Physiological assessment of aerobic training in soccer

Article *in* Journal of Sports Sciences · July 2005

DOI: 10.1080/02640410400021278 · Source: PubMed

3 authors:

Franco M Impellizzeri
University of Technology Sydney

Ermanno Rampinini
MAPEI Sport Research Centre

Samuele M Marcora
University of Bologna

Journal of Sports Sciences, June 2005; 23(6): 583 – 592

Taylor & Francis
Taylor & Francis Group

Physiological assessment of aerobic training in soccer

FRANCO M. IMPELLIZZERI[1], ERMANNO RAMPININI[1], & SAMUELE M. MARCORA[2]

[1]*Human Performance Laboratory, S. S. MAPEI, Castellanza, Varese, Italy and* [2]*School of Sport, Health and Exercise Sciences, University of Wales, Bangor, UK*

(Accepted 24 July 2004)

Abstract

Physiological assessment of soccer training usually refers to the measurement of anatomical, physiological, biochemical and functional changes specific to the sport discipline (training outcome). The quality, quantity and organization of physical exercises (training process) are, on the other hand, usually described by the external work imposed by the coach on his or her athletes. In this review, we demonstrate that this approach is not appropriate in soccer, as training is often based on group exercises. The physiological stress (internal load) induced by such training often differs between individuals. Here, we present some physiological laboratory-based tests and field tests used to evaluate training outcomes in soccer, together with methods based on heart rate and perceived exertion to quantify internal load imposed during training. The integrated physiological assessment of both training outcome and process allows researchers: (1) to improve interpretation of physical tests used to verify the effectiveness of training programmes; (2) to evaluate the organization of the training load in order to design periodization strategies; (3) to identify athletes who are poor responders; (4) to control the compliance of the training completed to that planned by the coach; and (5) to modify the training process before the assessment of its outcome, thus optimizing soccer performance.

Keywords: *Aerobic training, external load, heart rate, internal load, rating of perceived exertion, testing*

Introduction

Physical training can be described in terms of its outcome and its process. The outcomes of training are anatomical, physiological, biochemical and functional changes specific to the sport discipline, while the training process is characterized by the systematic repetition of physical exercises (Viru & Viru, 2000). Although physiological tests are commonly used to assess training outcome, the training process is often described as the external load – that is, the training prescribed by coaches (for example, running four times 1000 m at 15 $km \cdot h^{-1}$ with 3 min rest between runs or, in team sports, small-sided games). This is unfortunate because the stimulus for training-induced adaptations is the actual physiological stress (i.e. the internal load) imposed on the athletes by the external load (Booth & Thomason, 1991; Viru & Viru, 2000). Despite the external load being the main determinant of the internal load, other factors such as genetic background and "pre-training level of phenotype" (starting fitness level) could influence the internal training load imposed on the individual and, consequently, the training outcome (Bouchard & Rankinen, 2001). The assessment of internal training load is particularly relevant in team sports, where the external load is often the same for each member of the team because of the extensive use of group exercises (Bangsbo, 1994b). For example, during small-group play, the individual physiological response – measured as a percentage of maximal heart rate – is variable, as shown in Figure 1. In addition, the intensity during these exercises is not consistent from day to day, even within the same individual (Rampinini, Sassi, & Impellizzeri, 2004). Therefore, to monitor and control training, it is important to evaluate both its outcome and the actual internal training load (Figure 2).

Aerobic training is traditionally an important component of physical training in soccer. Its relevance to soccer has been confirmed by some studies showing a relationship between aerobic power ($\dot{V}O_{2max}$) and competitive ranking, quality of play and distance covered during the match (Bangsbo & Lindquist, 1992; Krustrup *et al.*, 2003; Wislöff, Helgerud, & Hoff, 1998). Recently, Helger-

Correspondence: F. M. Impellizzeri, Human Performance Laboratory, Sport S. MAPEI srl, Via Don Minzoni 34, 21053 Castellanza (Varese), Italy. E-mail: mapeisport@tin.it

ISSN 0264-0414 print/ISSN 1466-447X online
DOI: 10.1080/02640410400021278

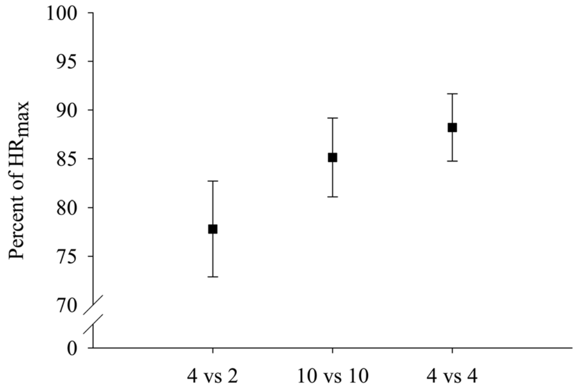

Figure 1. Exercise intensity expressed as a percentage of maximal heart rate (HR_{max}) in soccer players (n = 15) during small-group play (mean and standard deviation). Reproduced from Rampinini et al. (2004) with the permission of Taylor & Francis Group Ltd.

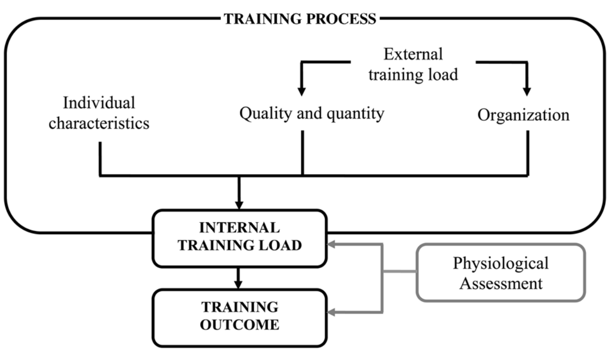

Figure 2. The training outcome is the consequence of the internal training load determined by (1) individual charateristics, such as genetic factors and previous training experience, and (2) the quality, quantity and organization of the external training load.

ud, Engen, Wisloff and Hoff (2001) showed that aerobic training can improve some aspects of soccer performance, including distance covered, time spent at high intensity, number of sprints and touches of the ball during a match. Furthermore, high aerobic fitness appears to improve recovery during high-intensity intermittent exercise, typical of soccer performance and training (Balsom, Ekblom, & Sjödin, 1994; Tomlin & Wenger, 2001).

