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ORIGINAL ARTICLE

Assessment of stress response and its interrelationship with external load in female soccer players

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Abstract
Introduction and Objective. The study aimed to evaluate the physiological stress response, i.e. internal load to intermittent and continuous exercise performed during the treadmill running in professional female soccer players, and additionally to determine the most appropriate method for assessing load in the athletes.
Material and method. Six professional female athletes (age 25.3±1.8 years, height 168.4±2.7 cm, weight 64.8±5.8 kg, maximal oxygen consumption ($\dot{V}O_{2max}$) 64±4.1 ml•kg^{-1}•min^{-1}, and heart rate (HR_{max}) 195±1.8 b.p.m.) performed a series of preseason treadmill tests. HR and $\dot{V}O_{2max}$ were measured in the athletes during intermittent load (increase and decrease of running time and treadmill speed) and an incremental load (gradual increases running time, treadmill speed and a treadmill incline angle). Banister's, Edwards', Stagno's and Lucia's training impulse (TRIMP) quantification methods were used to assess internal load. The relationships between $\dot{V}O_{2max}$ and above-mentioned TRIMPs load indicators were calculated using Pearson's correlation coefficient.
Results. Large, very large and near perfect correlations between TRIMP and $\dot{V}O_{2max}$ were observed during intermittent and incremental load (range r = 0.712 – 0.852 and r = 563 – 930; $p < 0.05$, respectively). Correlations between other TRIMPs and $\dot{V}O_{2max}$ demonstrated moderate, small and negative small relationships.
Conclusions. Changes in HR and oxygen consumption registered during intermittent or gradually increasing load conditions could be evaluated using the TRIMP method for both types of activities, and this method could potentially be useful for the testing of high-intensity intermittent physical fitness of players before the soccer season.

Key words
female soccer players, TRIMP, stress response, internal and external load

INTRODUCTION

The physiological or psychological stress that occurs during physical exercise leads to adaptations in the cardiovascular, neurological and metabolic systems. These adaptation changes are determined as internal load [1, 2]. At the same time, the distance, speed or acceleration measurement, as well as the analysis of movement over time, etc., are an external load [2–4]. Because soccer is an intermittent sport, it is important to keep in mind that athletes cannot be in constant motion during soccer games like distance runners. High-intensity activities usually alternate with periods of low-intensity activities, for example, walking or running at a low pace. Also, each foul or pass may be accompanied by an extra rest. Furthermore, soccer training, and especially matches, are characterized by high-intensity motor activity. Players are required to accelerate, decelerate, change direction and sprint, which can be repeated often during a match [5]. The running distance of high-level athletes in a game can reaches 10–13 km, out of which high-intensity running accounts for 8–10% of the total distance [6–8].

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It was previously shown that in team sports, athletes of different fitness levels would have different physical sensations at the same training load. Therefore, it is very important to monitor load during training [2, 9]. Monitoring exercise intensity is not only necessary to prevent injury and avoid trauma, but can also help make future training decisions and track a player's individual adaptation to training [5]. Thus, the combination of internal and external load measurements can provide information on a player's overall training load.

To date, the majority of studies of internal stress monitoring in soccer training have focused on male athletes, and only a small number of such studies has been performed on female soccer players [10, 11]. Therefore, the analysis of the relationship between external and internal stress in female soccer players is an important task for modern sport. This is known as the TRIMP (training impulse) method, derived from the heart rate (HR), and is widely used in team sports as a method to quantify internal load [12–15]. However, the application of this method in intermittent sports has still not been studied in detail, especially in female soccer players. It is also known that one of the indicators of aerobic fitness is the economy of training, which is calculated as oxygen consumption (VO_2) at a given load, and the HR, which is used for TRIMP calculation, has demonstrated a linear relationship in various conditions [12].

Thus, the main objective of this study was to determine correlations between various HR-based methods for quantifying internal training load (TL) (Banister's TRIMP, Edward's TRIMP, Stagno's TRIMP and Lucia's TRIMP [16–19]) and maximal oxygen consumption, and additionally to determine the most appropriate method for evaluating internal TL in female soccer players.

MATERIALS AND METHOD

Subjects. Six female professional athletes participated in the study (age – 25.3±1.8 years, height – 168.4±2.7 cm, weight – 64.8±5.8 kg, $\dot{V}O_{2max}$ 64±4.1 ml•kg^{-1}•min^{-1}, and HR_{max} 195±1.8 b.p.m.). Participants were asked to abstain from strenuous exercise, alcohol, coffee, tea or cola for 24 hours before the experiment. All volunteers also received a full written explanation of the study objectives and provided written informed consent to participate in the study. All participants played in the same club in the Chinese Women's Super League, which is the first level of the Chinese Women's League. The study was approved by the Local Ethics Committee of the Shan Dong Institute of Sports Science, and performed in accordance with the 1964 Declaration of Helsinki.

