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A modified TRIMP to quantify the in-season training load of team sport players

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Abstract

The aims of the study were to modify the training impulse (TRIMP) method of quantifying training load for use with intermittent team sports, and to examine the relationship between this modified TRIMP ($TRIMP_{MOD}$) and changes in the physiological profile of team sport players during a competitive season. Eight male field hockey players, participating in the English Premier Division, took part in the study (mean $\pm$ *s*: age 26 ± 4 years, body mass 80.8 ± 5.2 kg, stature 1.82 ± 0.04 m). Participants performed three treadmill exercise tests at the start of the competitive season and mid-season: a submaximal test to establish the treadmill speed at a blood lactate concentration of 4 mmol $\cdot$ l^{-1}; a maximal incremental test to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and peak running speed; and an all-out constant-load test to determine time to exhaustion. Heart rate was recorded during all training sessions and match-play, from which $TRIMP_{MOD}$ was calculated. Mean weekly $TRIMP_{MOD}$ was correlated with the change in $\dot{V}O_{2max}$ and treadmill speed at a blood lactate concentration of 4 mmol $\cdot$ l^{-1} from the start of to mid-season ($P < 0.05$). The results suggest that $TRIMP_{MOD}$ is a means of quantifying training load in team sports and can be used to prescribe training for the maintenance or improvement of aerobic fitness during the competitive season.

Keywords: *Field hockey, training load, adaptation, performance, workload*

Introduction

Quantifying physical effort during sports of a continuous nature can be done in several ways (Hopkins, 1991). In comparison, the intermittent nature of team sports, with random, discrete bouts of activity varying both in intensity and duration throughout match-play (Bangsbo, 1994; Boyle, Mahoney, & Wallace, 1994; Reilly & Borrie, 1992), poses particular difficulties. Previous research has reported that field hockey match-play elicits an exercise intensity of 71 – 92% of the athletes' maximal oxygen uptake ($\dot{V}O_{2max}$), which in itself represents a considerable training stimilus (Boyle *et al.*, 1994). However, the intensity and therefore training load during match-play differs considerably between playing position and between games (Boyle *et al.*, 1994).

Heart rate is commonly used to assess exercise intensity (Karvonen & Vuorimaa, 1988). Several methods have been proposed to evaluate exercise intensity during training and competition (Bannister, 1991; Gilman, 1996; Hopkins, 1991; Karvonen and Vuorimaa, 1988). Some authors have used the training impulse (TRIMP) as an integrative marker of exercise load during training and competition (Bannister, 1991; Morton, Fitz-Clarke, & Bannister, 1990; Padilla, Mujika, Orbańanos, & Angulo, 2000). Since the TRIMP is computed from both intensity (the mean exercise heart rate) and duration, it can be used to measure training load in match-play in sports that demand intensities of an intermittent nature (Bannister, 1991; Hopkins, 1991).

The TRIMP has recently been used to characterize exercise load during competitive time trials and races in professional road cycling and to establish appropriate training criteria for these events (Padilla *et al.*, 2000; 2001). However, the TRIMP method proposed by Bannister (1991) uses the mean exercise heart rate during an exercise bout, or the summation of every heart rate data point. Use of the mean exercise heart rate will fail to reflect the physiological demands of stochastic sport while the summation of all heart rate data points is impractical during long-duration, intermittent exercise such as team sports. To address this issue, heart rate zones have been used and the accumulated time spent at each zone

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multiplied by a relevant weighting, thus taking into account the importance of short-duration, high-intensity exercise (Foster *et al.*, 2001; Lucia *et al.*, 2003). The sum of all zones represents the total demand for a given period of training (Foster *et al.*, 2001; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003). However, in these studies the selected weighting for each zone increased in a linear fashion, which does not reflect the physiological responses to exercise above the anaerobic threshold (Wasserman, 1987). Furthermore, Foster *et al.* (2001) used heart rate zones in blocks of 10% from maximal heart rate despite the fact that the anaerobic threshold varies between participants of equal aerobic power (Wasserman, 1987), and therefore the metabolic stress might not be constant across participants even when they are exercising at the same percentage of maximal heart rate (Katch, Weltman, Sady, & Freedson, 1978; Wasserman, 1987).