For these reasons, this review will focus on the physiological assessment of aerobic training outcome and process in soccer. Current knowledge and the results of our recent studies in this area will be presented.

Assessment of aerobic training outcome

Both sport scientists and coaches have used several tests to assess aerobic training outcome in soccer. These tests can be broadly defined as physiological measures of aerobic power and capacity or measures of soccer-specific endurance performance.

Physiological measures of aerobic fitness

Several incremental tests to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and the lactate or ventilatory threshold have been used to evaluate aerobic fitness in soccer players (Al-Hazzaa *et al.*, 2001; Bunc and Psotta, 2001; Casajus, 2001; Helgerud *et al.*, 2001; Jensen & Larson, 1993; Puga *et al.*, 1993; Van Gool, Van Gerven, & Boumans, 1988). These maximal ($\dot{V}O_{2max}$) and submaximal (lactate and ventilatory thresholds) parameters of aerobic fitness are commonly considered accurate measures of aerobic power and capacity (Davis, 1995). Despite some debate (Bassett & Howley, 1997; Noakes, 1997), there is a general consensus that $\dot{V}O_{2max}$ is limited mostly by the ability of the cardiovascular system to transport oxygen to the active muscles, and the lactate threshold by the peripheral ability to utilize oxygen (e.g. mitochondrial enzyme activity) (Bassett & Howley, 2000). Therefore, the assessment of these variables using appropriate protocols could provide useful information to coaches about the effect of aerobic training on central and peripheral factors. Helgerud *et al.* (2001) used $\dot{V}O_{2max}$ and the lactate threshold to ascertain the effect of 8 weeks of interval training on the aerobic capacity of junior soccer players. However, $\dot{V}O_{2max}$ is not always sensitive to training-induced changes in aerobic fitness. Although Bangsbo (1994b) reported an increased $\dot{V}O_{2max}$ in 11 soccer players after 7 weeks of training before a Champions Cup match (the current Champions League), he did not find any further improvement in $\dot{V}O_{2max}$ during the season after this match. On the other hand, a significant decrease in blood lactate concentration at various submaximal running speeds was found both after the 7 weeks of pre-match training and during the season. Similarly, Bangsbo (1994b) reported no change in $\dot{V}O_{2max}$ after a pre-season training period in seven soccer players, while the speed corresponding to a blood lactate concentration of 3 $mmol \cdot l^{-1}$ was found to be significantly increased. Casajus (2001) reported an improvement in the ventilatory threshold without any change in $\dot{V}O_{2max}$ in a Spanish professional soccer team during the competitive season. These studies suggest that submaximal parameters of aerobic fitness such as the lactate and ventilatory thresholds could be more sensitive to training than $\dot{V}O_{2max}$ in the physiological assessment of aerobic training outcome in soccer (Bunc & Psotta, 2001).

The use of laboratory tests is limited to research purposes or with professional soccer teams because of practical problems, such as the cost of equipment and the expertise required. Furthermore, athletes are sometimes reluctant to be assessed in the laboratory. For these reasons, some field tests have been proposed as practical alternatives to laboratory assessments and they are commonly used by coaches and applied sport scientists working with soccer players to evaluate aerobic training outcome (Cooper, 1968; Leger & Lambert, 1982). One test used in the field to measure aerobic fitness is the multistage 20-m shuttle run test of Leger and Lambert (1982). This test comprises a continuous incremental protocol test to exhaustion. The maximal running speed reached at the end of the test was found to correlate highly with $\dot{V}O_{2max}$ ($r = 0.84$). Based on this association, Leger and Lambert (1982) proposed a regression equation to estimate $\dot{V}O_{2max}$. In Italy, another popular field test to estimate aerobic fitness in soccer players is Mognoni's test (Sirtori, Lorenzelli, Peroni-Ranchet, Colombini, & Mognoni, 1993). This submaximal running protocol, inspired by the study of Jacobs, Sjödin and Schele (1983), showed a significant correlation between OBLA ($4\ mmol \cdot l^{-1}$ lactate threshold) and blood lactate concentration at the end of a single bout of 6 min cycling at 200 W. Similarly, Sirtori *et al.* (1993) reported a significant correlation ($r = -0.94$) between blood lactate concentration at the end of a single 6-min run at $13.5\ km \cdot h^{-1}$ and speed at OBLA during a multistage running test. Based on this correlation, the authors determined a regression equation to estimate the velocity corresponding to OBLA in soccer players. Apart from the original study of Sirtori *et al.* (1993), there are no other published data about the validity or reliability of this test. Recently, we reported a significant correlation between blood lactate concentration measured at the end of a 6-min run and velocity at OBLA before and after 7 weeks of training ($r = -0.68$ and -0.83, respectively; $P < 0.01$) (Impellizzeri, Mognoni, Sassi, & Rampinini, 2004). We also found a significant correlation between training-induced changes in OBLA and changes in blood lactate accumulation at the end of a 6-min run ($r = 0.54$ and 0.60, respectively; $P < 0.05$). These findings suggest that this commonly used "Italian" submaximal field test could be an acceptable indicator of aerobic fitness in soccer players. The successful application of Mognoni's test in Italy is probably due to its quick execution (40 min for 20 players) and its submaximal nature, which makes it attractive to athletes. However, although some coaches use these test results to estimate aerobic power or capacity, it may be more appropriate to use the raw test results (e.g. peak velocity during Leger and Lambert's test or blood lactate concentration in Mognoni's test) to avoid the well-known problems related to prediction, such as population specificity or the influence of reliability of the predictor variable on the estimation (Thomas & Nelson, 2001).

