A new approach to quantify internal and external training load for intermittent sports

Un nuevo abordaje para cuantificar carga interna y externa de entrenamiento en deportes intermitentes

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ABSTRACT

The aim of this study was to propose a modified training impulse method (TRIMP) to quantify internal training load (ITL) in intermittent team sports and examine its relationship with external training load (ETL) during a preparatory period. Over 12 weeks, 11 male youth field hockey players (14.41 ± 0.51 years) were evaluated in regard to their ETL using triaxial accelerometers (Actigraph) and data was later contrasted with ITL, which was measured using heart rate (HR) monitors (Polar Team2) by four different TRIMP methods: Banister’s (bTRIMP), Edwards’s (eTRIMP), individualized (iTRIMP) and modified (mTRIMP). A correlation was found between HR (beat/min) and ETL (r = 0.699, R² = 0.489, p < 0.01) and among TRIMP methods (r = 0.808-0.984, p < 0.01), however, the consistency between methods did not agree (p < 0.01). The ETL correlated in all TRIMP methods: bTRIMP (r = 0.509, R² = 0.259, p < 0.01), eTRIMP (r = 0.336, R² = 0.113, p < 0.01), iTTRIMP (r = 0.224, R² = 0.050, p < 0.01) and mTRIMP (r = 0.516, R² = 0.267, p < 0.01). The proposed mTRIMP can be a valid option for ITL quantification; furthermore, indexes combining ITL and ETL should be used for a complete training assessment.

Keywords: Intermittent exercise; TRIMP; accelerometer; field hockey.

RESUMEN

El objetivo del estudio fue proponer un método modificado de estímulo de entrenamiento (training impulse, TRIMP) para cuantificar carga interna (CI) de entrenamiento en deportes de equipo intermitentes y examinar su relación con la carga externa (CE) durante un periodo de preparación. Durante 12 semanas, se evaluó la CE de 11 jugadores de un equipo juvenil varonil (14.41 ± 0.51 años) de hockey sobre pasto utilizando acelerómetros triaxiales (Actigraph) y la CI con monitores (Polar Team2) de frecuencia cardíaca (FC) por medio de cuatro diferentes métodos de TRIMP: Banister (bTRIMP), Edwards (eTRIMP), Individualizado (iTRIMP) y Modificado (mTRIMP). Se encontró relación entre FC y CE (r = 0.699, R² = 0.489, p < 0.01) y entre los cuatro métodos de TRIMP (r = 0.808 - 0.984, p < 0.01), aunque no hubo concordancia entre ellos (p < 0.01). La CE tuvo correlación con bTRIMP (r = 0.509, R² = 0.259, p < 0.01), eTRIMP (r = 0.336, R² = 0.113, p < 0.01), iTTRIMP (r = 0.224, R² = 0.050, p < 0.01) y mTRIMP (r = 0.516, R² = 0.267, p < 0.01). El mTRIMP puede ser una opción válida para cuantificar CI, además, se deben utilizar índices de CI y la CE para una valoración global del entrenamiento.

Palabras clave: Ejercicio intermitente; TRIMP; acelerómetro; hockey sobre pasto.

INTRODUCTION

Periodization is a process where coaches alternate load and recovery phases to improve athletes performance (Turner, 2011; Deweese et al, 2015). The amount of exercise exerted by the athletes (distance, power output, number of repetitions), with no regard of internal effects, is known as external training load (ETL); the physiological response to ETL (oxygen uptake, heart rate, blood lactate, rate of perceived exertion) is considered internal training load (ITL) (Buchheit, 2014). Precise and reliable ITL and ETL quantifying methods are required to analyze and establish causal relationships between training, physiological adaptations, and resulting performance level (Mujika, 2013; Halson, 2014). During team sports matches and training sessions players execute sport specific actions at diverse intensities, interjecting loading and resting periods in unpredictably way, which imposes players unique physiological demands (Vinson & Peters, 2016). Since team sports activity is intermittent by nature, it is difficult to quantify ETL and ITL, which is the reason for the need of individual quantification.

