong>HR_{mean} (bpm)</strong></td>
</tr>
<tr>
<td><strong>HR (bpm)</strong></td>
</tr>
<tr>
<td><strong>\Delta HR_{ratio} (%)</strong></td>
</tr>
<tr>
<td><strong>Intervals (N)</strong></td>
</tr>
<tr>
<td><strong>TRIMP (a.u.)</strong></td>
</tr>
<tr>
<td><strong>TRIMPc (a.u.)</strong></td>
</tr>
<tr>
<td><strong>s-RPE (a.u.)</strong></td>
</tr>
</tbody>
</table>

Training load indicators are: duration, time duration of the training session; \( \text{HR}_{\text{rest/max/mean}} \), resting, maximum, mean heart rate, respectively (bpm, beat per minute); \( \Delta \text{HR}_{\text{ratio}} \), standard deviation of the time-weighted heart rate (equation 4); \( \text{HR}_{\text{ratio}} \), fractional elevation of the heart rate (equation 2); intervals, number of exercise and recovery intervals. Estimated training load scores are: s-RPE, session rating of perceived exertion (equation 5); TRIMP, cumulative training impulse score (Banister, 1991; equation 1); TRIMPc, cumulative training impulse score (equation 3).
was higher using TRIMPc ($r = 0.77$; 95% CI = 0.76–0.78) than Banister’s TRIMP ($r = 0.74$; 95% CI = 0.73–0.75; $P = 0.002$).

As shown in Figure 1, the difference between both methods of calculation increased with the mean scores, indicating that proportional bias existed.

Table III shows the variables and parameters of the three algorithmic explanatory MLR models generated using the objective training load indicators as independent variables ($n = 328; k = 4$). The HR variability indicator ($HR_v$) was excluded in all three models and is not shown in Table III, and the number of intervals ($N_{int}$) was excluded in the s-RPE predictive model. Thus, when s-RPE was used as the predicted variable, the resultant best-fit model accounted for 55% of the variance (adjusted $r^2 = 0.551; SE_E = 168; P < 0.001$). When TRIMP and TRIMPc were the predicted variables, the corresponding model explained 92% of the variance (adjusted $r^2 = 0.919$ and 0.921; $SE_E = 13.5$ and 14.9, respectively; $P < 0.001$). The standardised $\beta$-weight coefficients indicated that the length of the training session had a similar weight in the three methods of workload quantification ($\beta > 0.5$), whereas as expected, the $\Delta HR_{ratio}$ had a greater weight ($\beta = 0.7$) in predicting both TRIMP and TRIMPc as compared to s-RPE ($\beta = 0.4$). The number of intervals entered both TRIMP models but had a minor role in predicting the dependent variable ($\beta \leq 0.1$).

**Discussion**

The results of this study show that, using currently available technology to identify and time the exercise and recovery intervals, the internal workload for

**Table II. Correlation between pooled group scores using objective (TRIMP and TRIMPc) and subjective (s-RPE) training load quantification methods across the study**

<table>
<thead>
<tr>
<th>Number of training sessions</th>
<th>Method of calculation</th>
<th>Correlation with s-RPE ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>106</td>
<td>TRIMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIMPc</td>
</tr>
<tr>
<td>Week 2</td>
<td>65</td>
<td>TRIMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIMPc</td>
</tr>
<tr>
<td>Week 3</td>
<td>69</td>
<td>TRIMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIMPc</td>
</tr>
<tr>
<td>Week 4</td>
<td>68</td>
<td>TRIMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIMPc</td>
</tr>
<tr>
<td>Weeks 1–4</td>
<td>328</td>
<td>TRIMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIMPc</td>
</tr>
</tbody>
</table>

TRIMP, training impulse score (Banister, 1991); TRIMPc, cumulative training impulse score; s-RPE, session rating of perceived exertion score; $r$, Pearson’s coefficient of correlation (95% CI).
interval training sessions can more accurately quantify by weighting each exercise and recovery
interval for the corresponding HR-derived intensity, and calculating the summated TRIMP value. This
modified method, that we designated as ‘cumulative TRIMP’ (TRIMPc), resulted in ~9% higher training
impulse scores compared to the classical method of calculation. The validity of this approach is sup-
ported by the better correlation with s-RPE – as an independent subjective workload indicator – and the
proportionally greater inter-method difference with increasing workload intensity, irrespective of work-
out duration during the training session.