Measures of soccer-specific endurance performance

An alternative approach is to measure performance in tasks reproducing technical skills, movement patterns and the physiological demands of competitive match-play (Bangsbo, 1994b; Bangsbo & Lindquist, 1992; Drust, Reilly, & Cable, 2000; Edwards, MacFayden, & Clark, 2003; Ekblom, 1989; Krustrup *et al.*, 2003; Nicholas, Nuttall, & Williams, 2000; Rosch *et al.*, 2000). One of the most popular examples of these soccer-specific endurance tests is the protocol proposed by Bangsbo (1994b). This test consists of 20-m shuttle runs of increasing speed interspersed by 10 s of active recovery until exhaustion, following acoustic signals recorded on a compact disk. Recently, Krustrup *et al.* (2003) have verified the validity and reliability of the Yo-Yo intermittent recovery test. Muscle biopsy and blood analysis, obtained before and after the execution of this test, have shown that this intermittent field test involves maximal aerobic power and the anaerobic energy system, confirming that the physiological demands of this soccer-specific endurance test are similar to those taxed during a soccer match (Bangsbo, 1994a). The correlations (r) between distance covered during the Yo-Yo test and the distance covered running at high intensity during a match (speed $> 15\ km \cdot h^{-1}$) were 0.75 and 0.71 in referees and players, respectively. Furthermore, the Yo-Yo test results were found to correlate with $\dot{V}O_{2max}$ ($r = 0.71$), suggesting that this test could provide information on both general aerobic fitness and soccer-specific endurance. Its reliability was reported to be 4.9% (coefficient of variation). Krustrup *et al.* (2003) have also proposed a submaximal alternative to this field test. In this version, the test is stopped after 6 min and aerobic-specific endurance is assessed by measuring the final heart rate or blood lactate accumulation. This submaximal version suggests an increasing interest in non-exhaustive tests and underlines the difficulty in using maximal tests frequently with soccer players.

The Loughborough Intermittent Shuttle Test (Nicholas *et al.*, 2000) is another example of a soccer-specific endurance test specifically designed to reproduce some activities typical of a soccer match. Briefly, it is composed of a first part consisting of five 15-min periods of variable-intensity shuttle running simulating soccer match activities, followed by a second part lasting about 10 min during which participants alternate 20 m running at an intensity corresponding to 55% and 95% of $\dot{V}O_{2max}$ until exhaustion. However, this test, like the laboratory-based protocol proposed by Drust *et al.* (2000), was developed for research purposes. Although Siegler, Gaskill and Ruby (2003) used an abridged version of the Loughborough Intermittent

Shuttle Test as a measure of training outcome in female soccer players, its long duration (∼ 85 min), in contrast with other field tests (Bangsbo & Lindquist, 1992; Edwards *et al.*, 2003), limits its regular use in an applied setting.

In the literature, there are several other soccer-specific endurance tests and probably more will be developed in the future. The strength of all of these tests lies in their logical and external validity – that is, their ability to measure soccer-specific endurance performance. However, these tests cannot be interpreted as pure measures of aerobic power and capacity, as performance during the tests can be influenced by several other factors, such as anaerobic power and capacity or motor control. Although the multi-factorial nature of these tests can be interpreted as a drawback from a physiological point of view, this could be an advantage when an integrated measure of physical training outcome is desired.

Interpretation of test results

Coaches, unlike most scientists, are interested in the individual rather than the group. This requires a different but correct statistical approach, such as the determination of the individual minimal detectable change. Unfortunately, most coaches interpret any change as a real increment or decrement in aerobic capacity. This approach can be misleading because it does not take measurement error into consideration (i.e. test reliability). Although the best method to assess reliability is a matter of debate (Atkinson & Nevill, 2000), it is possible to obtain from the literature the data necessary to determine the minimal detectable change – that is, the minimum change that can be interpreted as significant with an acceptable probability level. Recently, some excellent reviews have described in detail the methods to assess reliability (Atkinson & Nevill, 1998, 2001; Hopkins, 2000). The correct interpretation of test results on an individual basis is rigorously linked to the reliability of the tests. For this reason, coaches should always use tests of known reliability to determine the individual minimal detectable change. This could be particularly relevant during the competitive season, during which test results for the whole team could be unchanged. For example, Krustrup *et al.* (2003) showed that the distance covered during the Yo-Yo test by a group of professional soccer players increased significantly during the season compared with pre-season but no variation was found in-season. However, these authors underlined that during the season, some players had individual changes larger than the coefficient of variation corresponding to the reliability of the tests, indicating an acceptable probability of true change in aerobic-specific fitness.

In conclusion, the selection of any field or laboratory test should take into account its validity, reliability, feasibility and relevance for soccer (Balsom, 1994). In addition, the choice of the test should also be based on the aim of the assessment – that is, evaluation of the effect of training on either aerobic power and capacity, or soccer-specific endurance capacity.

Assessment of internal training load

The assessment of internal training load requires quantification of the intensity of the physiological stress imposed on the athlete and its duration. While the duration of a training session is easily measurable as time in minutes, intensity can be determined with different methods, such as heart rate and ratings of perceived exertion (RPE). Methods of assessment using these two different variables are presented in the following subsections.