For ETL quantification in team sports, global positioning system (GPS) movement tracking devices have been used (Jennings et al., 2012; Suarez-Arrones et al., 2012; Varley et al., 2012) as well as video-based time motion analysis (TMA) after matches or training sessions (Abdelkrim et al., 2015). The amount of exercise exerted by the athletes (distance, power output, number of repetitions), with no regard of internal effects, is known as external training load (ETL); the physiological response to ETL (oxygen uptake, heart rate, blood lactate, rate of perceived exertion) is considered internal training load (ITL) (Buchheit, 2014). Precise and reliable ITL and ETL quantifying methods are required to analyze and establish causal relationships between training, physiological adaptations, and resulting performance level (Mujika, 2013; Halson, 2014). During team sports matches and training sessions players execute sport specific actions at diverse intensities, interjecting loading and resting periods in unpredictably way, which imposes players unique physiological demands (Vinson & Peters, 2016). Since team sports activity is intermittent by nature, it is difficult to quantify ETL and ITL, which is the reason for the need of individual quantification.
examine its relationship with other TRIMP methods and ETL during a training period. We hypothesized that this novel mTRIMP method accurately represent ETL in intermittent training and have construct validity with other well established TRIMP methods.

MATERIALS AND METHODS

Design
This study had a quantitative approach with a descriptive and correlational scope. Design was observational non-experimental.

Sample
A non-probabilistic, sampling by convenience, single group method was employed. Eleven male Sub-16 field hockey players took part in this study; they were members of the Mexican national champion team (Demographic info is presented in Table 1). Participants were all volunteers. Since all subjects were underage, we obtained a written informed consent from their parents or legal guardians. Study protocol followed the guidelines expressed by the Helsinki declaration and was approved by UANL’s (Universidad Autónoma de Nuevo León) Health Sciences Research Bioethics Committee, No: COBICIS-58/12/2017/02-FOD-BRRC.

Procedure
Demographic info. Height (Digital stadiometer, model 274, Seca, Hamburg, Germany), weight, four-compartment body mass percentages (Medical digital scales, Model TBF_310, Tanita Corporation, Tokyo, Japan) and elbow and knee bone diameters (FUTREX caliper, Filderstadt, Germany) were measured. Before the start of protocol subjects underwent an intermittent fitness test (IFT 30-15), as specified by Buchheit (2010).

Incremental test. Bla profiles were determined for every subject with an incremental test. Protocol comprises successive stages of 3 minutes of treadmill run and a 1-minute passive recovery. Initial speed was set at 6 Km/h, with 2 Km/h increments at the end of every stage until volitional fatigue (Manzi et al., 2009). Maximum HR value observed during the test was considered as HRmax. In the 1-minute interval between bouts, HR was recorded, and capillary blood samples were taken for Bla analysis (Accutrend Plus Lactometer, Roche Diagnostics, Mannheim, Germany). HR was recorded using Polar Team2 HR monitor system (Polar electro Oy, Kempele, Finland), every stage HR value was set at 6 Km/h, with 2 Km/h increments at the end of every stage until volitional fatigue (Manzi et al., 2009). Maximum HR value observed during the test was considered as HRmax. In the 1-minute interval between bouts, HR was recorded, and capillary blood samples were taken for Bla analysis (Accutrend Plus Lactometer, Roche Diagnostics, Mannheim, Germany). HR was recorded using Polar Team2 HR monitor system (Polar electro Oy, Kempele, Finland), every stage HR value was determined as mean HR for every 3 minutes period.

Training sessions. Data recollection was made during a field hockey training program at the special preparation phase over a three-month period. Researchers did not have input on training session contents (designed and conducted by...
the coaching staff only). Training sessions were two hours long, with five days a week frequency. During the study every player participated in an average of 29.9 sessions; a total of 329 sessions were analyzed.