Study design. The testing process performed as a series of pre-season treadmill tests consisted of two stages: an intermittent load stage and an incremental load stage (Tab. 1). The intermittent load stage consisted of 3 steps: 1) warm-up, 2) sudden increase in speed and running time, 3) sudden decrease in speed and running time. Incremental loading stage (consisted of 9 steps) were performed in conditions in which the treadmill speed and treadmill gradient were increased every 2 minutes (a 0.5 km/h increase in treadmill speed and a 0.4% increase in treadmill gradient occurred as long as the athletes could keep the given load (i.e., running to failure)). Stage 2 followed immediately after stage one, without rest.

Table 1. Testing process conditions for stages of intermittent and incremental training load

Stages	Intermittent TL			Incremental TL								
Steps	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
Time, min.	3	6	1	2	2	2	2	2	2	2	2	2
Slop, %	0	0	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6
Speed, km/h	4	8	4	8.5	9	9.5	10	10.5	11	11.5	12	12.5

Load measurements. The test was performed on a professional treadmill (h/p/cosmos, Germany). Oxygen uptake and heart rate were measured with an Oxytone Alpha (JAEGER, Germany); calibration was performed before and after each test, according to the manufacturer's instructions. During the test, the JAEGER device measured $\dot{V}O_2$ every 5 seconds. To reach $\dot{V}O_{2max}$, the following conditions must be met: 1) subject's heart rate reaches 180 b.p.m., 2) respiratory rate is greater than 1; 3) oxygen uptake has a relatively stable plateau with increasing exercise intensity, 4) the subject cannot continue exercising under load after maximal effort.

During the tests, HR values were collected via a Polar team system (Polar Team Pro, Finland) sampling at 5 s intervals. The sampling rate of the GPS device sampled was 10 Hz, the accelerometer sampled was 200 Hz and 1,000 Hz for HR. The sensor was placed on the chest.

Calculations of TRIMP were performed as described by Banister, Edwards, Stagno and Lucia [16–19], and by using the formula:

$$\text{Banister's TRIMP (bTRIMP)} = D \times (\Delta\text{heart rate ratio}) \times e^{(b \times \Delta\text{heart rate ratio})}$$

where D = training time (min), constant e=2.718, weighting factor for women b=1.67, Δheart rate ratio = (average heart rate during exercise-resting heart rate)/(maximum heart rate during exercise-resting heart rate).

Edward's TRIMP (*e*TRIMP) = 1×(duration in zone 1) + 2×(duration in zone 2) + 3×(duration in zone 3) + 4×(duration in zone 4) + 5×(duration in zone5); zone 1 – 50–60%, zone 2 – 60–70%, zone 3 – 70–80%, zone 4 – 80–90% and zone 5 – 90–100% of HR_{max}.

Stagno's TRIMP (sTRIMP) (Zone 1 – 65–71% HR_{max}, weight factor 1.23; Zone 2 – 72–78% HR_{max}, weight factor 1.71; Zone 3 – 79–85% HR_{max}, weight factor 2.54; Zone 4 – 86–92% HR_{max}, weight factor 3.61; Zone 5 – 93–100% HR_{max}, weight factor 5.16).

Lucia's TRIMP (lTRIMP) (the method was calculated by multiplying the time spent in 3 different HR zones (zone 1 = below the ventilatory threshold, zone 2 = between the ventilatory threshold and the compensation point, zone 3 = above the respiratory compensation point) by a coefficient for each zone (zone 1 = 1, zone 2 = 2, zone 3 = 3) and summing-up the results).

Statistical analyses. Pearson's correlation coefficients (r) were used to determine the relationships between HR-based indicators (bTRIMP, eTRIMP, sTRIMP or lTRIMP) and $\dot{V}O_{2max}$. The mean, standard deviation (SD), and 95% confidence intervals (CI) were also calculated for the group data. Values of $p < 0.05$ were considered to be significant. Qualitative ranges for correlations were distributed as follows: trivial (0–0.1), small (0.11–0.3), moderate (0.31–0.5), large (0.51–0.7), very large (0.71–0.9) and near perfect (0.91–1.0) [20]. Data normality was confirmed by the Shapiro–Wilk test. Statistical analysis was performed using the Statistical Package for Social Sciences (version 26.0 for Windows, SPSS, Chicago, IL, USA).

RESULTS

In order to estimate the typical soccer activities, the intermittent and incremental movement patterns were applied. The correlation analysis for the various training modes demonstrated a wide range of correlations between oxygen consumption and the different TRIMP methods. During the first (intermittent) stage of treadmill running, very large and near perfect correlations were observed between eTRIMP or sTRIMP and $\dot{V}O_{2max}$ were r=0.712–0.852 and r=0.820–0.983, respectively (Tab. 2). Correlations between Banister's or Lucia's TRIMP and $\dot{V}O_{2max}$ demonstrated small and moderate relationships (r=0.187–0.501 and r=-0.243 –

Table 2. Correlations between oxygen consumption and HR-based TRIMP methods

Stages of TL	Steps	Banister's TRIMP	Edwards' TRIMP	Stagno's TRIMP	Lucia's TRIMP
Intermittent	1	0.187	0.712	–	–
	2	0.501	0.852	0.820	-0.229
	3	0.370	0.828	0.920	-0.243
Incremental	1	0.649	0.930	0.986	-0.631
	2	-0.032	0.751	0.907	-0.737
	3	0.805	0.623	0.749	-0.424
	4	0.385	0.785	0.575	-0.242
	5	0.472	0.562	0.704	0.095
	6	0.177	0.539	0.678	-0.068
	7	0.082	0.706	0.382	-0.105
	8	0.642	0.677	0.677	-0.227
	9	0.778	0.876	0.881	0.659