The variables used to calculate TRIMP as estab-
lished by Banister (1991) are the total duration of
training and the mean HR of the training session,
expressed according to resting and maximum HR
values. In addition, an exponential factor is used to
adjust for the different demands of ‘long-duration
low-intensity’ and ‘short-duration high-intensity’
exercise (equations 1 and 2). Such factor is based
on the lactate curve versus HR ratio during exercise
of increasing intensity. Although this relationship is
different in each individual, for practical purposes a
standardised valid equation for each sex is used.

However, the literature lacks consensus as to
the adequacy of the use of the classic TRIMP for
high-intensity or interval training because, in such
conditions, HR increases disproportionately in
comparison with steady-state exercise (Borresen &
Lambert, 2008, 2009; Foster et al., 2001; Robson-
Ansley, Gleeson, & Ansley, 2009).

Consistent with these views, the present results
suggest that the conventional procedure used to
calculate TRIMP does not adequately reflect work-
load variations within an interval training session.
This can be explained by the fact that classic TRIMP
calculations assign a single mean intensity (mean
HR) to compute the training impulse for the entire
workout. Using the TRIMPc approach, the vari-
tions of internal load throughout the session are
taken into account since the fractional elevation of
the maximum HR range (ΔHRratio in equation 2) is
more accurately calculated for each time period and,
consequently, the intensity factor (k1 in equation 1)
varies according to whether it relates to exercise or
recovery periods. Since, typically, a swimming train-
ing session is composed by a large number intervals,
most of them likely to be periods of incomplete
recovery from previous exercise, this may account
for the substantial difference in the quantification of
the training impulse between both methods. In fact,
TRIMPc scores were 9% higher (95% CI = 8.23–
9.72) than classical TRIMP scores, with the absolute
difference and the score variance increasing propor-
tionally to the mean score (Figure 1). These results
suggest that the classical TRIMP calculation under-
estimates the actual internal load because the mean
HR – the physiological intensity indicator – even if
adjusted for exercise intensity does not discriminate
between exercise and recovery periods during the
training session. Moreover, as pointed by Borresen
and Lambert (2008), the fact that the TRIMP
weighting factor is based on a fixed lactate–workload
relationship might introduce error in the quantifica-
tion of training load when an athlete’s training status
changes over time or when comparing training loads
of subjects who differ with respect to training status.
Such discrepancies might have a significant impact
not only in the quantification of the internal load but
also in the characterisation of the training stimulus.
In fact, the length of the recovery period between
high-intensity exercise intervals can generate differ-
ent oxygen uptake kinetics and HR responses
(Libicz, Roels, & Millet, 2005), whereas those
involving submaximal intensity may evoke similar
responses, although with large inter-subject variabil-
ity (Bentley et al., 2005).

A good relationship was observed between both
objective HR-based methods of calculating the
training impulse and the subjective load indicator
(s-RPE), which is considered an ecologically valid

<table>
<thead>
<tr>
<th>Predicted variable</th>
<th>s-RPE</th>
<th>TRIMP</th>
<th>TRIMPc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant (a)</td>
<td>-695.3</td>
<td>-185.0</td>
<td>-208.8</td>
</tr>
<tr>
<td>Duration (minute)</td>
<td>6.573 (0.586)</td>
<td>1.126 (0.530)</td>
<td>1.197 (0.503)</td>
</tr>
<tr>
<td>ΔHRratio (%)</td>
<td>9.559 (0.359)</td>
<td>3.393 (0.673)</td>
<td>3.702 (0.656)</td>
</tr>
<tr>
<td>Intervals (N)</td>
<td>Excluded</td>
<td>0.014 (0.069)</td>
<td>0.030 (0.138)</td>
</tr>
</tbody>
</table>

Data are MLR model raw-score constants (a) and raw-score (b) and standardised coefficients (β-weights, in parenthesis). Predicted
variables are: s-RPE, session rating of perceived exertion (equation 5); TRIMP, training impulse score (Banister, 1991; (equation 1);
TRIMPc, cumulative training impulse score (equation 3). Predictor variables are: duration, time duration of the training session; ΔHRratio,
fractional elevation of the HR (equation 2); intervals, number of exercise and recovery intervals.