To address these issues, we propose introducing a weighting factor for each zone, as originally proposed by Bannister (1991). This weighting reflects the profile of a typical blood lactate response curve to increasing exercise intensity. Thus, as exercise intensity increases, as indicated by the heart rate response, the weighting increases exponentially. We also propose setting the position of the zones in relation to the two breakpoints on a typical blood lactate response curve to increasing intensity, the lactate threshold, and the onset of blood lactate accumulation, defined as blood lactate concentrations of 1.5 and 4 $\text{mmol} \cdot \text{l}^{-1}$, respectively (Usaj & Starc, 1996). This will ensure that the metabolic stress measured via the percentage heart rate method is a true reflection of each individual's physiological stress imposed by the exercise bout. This will be specific to the population under investigation.

To date no studies have modified the TRIMP method to quantify training load within a team sport setting to monitor training load and the concomitant changes in physiological profile. The aims of this study were to modify the TRIMP method of quantifying training load for use with intermittent team sports, and to examine the relationship between this modified TRIMP and changes in the physiological profile of team sport players during a competitive season.

Methods

Participants

Eight male field hockey players, participating in the English Premier Division, took part in this study. They were all members of the same hockey club and had played at this standard for a minimum of 3 years. Six of the participants currently represented their country. Their physical characteristics (mean $\pm s$) were as follows: age 24 ± 4 years, body mass 80.8 ± 5.2 kg, and stature 1.81 ± 0.04 m. Before providing written informed consent, all participants were informed of the nature of the study, of all associated risks, and of their right to withdraw at any time. The study protocol followed the guidelines laid down by the World Medical Assembly Declaration of Helsinki and was granted approval by the university's research ethics committee.

Test protocols

Each participant performed three treadmill (Powerjog J100, Sport Engineering Ltd, Birmingham, UK) exercise tests on two occasions: at the start of the competitive season and 8 weeks later (mid-season). A submaximal test; a maximal test, and an all-out test were performed. Participants were asked to refrain from all exercise and the use of alcohol, tobacco, and caffeine in the 48 h before testing.

Submaximal test. The submaximal test was adapted from Heck *et al.* (1985) and consisted of 4×4-min exercise bouts at running speeds of 10, 12, 14, and 16 $\text{km} \cdot \text{h}^{-1}$ at a fixed gradient of 2% to replicate running on artificial surfaces (Buchfuhrer *et al.*, 1983). In the 1-min interval between bouts, a capillary blood sample was taken from the fingertip and analysed for lactate (Analox Microstat GM7, Analox Instruments Ltd, London, UK). Expired air was analysed continuously (Oxycon Alpha, Jaeger, Germany) and $\dot{V}O_2$ for the final minute of each bout calculated. Heart rate was recorded using short-wave telemetry (Polar Accurex Plus, Polar Electro, Kempele, Finland) throughout the trial. Following the test, blood lactate concentrations were plotted against speed and heart rate, and the speed at 4 $\text{mmol} \cdot \text{l}^{-1}$ (v_{OBLA}), heart rate at 1.5 $\text{mmol} \cdot \text{l}^{-1}$ (HR_{Lac}) and at 4 $\text{mmol} \cdot \text{l}^{-1}$ (HR_{OBLA}) were identified via linear interpolation (Beaver, Wasserman, & Whipp, 1986; Heck *et al.*, 1985; Usaj & Starc, 1996).