Heart rate based methods to quantify training load

The use of heart rate to describe and determine exercise intensity is based on the well-known linear relationship between heart rate and $\dot{V}O_2$ over a wide range of steady-state submaximal workloads (Åstrand & Rodahl, 1986). This approach has been used to estimate the energy cost of soccer-specific exercises and matches (e.g. Bangsbo, 1994b; Rhode & Espersen, 1988). However, the validity of this approach could be questioned due to the non-steady-state nature of soccer training and performance. During intermittent exercise, heart rate responds relatively slowly to abrupt changes in work rate and it may not accurately reflect changes in $\dot{V}O_2$ (Achten & Jeukendrup, 2003; Tumilty, 1993). Considering the intermittent nature of the high-intensity work completed during soccer training and competition (Bangsbo, 1994a,b; Reilly, 1997), the usefulness of heart rate based methods for measuring internal aerobic training load in soccer can be questioned. For this reason, we compared $\dot{V}O_2$ estimated from heart rate with $\dot{V}O_2$ measured using a portable metabolic cart, during 6 min of small-group play (5 versus 5 with goalkeeper and free touches) in a group of 15 semi-professional soccer players (unpublished results). The individual relationship between heart rate and $\dot{V}O_2$ was determined using an incremental treadmill running test in the laboratory (increments of 1 $km \cdot h^{-1}$ every 5 min, inclination 3%). Although we found no significant difference between average predicted [47.6 (5.5) $ml \cdot kg^{-1} \cdot min^{-1}$] and measured [49.8 (4.7) $ml \cdot kg^{-1} \cdot min^{-1}$] $\dot{V}O_2$ during non-steady-state intermittent exercise in this group of soccer players, using Bland and Altman's limits of agreement there was a non-significant bias

(-1.6 ml·kg^{-1}·min^{-1}; $P > 0.05$) but a **random error** of 7.4 ml·kg^{-1}·min^{-1}. In line with others (Achten & Jeukendrup, 2003), these results suggest that the estimation of $\dot{V}O_2$ from heart rate monitoring during non-steady-state intermittent exercise could be accurate at the group but not at the individual level (Figure 3).

Even without establishing the individual heart rate – $\dot{V}O_2$ relationship, heart rate itself is considered indicative of physiological strain (Reilly, 1997). Traditionally, the percentage of maximal heart rate (HR_{max}) has been used to define exercise intensity in soccer training. The use of heart rate reserve [$(HR_{exercise} - HR_{rest})/(HR_{max} - HR_{rest})$] seems to be more accurate, because percentage of maximal heart rate does not correspond to % $\dot{V}O_{2max}$, while percentage of heart rate reserve has been proposed to be equivalent to % $\dot{V}O_{2max}$. However, Swain and Leutholtz (1997) and Swain, Leutholtz, King, Haas and Branch (1998) have recently demonstrated that, during cycling and treadmill running, percentage heart rate reserve does not correspond exactly to % $\dot{V}O_{2max}$, especially in unfit individuals exercising at low intensities. On the other hand, when expressing exercise intensity as % $\dot{V}O_2$ reserve [$(\dot{V}O_{2exercise} - \dot{V}O_{2rest})/\dot{V}O_{2max} - \dot{V}O_{2rest})$], these authors found very good agreement with percentage heart rate reserve across the entire exercise intensity spectrum. We extended this finding to non-steady-state intermittent exercise by determining the relationship between percentage heart rate reserve and both % $\dot{V}O_2$ reserve and % $\dot{V}O_{2max}$ in the above mentioned group of 15 soccer semi-professionals during five-a-side play. Breath-by-breath and heart rate data, averaged every 30 s, are presented in Figure 4. It is clear that the agreement between percentage heart rate reserve and % $\dot{V}O_2$ reserve is greater than that between percentage heart rate reserve and % $\dot{V}O_{2max}$. Based on this finding, percentage heart rate reserve seems to be an indirect accurate measure of metabolic intensity and it can be used to characterize and prescribe exercise intensity in soccer even when comparing different players.

One of the most widely used heart rate based methods to determine internal training load is the "training impulse" (TRIMP) described by Banister (1991). It is calculated by multiplying training session duration by its average intensity (percentage of heart rate reserve) and by a sex-specific coefficient. This method allows physiologists to quantify internal training load in a single term balancing exercise duration and intensity. Another method to quantify internal training load is that proposed by Edwards (1993), which entails measuring the product of the accumulated training duration in five heart rate zones by a coefficient relative to each zone (from 50 – 60% of HR_{max} = 1 to 90 – 100% of HR_{max} = 5) and then summing the results. This method was used, for example, as a reference criterion to validate an RPE-based training load in speed skaters (Foster, 1998) (see next subsection). A similar but less sophisticated approach is to classify the exercise intensity as the minutes spent in three zones (easy, moderate, high) determined from two reference heart rate values, such as the ones corresponding to the lactate and ventilatory thresholds (Gilman, 1996;

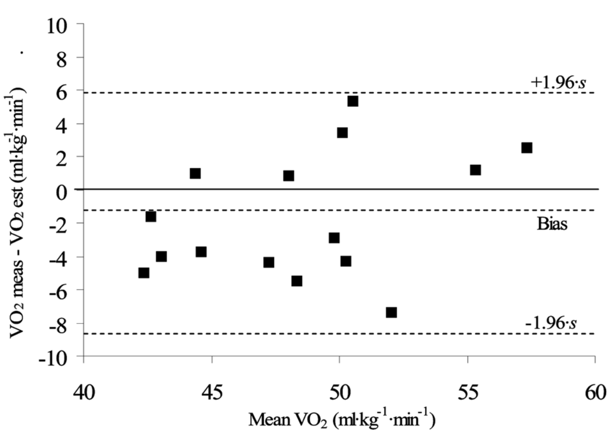

Figure 3. Bland and Altman plot of measured $\dot{V}O_2$ versus estimated $\dot{V}O_2$ during small group play (5 versus 5) (n = 15). Bias ± random error: -1.6 ± 7.4 ml·kg^{-1}·min^{-1}.