**HR monitoring.** Polar Team2 Pro HR monitors (Polar electro Oy, Kempele, Finland) were placed on each player during all training sessions. Transmitters were connected to an elastic chest strap, which had electrodes that has to be moisten for optimal skin contact. Sampling rate was at 1-second interval; each player’s HR responses was recorded and exported to a personal computer for future analysis.

**External training load.** ETL was determined using triaxial accelerometers (Actigraph) placed at the back as instructed by Scanlan (2014). The devise was fixed onto the HR monitor chest strap using Velcro. This position places the accelerometer nearest possible to subjects center of mass, which better represents whole body movements. Each accelerometer had a full-scale output range of ± 6g and sampled at a rate of 100 Hz. Whole-body movements were determined as the accumulated instantaneous rate of change in acceleration in the three movement planes. ETL was then calculated using Player’s Load methodology by the following formula:

\[
\text{Player’s Load} = \sqrt{(a_{yz} - a_{y-1})^2 + (a_{xz} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2} \times \frac{100}{\sqrt{3}}
\]

Where: \(a_{yz}\) = anteroposterior acceleration; \(a_{xz}\) = mediolateral acceleration; \(a_{z1}\) = craniocaudal acceleration. Accelerometer data at Player’s Load arbitrary units of each training session were recorded in the Actigraph device. Subsequently, data was exported to a computer using Actilife software (version 6.13.3, Pensacola, Florida, USA). bTRIMP is calculated by multiplying mean HRres by session’s total minutes and then by a weighting factor (Banister, 1991). HRres is calculated by the following formula:

\[
HR_{res} = \frac{HR_{exe} - FC_{rest}}{FC_{max} - FC_{rest}}
\]

Where: HRrest = Heart rate at rest; HRexe = Average heart rate during exercise; HRmax = Maximal heart rate. Session’s bTRIMP is then calculated in arbitrary units using the following formula

\[
TRIMP (AU) = HR_{res} \times t \times y
\]

Where: \(t\) = time in minutes, \(y = 0.64 \times e^{1.92 \times HR_{res}}\) (for male subjects), \(e = 6.13, 2016, Pensacola, Florida, USA). bTRIMP is calculated by multiplying mean HRres by session’s total minutes and then by a weighting factor (Banister, 1991). HRres is calculated by the following formula:

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\[
TRIMP (AU) = HR_{res} \times t \times y
\]

The exponential curve equation that better represents individual Bla response to incremental test. The equation consider “y” value as Bla and “x” value as HRres:

\[
y = a \times e^{bx}
\]

Once individual weighting factors are obtained, session iTRIMP is calculated with the sum of each observed by the following formula:

\[
iTRIMP = \sum HR_{res} \times t \times y
\]

Where: HRres = Percentage of heart rate reserve observed at every 1-second interval, \(t\) = time in minutes (at 1-second interval \(t = 1/60\), \(y\) = individual weighting factor.

mTRIMP. Calculation for mTRIMP was made similar to iTRIMP, with the only difference that instead of individual weighting factors, Banister’s (1991) generic weighting factor is used by the following formula:

\[
mTRIMP = \sum HR_{res} \times t \times (0.64 \times e^{1.92 \times HR_{res}})
\]

**Training ratios.** To assess individual players’ ITL to ETL relationships, several ratios were calculated. For ETL/time analysis Player’s load:minute ratio was calculated. For ITL/time analysis TRIMP:minute ratios were calculated by the four TRIMP methods. To analyze the internal effect of ETL TRIMP:Player’s load ratios were also calculated by the four TRIMP methods.