Maximal test. After a 5-min recovery, the participants undertook a maximal incremental test to volitional fatigue, which was adapted from Buchfuhrer *et al.* (1983). The treadmill was set at an initial speed of 8 $\text{km} \cdot \text{h}^{-1}$ for 60 s at which time the speed was increased to 10 $\text{km} \cdot \text{h}^{-1}$ and thereafter by 0.5 $\text{km} \cdot \text{h}^{-1}$ every 30 s. The treadmill gradient was kept constant at 2%. Expired air and heart rate were monitored throughout. Maximal oxygen uptake was determined as the highest rate of oxygen consumption over a 30-s period and maximum heart rate as the highest heart rate recorded at the end of the maximal incremental test. Peak running speed was determined as the fastest treadmill speed sustained for an entire 30-s step (Noakes, Myburgh, & Schall, 1990).

All-out test. After a 45-min rest, the participants completed an all-out test adapted from Cunningham and Faulkner (1969), to determine time to exhaustion. Time to exhaustion during this test has previously been reported to be a valid indicator of anaerobic work capacity (Green, 1995). The treadmill speed and gradient were set at 16 $km \cdot h^{-1}$ and 20% respectively. Time to exhaustion was recorded from the moment the participant released his hands from the rails and started running freely until volitional fatigue, defined as the time the hands were placed back on the rails. The test was modified from the original speed and gradient of 13 $km \cdot h^{-1}$ and 20% respectively to ensure that the participants did not become fatigued within 50 s of exercise as suggested by Green (1995).

Modified TRIMP

Figure 1 shows the blood lactate concentration of the eight participants against the fractional elevation in heart rate. Fractional elevation was calculated as follows:

$$\text{fractional elevation} = (HR_{exercise} - HR_{rest}) \div (HR_{max} - HR_{rest}) \quad (1)$$

An exponential line of best fit was fitted to the data points and an equation produced (equation 2), where x is the mean fractional heart rate elevation for each zone and e is the Napierian natural logarithm having a value of 2.712:

$$\text{weighting factor} = 0.1225e^{3.9434x} \quad (2)$$

Five heart rate zones were determined from the lactate versus fractional elevation plot. Zones 2 and 4 were anchored on HR_{Lac} and HR_{OBLA} respectively: HR_{Lac} and HR_{OBLA} were considered the heart rates corresponding to the two breakpoints on a typical blood lactate response curve to increasing intensity of exercise (Usaj & Starc, 1996). A zone width of 7% fractional elevation was set and zones 1, 3, and 5 were fitted around zones 2 and 4. In addition, all individual profiles were checked to ensure that the two blood lactate break points lay within the set group zones 2 and 4. From equation (2), weighting factors for each of the heart rate zones were calculated. Table I shows the heart rate zones, weighting factors, and training descriptors for each of the five zones.

During all training sessions and competitive matches between the start of and mid-season, the participants' heart rates were recorded as previously described. All heart rate data were downloaded to an IBM-compatible computer using the Polar Training Advisor Software package (Polar Electro OY, Finland). The software allows for the determination of the aggregate training time spent in each zone.

The modified TRIMP ($TRIMP_{MOD}$) values for each training session and match were then calculated by multiplying the weighting factor by the time spent in the respective heart rate zones. The total $TRIMP_{MOD}$ for a particular training session or match was equal to the sum of all heart rate zones. The $TRIMP_{MOD}$ and time spent each training session engaged in high-intensity activity – that is, zones 4 and 5 – were calculated for each participant.

Statistical analysis

The results are presented as means ± standard deviations. After verifications of underlying assumptions, differences in physiological measures between the start of and mid-season were analysed using paired samples *t*-tests. Correlation analyses between the percentage change from the start of to