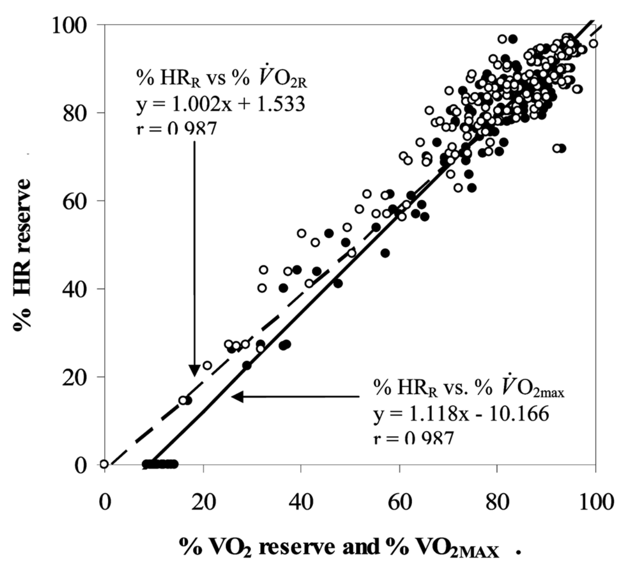

Figure 4. Relationship between percentage heart rate reserve (HR_R) and % $\dot{V}O_{2max}$ (●) and % $\dot{V}O_2$ reserve (○) during small-group play (5 versus 5) (n = 15). The mean slope and intercept of percentage heart rate reserve versus % $\dot{V}O_{2max}$ were significantly different from 0 and 1 ($P < 0.001$). The mean slope of percentage heart rate reserve versus % $\dot{V}O_2$ reserve was not significantly different from 1, while the intercept was different from 0 ($P < 0.01$). The slopes and intercepts of the two regressions were different ($P < 0.001$). The regression equations are the average of 15 individual regressions.

Gilman & Wells, 1993). This method does not quantify in a single term the internal training load, as does the TRIMP and the method of Edwards, but it allows a more accurate description of intensity distribution within a training session. This could be very useful because, especially in trained athletes, the main stimulus inducing an increase in aerobic capacity appears to be high-intensity aerobic training (Gaskill, Serfass, Bacharach, & Kelly, 1999; Londeree, 1997).

The heart rate based methods were developed to monitor endurance training and, to our knowledge, there are no published studies regarding their application in soccer training. The only attempt to develop a method to determine the aerobic internal training load using heart rate in soccer was made by Flanaghan and Merrick (2001), who suggested multiplying mean exercise intensity expressed as absolute heart rate by an intensity coefficient determined in the laboratory during incremental tests on a treadmill. Using this method, Flanaghan and Merrick categorized some soccer-specific exercises in order to periodize training. Although interesting, this method was not further developed and validated. Recently, to verify the usefulness of heart rate to monitor aerobic internal training load in soccer, we quantified the individual internal training load in a group of 15 junior soccer players by recording heart rate during all sessions within 7 weeks of in-season soccer training (unpublished results). Before and after this training period, the players performed an incremental treadmill test to measure changes in aerobic fitness. On the basis of the individual relationship between heart rate and lactate during these tests, we determined the time in minutes spent in three zones: below the lactate threshold, between the lactate threshold and OBLA, and above OBLA. We found a significant positive correlation between percent improvement of $\dot{V}O_2$ at OBLA and minutes spent above OBLA during training ($r = 0.55$; $P < 0.05$). Using the median split technique, we divided these soccer players in two groups according to the time spent in the high-intensity zone. The players who trained for more time above OBLA showed a significantly higher relative improvement in aerobic capacity compared with the other players, which actually showed signs of detraining (Figure 5). This finding exemplifies the intimate relationship between training process and outcome and suggests that heart rate, even with several limitations, could provide useful information about the internal aerobic training load and its effectiveness.

Despite the availability of valid and reliable portable blood lactate analysers (Bishop, 2001; Pyne, Boston, Martin, & Logan, 2000), their systematic use as indicators of exercise intensity in the field is not practical. Therefore, the recording of heart rate seems to be the only simple and objective way to quantify aerobic internal training load and to prescribe exercise intensity in soccer. However, the regular application of these heart rate based methods and the direct determination of blood lactate are limited to scientific research and a few top professional teams, because of time-consuming data collection and analysis, the high cost of heart rate monitoring systems and modern portable analysers, and problems associated with blood lactate measurement. An additional problem with heart rate methods for quantification of internal training load in team sports such as soccer is that heart rate transmitter belts are not permitted during official competitive matches. This is an important limitation because, according to our data, the internal training load induced by a match represents a relatively high percentage of the weekly training load. For example, in weeks characterized by two official matches, their internal training load can represent about 50% of total weekly training load (Figure 6A). When only one match a week is played, that figure drops to 25% (Figure 6B). For these reasons, it is important to devise and validate alternative or additional methods to quantify aerobic exercise intensity and internal training load in soccer.

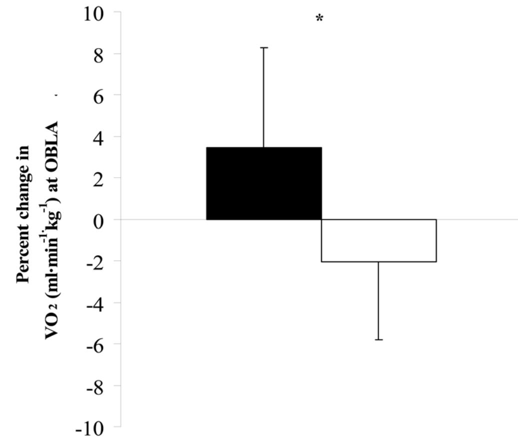

Figure 5. Comparison of percent changes of aerobic capacity ($\dot{V}O_2$ at OBLA) between two groups of soccer players divided according to their median value of minutes spent at high intensity (i.e. above the heart rate corresponding to OBLA). (■, players that spent time at high intensity above median team value ($n = 7$); □, players that spent time at high intensity below median team value ($n = 8$). *Note*: OBLA = 4 mmol·l^{-1} lactate threshold; * $P < 0.05$ (Mann-Withney *U*-test).