**Statistical analyses**

All statistical analyses were conducted with SPSS statistical software (version 22 for Windows, SPSS Inc., Chicago, USA). Results are expressed as mean ± SD. Data normality was proven with Shapiro-Wilk test. Pearson coefficient was used to examine correlation between HR and ETL, between TRIMP methods, and between TRIMP methods and player’s load. Determination coefficient (R²) was used for correlation effect size evaluation, 0.8 and above was considered large, around 0.5 moderate and 0.2 or less as small (Manzi et al., 2009; Scanlan et al., 2014). To establish differences for Player’s load, bTRIMP, eTRIMP, iTTRIMP and mTRIMP between players a one way ANOVA analysis was used. ETA value was considered for effect size. A t test for related samples was used to differentiate paired mean TRIMP values. Cohen’s d was used for effect size, 0.2 or below was considered as low, between 0.2 and 0.5 as moderate and above 0.5 as large. Bland and Altman plots were used to evaluate agreement between TRIMP methods. Differences between the measurements of ITL by the four methods were plotted in relation to the mean values; 95% of the differences were expected lie between the two limits of agreement that were the mean difference ± 1.96 SD of the differences, expressed as bias ± random error. Statistical significance was established at \(p < 0.05\).
RESULTS AND DISCUSSION

Results

Lineal relationship \((r = 0.699, p < 0.01)\) between HR and ETL was observed during field hockey intermittent training (Figure 1). Determination coefficient \(R^2 = 0.489\) dictates that 48.9% of the HR changes is explained by Player’s load. Individual subject analyses indicate stronger relationships between these two variables, with a range of \(r = 0.701 - 0.933, (p < 0.01)\). On an individual basis, Player’s load explains HR within a 49.1 and 87% range.

Table 2 shows individual weighting factors. Descriptive data of Player’s load, bTRIMP, eTRIMP, iTTRIMP and mTRIMP for each player is presented in Table 3. One-way ANOVA showed significant differences \((p < 0.01)\) on all measured parameters. Session ETL between subjects showed an F value of 17.38. ETA effect size indicates that the subject explains 66.6% of the Player’s load differences. Session ITL by the bTRIMP, eTRIMP, iTTRIMP and mTRIMP methods showed F values of 8.74, 8.46, 17.7 and 7.94 respectively. ETA effect size indicate that the subject explains 53.5%, 52.9%, 67% and 51.7% of bTRIMP, eTRIMP, iTTRIMP and mTRIMP differences respectively. Minutes per session showed an F value of 3.5. ETA effect size indicates that the subject explains 37.2% of minute’s differences.

Table 4 shows descriptive data for Player’s load:minute and TRIMP:minute ratios. Player’s load:minute ratio shows an F value of 9.02. ETA effect size indicates that the subject explains 54.1% of the ratio’s differences. Differences for TRIMP:minute ratios at bTRIMP, eTRIMP, iTTRIMP and mTRIMP show F values of 10.11, 9.68, 19.12 and 10.17 respectively. ETA effect size indicates that the subject explains 53.5%, 52.9%, 67% and 56.4% of the TRIMP:minute ratio differences respectively.

Table 5 shows descriptive data for the four TRIMP methods Player’s load: ratios. Between subjects TRIMP:Player’s load ratios for bTRIMP, eTRIMP, iTTRIMP and mTRIMP show F values of 4.97, 13.43, 26.15 and 4.61 respectively. ETA effect size indicate that subjects explained 43.1%, 61.7%, 73.9% and 41.8% of the differences in TRIMP:Player’s load ratios respectively.

Large to almost perfect correlation coefficients between the four TRIMP methods show that they follow

![Figure 1. Scatter plot between ETL and HR in beats per minute.](image-url)

Table 2. Weighting factors according to exponential equation \(y = a^e^{x}\).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Subject 01</th>
<th>Subject 02</th>
<th>Subject 03</th>
<th>Subject 04</th>
<th>Subject 05</th>
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Note. - \(e = \) Neperian Logarithm 2.7182.