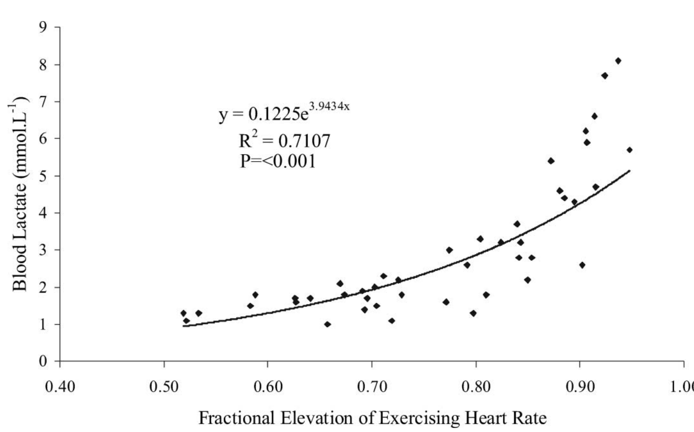

Figure 1. Blood lactate and fractional elevation of exercising heart rate for all participants. Exponential line provides calculation of the weighting factor.

mid-season for $\dot{V}O_{2max}$, V_{OBLA}, peak running speed, and time to exhaustion were performed against the mean weekly $TRIMP_{MOD}$ and the mean weekly time spent in high-intensity activity using Pearson's product–moment coefficient. Statistical significance was set at $P<0.05$.

Results

There were no changes in $\dot{V}O_{2max}$, v_{OBLA}, peak running speed, or time to exhaustion from the start of to mid-season ($P > 0.05$) (Table II). Mean weekly $TRIMP_{MOD}$ was 826 ± 123. The $TRIMP_{MOD}$ values during match-play were higher than during training sessions: 355 ± 60 and 236 ± 41, respectively ($P<0.001$).

Although there was no difference in $\dot{V}O_{2max}$ between the start of and mid-season, considerable inter-individual differences were observed. These can be seen in Figure 2 and the percentage change in $\dot{V}O_{2max}$ was correlated with mean weekly $TRIMP_{MOD}$ ($r=0.80$, $P=0.017$). Similarly, mean weekly $TRIMP_{MOD}$ was correlated with the percentage change in v_{OBLA} ($r=0.71$, $P=0.024$), as shown in Figure 3. Peak running speed and time to exhaustion were not correlated with mean weekly $TRIMP_{MOD}$ ($P > 0.05$).

The percentage changes in $\dot{V}O_{2max}$ and in v_{OBLA} were also correlated with mean weekly time spent engaged in high-intensity activity ($r=0.65$, $P=0.041$, and $r=0.67$, $P=0.034$ respectively). These are shown in Figures 4 and 5, respectively. There were no correlation observed between mean weekly time spent engaged in high-intensity activity (zones 4 and 5) and changes in peak running speed or time to exhaustion ($P > 0.05$).

Substitution of zero for the y-value (i.e. no change) in the regression equations (Figures 2 and 3) showed that to maintain $\dot{V}O_{2max}$ and v_{OBLA} during the competitive season, players should accumulate a mean weekly $TRIMP_{MOD}$ of 775 and 849 respectively. Similarly, mean weekly times engaged in high-intensity activity of 46 and 73 min were required to maintain $\dot{V}O_{2max}$ and v_{OBLA} respectively.

Table I. Heart rate zones, corresponding weighting factors, and training descriptors.

Zone	% Maximal heart rate	Weighting	Training Type
5	93–100	5.16	Maximal training
4	86–92	3.61	OBLA training
3	79–85	2.54	Steady-state training
2	72–78	1.71	Lactate threshold training
1	65–71	1.25	Moderate activity

Table II. Physiological measures at the start of the competitive season and mid-season (mean ± *s*).

	Start of season	Mid-season
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.8 ± 3.6	58.4 ± 4.5
Peak running speed ($km \cdot h^{-1}$)	19.6 ± 0.9	19.3 ± 0.7
v_{OBLA} ($km \cdot h^{-1}$)	15.3 ± 0.66	15.3 ± 0.9
Time to exhaustion (s)	37.8 ± 1.8	37.1 ± 1.5