Rating of perceived exertion based method to quantify training load

An alternative method to heart rate for quantifying internal training load has been proposed and validated by Foster *et al.* (1995) and Foster (1998)

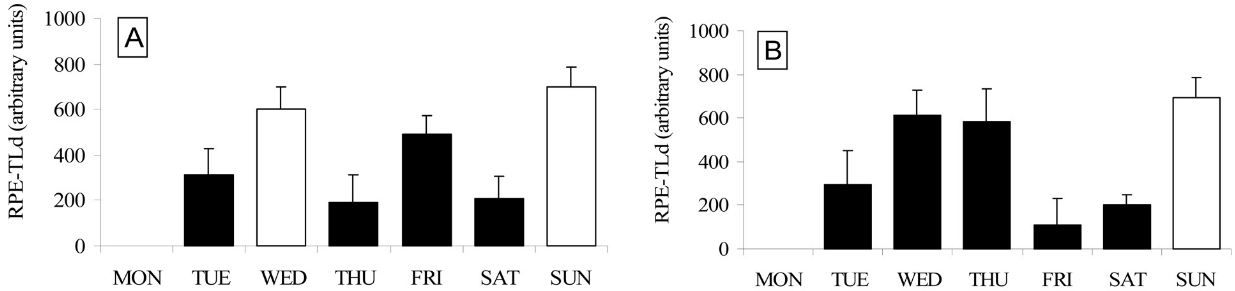

Figure 6. Examples of weekly periodization in an Italian professional soccer team ($n = 18$) in weeks with two matches (Italian Cup and regular season) (A) and one match a week (regular season) (B). White bars represent training load corresponding to matches. Data are presented as the mean and standard deviation. RPE-TLd, RPE-based internal training load.

in endurance athletes and subsequently applied to basketball (Foster *et al.*, 2001). This method consists of multiplying the rating of perceived exertion of the whole training session, as measured by Borg's CR10 scale (Borg, Hassmen, Lagerstrom, 1987), by its duration, to derive a single index of internal training load (RPE-TLd). To verify the utility of Foster's RPE method as an indicator of aerobic training load in soccer, we correlated RPE-TLd with various heart rate based methods: Banister's (1991) TRIMP and Edwards' (1993) training load. Suggesting the usefulness of RPE to monitor internal training load in soccer, we found significant individual correlations between heart rate based training loads and RPE-TLd ($r = 0.50 - 0.85$; $P < 0.01$) (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). While the moderate correlations found in some individuals might be negatively interpreted to suggest that RPE-TLd cannot be used as a substitute for heart rate based methods, these correlations also suggest that factors other than heart rate determine the overall internal training load as measured by RPE-TLd, such as the contribution from anaerobic energy production. This was suggested by Drust *et al.* (2000), who compared the physiological responses during simulated soccer activities on a treadmill to continuous exercise at the same mean velocity. Although $\dot{V}O_2$ and heart rate were similar, minute ventilation and RPE were significantly higher during the intermittent exercise. The higher ventilation found during the simulated soccer activities suggests a respiratory compensation induced by higher lactic acid production in the active skeletal muscle. This is not surprising, as Borg *et al.* (1987) have also shown that a combination of heart rate and blood lactate concentration predicts RPE more accurately than either variable alone.

In addition to physiological variables, several psychological factors (e.g. anxiety and depression) can influence RPE during exercise (Morgan, 1994). The psychobiological nature of the RPE (Borg, 1982) could be particularly useful in preventing overtraining or over-reaching, because of the well-known multifactorial nature of these syndromes (Kentta & Hassmen, 1998; Morgan, 1994). Furthermore, during "over-reaching", RPE for a given heart rate was reported to be increased (Martin & Andersen, 2000), suggesting that RPE could be more sensitive to accumulated fatigue than heart rate. For these reasons, this simple method could be a precious tool for coaches, at all levels, to monitor the training process by quantifying in a single term the overall internal load. Despite questions about validity and the need for further investigations of specific factors that can influence RPE-TLd, this simple method has the potential to become a key tool for coaches and sport scientists to monitor internal training load.

Integration of process and outcome

The most convincing scientific evidence of the close relationship between training process and outcome and the utility of their physiological assessment was provided by several modelling studies (e.g. Banister, 1991; Busso, Benoit, Bonnefoy, Feasson, & Lacour, 2002; Millet *et al.*, 2002; Morton, Fitz-Clarke, & Banister, 1990). In these investigations, mathematical models were developed to describe and/or predict the effect of training on performance, considering the individual internal training load as the input of a system (the athlete), which determines an output represented by the performance (Banister, 1991). While such sophisticated quantitative analysis is now limited to scientific studies, we propose that a similar but more qualitative approach should be used by coaches to understand and control the training prescribed for their athletes (Figure 2). This requires the quantification of both training outcome (physiological tests) and training process (internal training load). An example of the practical application of the integration of training process and outcome was provided by Gaskill *et al.* (1999) for cross-country skiers. These authors identified a group of athletes deemed to be low responders based on both laboratory tests and competitive performance. The following season the training programme of the "responders" was unchanged, whereas for the "low responders" the proportion of high-intensity training was increased. As a consequence, both the responders and low-responders showed an improvement in $\dot{V}O_{2max}$, $\dot{V}O_2$ at the lactate threshold, maximal arm power and competitive performance compared with the basic endurance training period. A similar approach could be used in soccer training. However, this approach requires good control of actual individual internal load, as the athletes who are low responders can be identified only if the actual training stimulus is similar to that used by responders.

Preliminary but more specific evidence of the usefulness of the approach described in Figure 2 was provided by us in a descriptive study conducted with a group of 15 junior soccer players. In this study, quantification of the internal training load (using time spent in different exercise intensity zones delimited by heart rate at the lactate threshold and OBLA) enabled us to understand better the different individual training outcomes measured as $\dot{V}O_2$ at OBLA. In fact, despite a similar external training load (mainly small group play), we found a highly variable internal training load because of the individual characteristics of the athletes as previously suggested by Hoff, Wislöff, Engen, Kemi and Helgerud (2002). As expected, players who had experienced higher internal training loads showed the greater improvement in aerobic fitness as suggested by (1) the significant correlation between minutes spent above OBLA throughout the 7 weeks of training and percentage change in $\dot{V}O_2$ at OBLA ($r = 0.55$; $P < 0.05$), and (2) the significantly higher relative improvement in aerobic capacity in the players who trained for more time above OBLA (Figure 3). The control of players' responsiveness after a training period using physiological tests can be used to design more effective training programmes. Even without statistical analysis, the systematic application of our proposed approach should provide the coach with the knowledge necessary not only to interpret training-induced changes once they have occurred, but also to modify the training process before the assessment of its outcome, thus optimizing his or her athletes' performances.