Large to almost perfect correlation coefficients between the four TRIMP methods show that they follow
the same tendencies (Table 6). Effect size between TRIMP methods correlations were from medium to large, at the $R^2 = 0.652$ to 0.968 range.

Mean values of bTRIMP, eTRIMP, iTRIMP, and mTRIMP were $102.76 \pm 44.16$, $121.44 \pm 53.36$, $201.03 \pm 118.33$, and $120.33 \pm 50.33$ respectively. Differences were observed between bTRIMP and eTRIMP ($t(228) = 13.9$, $p < 0.01$), mTRIMP ($t(228) = -28.7$, $p < 0.01$) and iTRIMP ($t(228) = -17.4$, $p < 0.01$). Differences were also found between iTRIMP and bTRIMP ($t(228) = 17.4$, $p < 0.01$), eTRIMP ($t(228) = -16.3$, $p < 0.01$) and mTRIMP ($t(228) = -15.09$, $p < 0.01$). There were no differences between eTRIMP and mTRIMP (Figure 2). Effect size was moderate between bTRIMP with eTRIMP ($d = 0.38$) and mTRIMP ($d = 0.37$); and large with iTRIMP ($d = 1.10$). Large effects sizes were found between iTRIMP and eTRIMP ($d = 0.86$) and mTRIMP ($d = 0.88$). Since no differences were found between eTRIMP and mTRIMP, level of agreement was assessed using the

### Table 4

<table>
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<tr>
<th>Subject</th>
<th>Player’s load/min</th>
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**SD = Standard deviation.**

### Table 6

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<td>4</td>
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**Correlation coefficient to $p < 0.01$.**

Bland and Altman Plot (Figure 3). Lineal regression analysis between paired measurements differences and means show high significance of \( t (p < 0.01) \), which indicates bias between methods and a lack of agreement.

There was significant correlation between TRIMP and Player’s load \( (p < 0.01) \). Large correlation was found between Player’s load with bTRIMP \( (r = 0.509, R^2 = 0.259) \) and mTRIMP \( (r = 0.516, R^2 = 0.267) \). Moderate correlation was found with eTRIMP \( (r = 0.336, R^2 = 0.113) \). Small correlation was found with iTRIMP \( (r = 0.224, R^2 = 0.050) \). Effect sizes range from small to medium as shown in Figure 4.

**Figure 2.** Comparison between mean values of ITL in Arbitrary Units (AU) between all four TRIMP methods. **Differences with other methods at \( p < 0.01 \).

**Figure 3.** Bland and Altman Plot between eTRIMP and mTRIMP methods. Centerline represents the mean of the differences between methods, superior and inferior lines represent confidence intervals at 96%.

**Figure 4.** Scatter plots and determination coefficient between TRIMP methods and “Players load”.

Discussion

Due to the belief of HR’s delayed kinetics during high-intensity exercise, and the assumption that it does not respond well to maximal anaerobic efforts, the use of HR-based TRIMP methods for ITL quantification at intermittent sports has been questioned (Buchheit et al., 2013; García-Ramos et al., 2014; Saboul et al., 2015). Nevertheless, we found a significant relationship between absolute HR and Player’s load in this study. It was found that HR followed a similar behavior than Player’s load during intermittent training sessions, verifying reports pointing to a lineal relationship between HR and ETL intensity (Lucia et al., 2003). When relationships are analyzed on an individual basis, even greater correlation coefficients were found in contrast to group analysis. Proving that HR responses to ETL depend on individual characteristics, conditioning level in particular (Manzi et al., 2009). This relationship indicates that HR responses during field hockey training accurately represent players’ external effort.