Discussion

This is the first study to modify Bannister's TRIMP for use with team sports players. Our results suggest that there is a relationship between mean weekly $TRIMP_{MOD}$ and changes in $\dot{V}O_{2max}$ and v_{OBLA} during a competitive season in English Premier Division field hockey players. Similarly, there were relationships between mean weekly time spent engaged in high-intensity activity and changes in $\dot{V}O_{2max}$ and v_{OBLA}. Several studies have reported the importance of $\dot{V}O_{2max}$ and v_{OBLA} to field hockey and endurance performance (Cunningham & Faulkner, 1969; MacDougall & Sale, 1981; Noakes *et al.*, 1990; Reilly & Seaton, 1990). Our findings present a

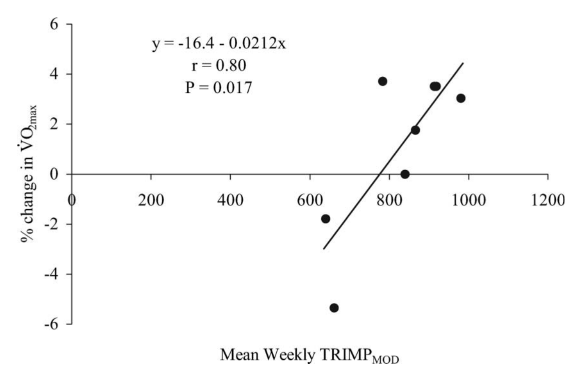

Figure 2. The relationship between mean weekly $TRIMP_{MOD}$ and percentage change in $\dot{V}O_{2max}$ during the period monitored.

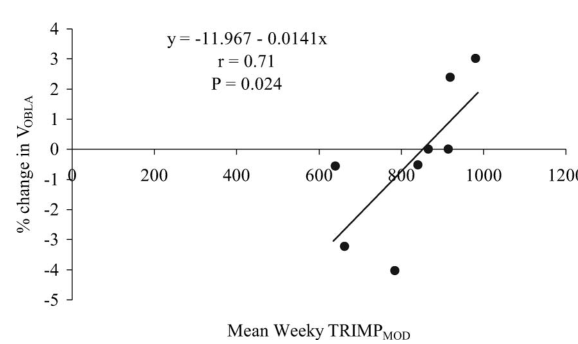

Figure 3. The relationship between mean weekly $TRIMP_{MOD}$ and percentage change in v_{OBLA} during the period monitored.

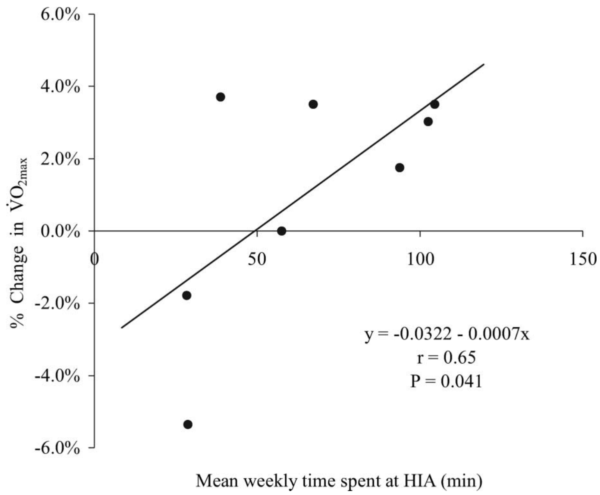

Figure 4. The relationship between mean weekly time engaged in high-tensity activity (HIA) and percentage change in $\dot{V}O_{2max}$ during the period monitored.

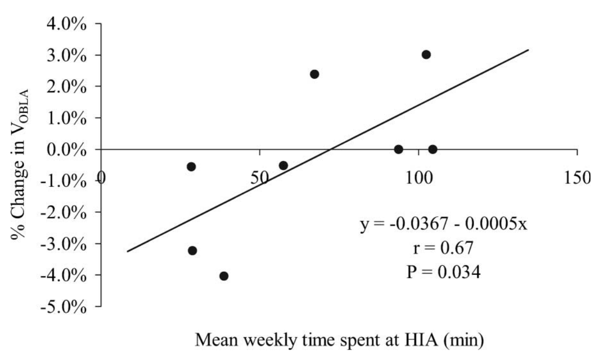

Figure 5. The relationship between mean weekly time engaged in high-intensity activity (HIA) and percentage change in v_{OBLA} during the period monitored.

method by which training can be quantified and prescribed to address these physiological measures.