-0.229, respectively). In the case of lTRIMP and $\dot{V}O_{2max}$ a negative correlation was observed. It should be noted that for sTRIMP and lTRIMP, the first step of the intermittent stage was not determined (Tab. 2). During the second (incremental) stage of the testing, stress indicators showed a wide range of correlations depending on TRIMP methods. Thus, large and very large correlations were observed between eTRIMP and oxygen uptake (r=0.539–0.909). Correlations range for sTRIMP and $\dot{V}O_{2max}$ varied from moderate to very large (r=0.382–0.907). The correlation coefficient for bTRIMP or lTRIMP was in the range trivial–large (r=-0.032–0.700 and r=-0.095 – -0.699, respectively). The same as during the first stage, lTRIMP and $\dot{V}O_{2max}$ correlations were negative (Tab. 2). Correlation analysis was also performed between HR and oxygen consumption. During both training stages (intermittent and incremental), very large and near perfect correlations between these indicators were observed. The correlation coefficient was in the range r=0.813–0.993 (Tab. 3). Correlations were identified as significant for all cases ($p < 0.05$).

DISCUSSION

TRIMP is known to quantify the training dose by weighting the heart rate according to the relationship between the fractional increase in heart rate and blood lactate concentration [21]. Thus, the aim of the study was to evaluate the physiological stress response to intermittent and continuous exercise performed during the treadmill test, and estimate whether information such as HR and $\dot{V}O_2$ (which are routinely collected during athletes testing at the elite level), could potentially be used to assess preseason performance in women's soccer.

The results obtained in this study showed a very large and almost perfect correlation only between eTRIMP and $\dot{V}O_{2max}$ during both intermittent and incremental (gradually increasing) loads. In the case of the sTRIMP method, good results were obtained only during the incremental loading stage. In other cases (bTRIMP or lTRIMP), the small correlation was the dominant one.

As shown previously [22], to quantify full training sessions and matches during the season in female soccer, Alexiou and Coutts monitored HR and session rating of perceived exertion (RPE) during each training session. Correlations for session-RPE and three HR-based methods (bTRIMP, lactate thresholds and eTRIMP) separated by session type were used for TL estimation. The session-RPE TL showed a significant correlation with all training types common to soccer. Nevertheless, higher correlations were only found with less intermittent. Casamichana et al. [23] also examined the relationship between session-RPE and the Edward's TRIMP methods calculation of internal training load using GPS devices only in male soccer. High level of associations between session-RPE and eTRIMP methods were observed in his study. A similar study also demonstrated [10] that during the intermittent fitness test (with the use of a GPS accelerometer), male soccer players showed a large–near perfect within-individual relationship between accelerometer-based metrics and eTRIMP. It is important to note that the training sessions were performed as part of an in-season phase. In the current study, the training load was performed as a series of pre-season tests. As noted above, in this study eTRIMP showed a high level of correlation with $\dot{V}O_2$. Thus, the obtained results confirmed the sensitivity and specificity of the test for determining changes in the physical fitness of soccer players.

In spite of other methods of TRIMP calculation demonstrating a small correlation with $\dot{V}O_{2max}$ in the current study, nevertheless, these TRIMPs have been successfully used for stress response estimation in various investigations [10, 24, 25]. The lower relationships might be explained by the intermittent nature or the very high intensity of these activities [22]. Apparently, the differences in the indices of different TRIMP calculation methods depended on the testing conditions. In addition,

Limitations of the study. Certain limitations in the current study should be noted in that it examined training loads only on a small sample of a single professional team. It is also necessary to consider the limitations of the TRIMP calculation methods. The average heart rate during exercise may not reflect the fluctuations that occur during intermittent training. Factors such as hydration, rest, illness, and underestimation of exercise stress induced by working at high loads that exceed your maximum aerobic capacity affect the heart rate.

Besides, the TRIMP model does takes into account the stress created by strength/power-based training, such as sprinting, weight lifting, climbing, plyometrics, etc., which place you under significant stress [26]. Regarding the eTRIMP method, the main disadvantage is that the weightings used by Edwards [17] are not validated, i.e., there has been no study looking at the TL quantification obtained by this method to assess the dose-response relationship [27].

Table 3. Correlations between HR and oxygen consumption

Stages	Intermittent TL			Incremental TL								
Steps	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
r	0.948	0.884	0.813	0.855	0.993	0.884	0.914	0.83	0.842	0.844	0.828	0.898

CONCLUSIONS

The results obtained in this study showed that the changes in HR and oxygen consumption registered during treadmill running in intermittent or gradually increasing load conditions could be sufficiently well evaluated with the internal load calculation eTRIMP method for both types of activities. In addition, it has been suggested that the eTRIMP method could potentially be useful for the testing of high-intensity intermittent physical fitness of players before the soccer season.

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