In summary, this review was intended to stimulate sport scientists and especially coaches not only to use physiological tests to assess training outcome but also to take advantage of recent technological and scientific progress to systematically assess the training programmes they have so carefully planned. Further improvement in the physical fitness of soccer players can be obtained by monitoring the training process rather than developing new physiological tests every few years to assess training outcomes. Further research is necessary to understand the phenomenon more fully and apply the methods to quantify internal training load proposed in this review.

Acknowledgements

The authors would like to thank M. Fanchini and the Pro Patria Football Club for their collaboration during the collection of the data presented in part of this review. We would like also to thank R. Sassi of Valencia Football Club, Carlo Castagna and Aaron Coutts for their suggestions.

References

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: Applications and limitations. *Sports Medicine*, *33*, 517–538.

Al-Hazzaa, H. M., Almuzaini, K. S., Al-Refaee, S. A., Sulaiman, M. A., Dafterdar, M. Y., Al-Ghamedi, A., & Al-Khuraiji, K. N. (2001). Aerobic and anaerobic power characteristics of Saudi elite soccer players. *Journal of Sports Medicine and Physical Fitness*, *41*, 54–61.

Åstrand, P. O., & Rodahl, K. (1986). *Texbook of work physiology*. New York: McGraw-Hill.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, *26*, 217–238.

Atkinson, G., & Nevill, A. (2000). Typical error versus limits of agreement. *Sports Medicine*, *30*, 375–381.

Atkinson, G., & Nevill, A. M. (2001). Selected issues in the design and analysis of sport performance research. *Journal of Sports Sciences*, *19*, 811–827.

Balsom, P. (1994). Evaluation of physical performance. In B. Ekblom (Ed.), *Football (soccer)* (pp. 102–123). Oxford: Blackwell Scientific.

Balsom, P. D., Ekblom, B., & Sjödin, B. (1994). Enhanced oxygen availability during high intensity intermittent exercise decreases anaerobic metabolite concentrations in blood. *Acta Physiologica Scandinavica*, *150*, 455–456.

Bangsbo, J. (1994a). Energy demands in competitive soccer. *Journal of Sports Sciences*, *12* (special issue), S5–S12.

Bangsbo, J. (1994b). The physiology of soccer – with special reference to intense intermittent exercise. *Acta Physiologica Scandinavica*, suppl. *619*, 1–155.

Bangsbo, J., & Lindquist, F. (1992). Comparison of various exercise tests with endurance performance during soccer in professional players. *International Journal of Sports Medicine*, *13*, 125–132.

Banister, E. W. (1991). Modeling elite athletic performance. In H. Green, J. McDougall and H. Wenger (Eds.), *Physiological testing of elite athletes* (pp. 403–424). Champaign, IL: Human Kinetics.

Bassett, D. R., Jr., & Howley, E. T. (1997). Maximal oxygen uptake: "Classical" versus "contemporary" viewpoints. *Medicine and Science in Sports and Exercise*, *29*, 591–603.

Bassett, D. R., Jr., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, *32*, 70–84.

Bishop, D. (2001). Evaluation of the Accusport lactate analyser. *International Journal of Sports Medicine*, *22*, 525 – 530.

Booth, F. W., & Thomason, D. B. (1991). Molecular and cellular adaptation of muscle in response to exercise: Perspectives of various models. *Physiological Review*, *71*, 541 – 585.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*, 377 – 381.

Borg, G., Hassmen, P., & Lagerstrom, M. (1987). Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *European Journal of Applied Physiology and Occupational Physiology*, *56*, 679 – 685.

Bouchard, C., & Rankinen, T. (2001). Individual differences in response to regular physical activity. *Medicine and Science in Sports and Exercise*, *33*, S446 – S451 (discussion S452 – S453).

Bunc, V., & Psotta, R. (2001). Physiological profile of very young soccer players. *Journal of Sports Medicine and Physical Fitness*, *41*, 337 – 341.

Busso, T., Benoit, H., Bonnefoy, R., Feasson, L., & Lacour, J. R. (2002). Effects of training frequency on the dynamics of performance response to a single training bout. *Journal of Applied Physiology*, *92*, 572 – 580.

Casajus, J. A. (2001). Seasonal variation in fitness variables in professional soccer players. *Journal of Sports Medicine and Physical Fitness*, *41*, 463 – 469.

Cooper, K. H. (1968). A means of assessing maximal oxygen intake: Correlation between field and treadmill testing. *Journal of the American Medical Association*, *203*, 201 – 204.

Davis, J. A. (1995). Direct determination of aerobic power. In P. J. Maud & C. Foster (Eds.), *Physiological assessment of human fitness* (pp. 9 – 17). Champaign, IL: Human Kinetics.

Drust, B., Reilly, T., & Cable, N. T. (2000). Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. *Journal of Sports Sciences*, *18*, 885 – 892.

Edwards, A. M., MacFayden, A. M., & Clark, N. (2003). Test performance indicators from a single soccer specific fitness test differentiate between highly trained and recreationally active soccer players. *Journal of Sports Medicine and Physical Fitness*, *43*, 14 – 20.

Edwards, S. (1993). High performance training and racing. In S. Edwards (Ed.), *The heart rate monitor book* (pp. 113 – 123). Sacramento, CA: Feet Fleet Press.

Ekblom, B. (1989). A field test for soccer players. *Science and Football*, *1*, 13 – 15.

Flanaghan, T., & Merrick, E. (2001). Quantifying the work-load of soccer players. In W. Spinks, T. Reilly, & A. Murphy (Eds.), *Science and football IV* (pp. 341 – 349). London: E & FN Spon.