The importance of training load in improving performance is well established (Foster *et al.*, 2001; Hopkins, 1991). Coaches design periodized training programmes to elicit the required physiological adaptations. Although these periodized training programmes are in essence quantitative in nature (Foster *et al.*, 2001), there is difficulty in finding a means whereby a single measure can effectively quantify training load. Bannister's (1991) proposed method takes into account only the mean heart rate for either the interval or total training bout, and therefore does not reflect the importance of short-duration, high-intensity exercise. Foster *et al.* (2001) addressed this problem by using heart rate zones; however, the selected weighting for each zone increased in a linear fashion, which does not reflect the physiological responses to exercise above the anaerobic threshold. Foster *et al.* (2001) also used heart rate zones in blocks of 10% from maximal heart rate despite the fact that the anaerobic threshold varies between individuals of equal aerobic power (Wasserman, 1987), and therefore the metabolic stress might not be constant across participants even when they are exercising at the same percentage of maximal heart rate (Katch *et al.*, 1978; Wasserman, 1987). This is the first study to address these limitations and the results obtained support the use of $TRIMP_{MOD}$ as a quantitative measure of training load during non-steady-state exercise, including high-intensity, sport-specific training and competitive team sport matches.

No relationships were observed between either mean weekly $TRIMP_{MOD}$ or mean weekly time spent engaged in high-intensity activity and changes in peak running speed and time to exhaustion. This might be due to $TRIMP_{MOD}$ relying on heart rate as a measure of intensity. Anaerobic adaptations occur within the muscle site, and include enhanced intramuscular adenosine triphosphate and phosphocreatine concentrations (Hellsten-Westing, Norman, Balsom, & Sjodin, 1993) and increased activity of key anaerobic enzymes such as creatine kinase and phosphofruktokinase (Nevill, Brooks, Boobis, & Williams, 1989). These changes are best elicited when exercise intensities are maximal – that is, all-out (Hellsten-Westing *et al.*, 1993; Nevill *et al.*, 1989). At such intensities, the duration of exercise might not be sufficient to bring about an elevation in heart rate that would impact on the modified TRIMP values (Bannister, 1991; Foster *et al.*, 2001; Gilman, 1996; Karvonen & Vuorimaa, 1988). Furthermore, although peak running speed has been suggested to be a strong predictor of endurance performance (Noakes *et al.*, 1990), neuromuscular and anaerobic characteristics could play an important role (Paavolainen, Nummela, & Rusko, 1999), which again might not be reflected in the modified TRIMP values.

The $TRIMP_{MOD}$ for match-play varied considerably from $TRIMP_{MOD}$ for training sessions: 355 ± 60 and 236 ± 41, respectively ($P < 0.001$). This implies that a player's largest training dose is match-play, which is in line with the findings of previous studies (Reilly & Borrie, 1992; Reilly & Seaton, 1990). As such, players who do not participate regularly in first-team action, such as substitutes, might need to undertake additional aerobic training to maintain $\dot{V}O_{2max}$ and v_{OBLA} during a competitive season.

In conclusion, the results of this study show that the mean weekly $TRIMP_{MOD}$ and the mean weekly time spent engaged in high-intensity activity are correlated with changes in $\dot{V}O_{2max}$ and v_{OBLA} during the competitive season. The $TRIMP_{MOD}$ therefore can be used to quantify training load during team sports of a high-intensity and intermittent nature, such as field hockey. This method can be used by coaches to tailor training sessions, on an individual player basis, to ensure that all players are receiving a sufficient training stimulus to maintain aerobic fitness. The results suggest that the $TRIMP_{MOD}$ can be used for the monitoring of in-season training load in high-intensity, intermittent field sports and therefore warrants further investigation.

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