The most recent TRIMP method proposed by Manzi (2009) sustain that Bla curve plotted against fractional elevation in HR shifts to the right with performance improvement (Manzi et al., 2009; Manzi et al., 2010; Manzi et al., 2013; Manzi et al., 2015). As fractional HR (HRres) takes into account HRmin and HRmax for its calculation, one may think that it has an element for the subject’s individual capacity, and in that regard, it is supposed to reflect individual internal exercise intensity. Nevertheless, results show different individual weighting factors, as curves show distinctive subject’s Bla responses at the same HRres ranges. This affirms the idea first declared by Stagno et al. (2007) and later by Manzi et al. (2009; 2010). This gives us a basis to think that HRres alone is not an accurate marker for internal exercise intensity, and that coaches should consider Bla responses for HR assessment in training.

Some studies compared ETL differences between various exercise modes (Montgomery et al., 2010; Weaving et al., 2017), match periods and high and low success teams (Hulin et al., 2014), training and competition (Delaney et al., 2016), and ITL values (Casamichana et al., 2013; Scanlan et al., 2014). These studies compared group mean values, but as far
as we know, there are not studies that analyzed individual ETL differences between subjects submitted to the same training sessions. Data in this study show disparities in Player´s load values between subjects. This suggests that players are not exposed to the same external physical demands during training sessions, which opens up a new line of analysis in function of knowing if ETL differences have a positive or negative impact on the magnitude of the stimulus required to incite training adaptation.

Previous studies (Borresen & Lambert, 2008; Borresen & Lambert, 2009; Lambert & Borresen, 2010; Mujika, 2017) affirm that the same ETL can elicit differentiated internal responses according to individual characteristics and conditioning levels. This is confirmed in this study, observing different subject’s ITL mean values, even if all of them attended the same training sessions. Data suggests that large effect sizes in ITL differences are partially explained by differences in relative and absolute ETL values between subjects. Also, this could be affected by different playing positions, albeit a positional analysis was not made in this study, previous studies have reported that playing position has a significant effect in physiological responses (Buglione et al., 2013). Another explanation can be the differences observed in aerobic capacity expressed as VO2max, which was calculated by field tests (Buchheit, 2010) prior to protocol beginning.

Lower values in comparison to the other three methods suggest that bTRIMP underestimates training stimulus. This can be explained by the use of session’s mean HR values (Banister, 1991), which equals continuous training at medium intensity to intermittent training incorporating high and low intensities when both of them have the same mean HR (Saboul et al., 2015). As mTRIMP consider each HR value, it weights high intensity efforts, emitting higher values, even if both methods use the same weighting factor. Contrasting mTRIMP and bTRIMP, verifies that bTRIMP underestimates ITL, in particular during interval and intermittent training. eTRIMP classify HR values in training zones by HRres, which was calculated by field tests (Buchheit, 2010) prior to protocol beginning.

Despite differences in mean values, high correlation between TRIMP methods indicates they may have similar responses to ETL. This suggests that any of them can be considered as a useful tool for ITL assessment given that results are emitted in arbitrary units and assuming an inter-subject analysis is not necessary.

Scanlan et al. (2014) established the relationship between bTRIMP and eTRIMP with Player’s load. While no reference for iTIMP/Player’s load relationship was found, a lower correlation coefficient with the rest of the methods was observed. This was an expected result, given that all subjects were included in the sample. Extremely diverse weight factors incite differentiated ETL responses for each subject, which result in a lower general correlation coefficient. Contrary to the rest of the methods, which having the same weighting factor for every subject elicit consistent relationships.

CONCLUSIONS

HR responses during intermittent sports training, like field hockey, are tightly related to TL in high and low intensity stimulus, which allows to use HR based TRIMP methods for quantification and assessment of ITL. bTRIMP is considered to underestimate internal responses to ETL. eTRIMP and the new mTRIMP more precisely represent general internal responses compared to bTRIMP. Nevertheless, iTIMP better reflects individual responses to ETL. Even if is highly recommendable to use iTIMP to ITL quantification, mTRIMP can be a valid option when coaches do not have access to perform incremental effort tests for Bla profile determination. A combination of ITL and ETL methods must be used for a global assessment of training loads.

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