Excluded: a variable not entering the stepwise regression MLR model.
and practical method for monitoring internal load (Wallace et al., 2009). Our results are consistent with previous reports of good agreement between s-RPE and Banister’s TRIMP in swimmers (Wallace et al., 2009), along with good agreement with other HR-based methods both in swimmers (Psycharakis, 2011; Wallace et al., 2008, 2009) and other athletes (Borresen & Lambert 2009; Foster, 1998; Herman, Foster, Maher, Mikat, & Porcari, 2009). The very high individual correlation obtained here ($r = 0.74$; 95% CI = 0.73–0.75) is nearly identical to those recorded in well-trained swimmers by Wallace et al. (2009; $r = 0.74$; 95% CI = 0.67–0.81), in physically active men and women by Borresen and Lambert (2008; $r = 0.76$; 95% CI = 0.56–0.88) and in young soccer players ($r = 0.75$; 95% CI = 0.17–0.94) by Akubat et al. (2012) but higher than observed in senior football players by Impellizzeri, Rampinini, Coutts, Sassi, and Marcora (2004; $r = 0.60$; 95% CI = 0.57–0.63). Importantly, the correlation with s-RPE was higher when using the TRIMPc calculation method ($r = 0.76–0.78$) as compared with the classical TRIMP method ($r = 0.73$ vs. 0.76), which supports the validity of the new procedure.

Interestingly, the number of intervals during the training workout had only a minor effect in predicting both TRIMP scores – although its weight was greater in estimating TRIMPc values – and none in predicting s-RPE scores. However, the strength of the link with s-RPE was virtually unaffected, suggesting that this subjective internal load indicator may not sufficiently discriminate between mostly continuous and interval types of training. The explanatory MLR analysis provided further insight into these relationships. Whereas the length of the training session had a similar weight in the prediction of the subjective (s-RPE) and both HR-based methods – simply reflecting the use of this external indicator in their calculation – the $\Delta HR_{\text{ratio}}$ had a greater influence in predicting both TRIMP scores. This finding was expected, since both methods use the fractional elevation of HR as the internal load indicator, although, as discussed before, the classical TRIMP method does not discriminate between exercise and recovery periods. However, since the number of intervals was relatively less important in estimating the overall workload score, it seems logical to conclude that the underestimation of the classical TRIMP method is almost entirely related to the discrimination between exercise and recovery periods and, consequently, to the more accurate use of the intensity factor across the range of variation of the $\Delta HR_{\text{ratio}}$ during the workout session.

From the point of view of practicality, the technical difficulties associated with monitoring HR in the aquatic environment (Wallace et al., 2009) were substantially reduced with the HR monitors used in this study, which do not rely on aerial/aquatic transmission of the electrocardiographic signal. Two thin isolated wires connect the electrode chest band with the recording unit placed in the back of the swimmer, acting also as shoulder belts and helping to prevent the longitudinal displacement of the electrode band. Most important, the monitors and timekeeping beacon transmitters placed at the pool edges record HR and lap times automatically and simultaneously, making it possible to time the intervals and to discriminate between exercise and recovery phases. Although they cannot yet be considered as completely reliable and there is room for further technical improvement, they proved to be very useful instruments for HR monitoring in the aquatic environment.

**Conclusions**

The present findings, using currently available technology to identify and time the exercise and recovery intervals, suggest that Banister’s classical method of TRIMP calculation underestimates the magnitude of the training impulse, since acute load changes are not adequately accounted for due to the typically non-steady-state, variable intensity of swimming training exercises. This likely occurs because the mean HR – the physiological intensity indicator – even if adjusted for exercise intensity, does not discriminate between exercise and recovery periods during an interval training session. We therefore suggest that for training workouts in which moderate- to high-intensity exercise alternate with incomplete recovery pauses, as is common in swimming training, the proposed TRIMPc quantification method can provide an improved estimate of the internal training load.

**Acknowledgements**

The authors thank the swimmers and coaches (Jordi Murio and Patrick Pearson) for their collaboration and commitment to this study. We also thank Chris Brammer who provided valuable feedback on drafts of this study.

**Funding**

The data here presented are part of a larger study (ALTITUDE project) supported by grants awarded by the Ministry of Science and Innovation of Spain [Ministerio de Ciencia e Innovación, DEP2009-09181], the Higher Sports Council of Spain [Consejo Superior de Deportes 35/UBP/10, 005/UBP10/11, 112/UBP10/12, CAR-Ugr 2009, CAR-Ugr 2011], Dutch Olympic Committee [NOC*NSF WOT/44090101] and the National Institute of Physical Education of Catalonia Generalitat de Catalunya [Research Support Grants 2011, 2012]. A.G.R. was supported by a FPU grant from the Ministry of Economy and Innovation of Spain [FPU 12/0060].
References