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine and Science in Sports and Exercise*, *30*, 1164 – 1168.

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, *15*, 109 – 115.

Foster, C., Hector, L. L., Welsh, R., Schrager, M., Green, M. A., & Snyder, A. C. (1995). Effects of specific versus cross-training on running performance. *European Journal of Applied Physiology and Occupational Physiology*, *70*, 367 – 372.

Gaskill, S. E., Serfass, R. C., Bacharach, D. W., & Kelly, J. M. (1999). Responses to training in cross-country skiers. *Medicine and Science in Sports and Exercise*, *31*, 1211 – 1217.

Gilman, M. B. (1996). The use of heart rate to monitor the intensity of endurance training. *Sports Medicine*, *21*, 73 – 79.

Gilman, M. B., & Wells, C. L. (1993). The use of heart rates to monitor exercise intensity in relation to metabolic variables. *International Journal of Sports Medicine*, *14*, 339 – 344.

Helgerud, J., Engen, L. C., Wislöff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine and Science in Sports and Exercise*, *33*, 1925 – 1931.

Hoff, J., Wislöff, U., Engen, L. C., Kemi, O. J., & Helgerud, J. (2002). Soccer specific aerobic endurance training. *British Journal of Sports Medicine*, *36*, 218 – 221.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*, 1 – 15.

Impellizzeri, F. M., Mognoni, P., Sassi, A., & Rampinini, E. (2004). Validity of a submaximal running test to evaluate arobic fitness changes in soccer players. *Journal of Sports Sciences*, *22*, 547.

Impellizzeri, F. M., Rampinini, E., Coutts, A., Sassi, A., & Marcora, S. M. (2004). The use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise*, *36*, 1042 – 1047.

Jacobs, I., Sjödin, B., & Schele, R. (1983). A single blood lactate determination as an indicator of cycle ergometer endurance capacity. *European Journal of Applied Physiology and Occupational Physiology*, *50*, 355 – 364.

Jensen, K., & Larson, B. (1993). Variation in physical capacity in a period including supplemental training of the national Danish soccer team for women. In T. Reilly, J. Clarys, & A. Stibbe (Eds.), *Science and football II* (pp. 114 – 117). London: E & FN Spon.

Kentta, G., & Hassmen, P. (1998). Overtraining and recovery: A conceptual model. *Sports Medicine*, *26*, 1 – 16.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The Yo-Yo intermittent recovery test: Physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise*, *35*, 697 – 705.

Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict $\dot{V}O_{2max}$. *European Journal of Applied Physiology and Occupational Physiology*, *49*, 1 – 12.

Londeree, B. R. (1997). Effect of training on lactate/ventilatory thresholds: A meta-analysis. *Medicine and Science in Sports and Exercise*, *29*, 837 – 843.

Martin, D. T., & Andersen, M. B. (2000). Heart rate – perceived exertion relationship during training and taper. *Journal of Sports Medicine and Physical Fitness*, *40*, 201 – 208.

Millet, G. P., Candau, R. B., Barbier, B., Busso, T., Rouillon, J. D., & Chatard, J. C. (2002). Modelling the transfers of training effects on performance in elite triathletes. *International Journal of Sports Medicine*, *23*, 55 – 63.

Morgan, W. P. (1994). Psychological components of effort sense. *Medicine and Science in Sports and Exercise*, *26*, 1071 – 1077.

Morton, R. H., Fitz-Clarke, J. R., & Banister, E. W. (1990). Modeling human performance in running. *Journal of Applied Physiology*, *69*, 1171 – 1177.

Nicholas, C. W., Nuttall, F. E., & Williams, C. (2000). The Loughborough Intermittent Shuttle Test: A field test that simulates the activity pattern of soccer. *Journal of Sports Sciences*, *18*, 97 – 104.

Noakes, T. D. (1997). 1996 J. B. Wolffe Memorial Lecture. Challenging beliefs: ex Africa semper aliquid novi. *Medicine and Science in Sports and Exercise*, *29*, 571 – 590.

Puga, N., Ramos, J., Agostinho, J., Lomba, I., Costa, O., & De Freitas, F. (1993). Physical profile of a first division Portuguese professional soccer team. In T. Reilly, J. Clarys, & A. Stibbe (Eds.), *Science and football II* (pp. 40 – 42). London: E & FN Spon.

Pyne, D. B., Boston, T., Martin, D. T., & Logan, A. (2000). Evaluation of the Lactate Pro blood lactate analyser. *European Journal of Applied Physiology*, *82*, 112 – 116.

Rampinini, E., Sassi, A., & Impellizzeri, F. M. (2004). Reliability of heart rate recorded during soccer training. *Journal of Sports Sciences*, *22*, 558.

Reilly, T. (1997). Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences*, *15*, 257 – 263.

Rhode, H. C., & Espersen, T. (1988). Work intensity during soccer training and match-play. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), *Science and football* (pp. 76 – 80). London: E & FN Spon.

Rosch, D., Hodgson, R., Peterson, T. L., Graf-Baumann, T., Junge, A., Chomiak, J., & Dvorak, J. (2000). Assessment and evaluation of football performance. *American Journal of Sports Medicine*, *28*, S29 – S39.

Siegler, J., Gaskill, S., & Ruby, B. (2003). Changes evaluated in soccer-specific power endurance either with or without a 10-week, in-season, intermittent, high-intensity training protocol. *Journal of Strength and Conditioning Research*, *17*, 379 – 387.

Sirtori, M. D., Lorenzelli, F., Peroni-Ranchet, F., Colombini, A., & Mognoni, P. (1993). A single blood lactate measure of OBLA running velocity in soccer players. *Medicina dello Sport*, *43*, 281 – 286.

Swain, D. P., & Leutholtz, B. C. (1997). Heart rate reserve is equivalent to % $\dot{V}O_2$ reserve, not to % $\dot{V}O_{2max}$. *Medicine and Science in Sports and Exercise*, *29*, 410 – 414.

Swain, D. P., Leutholtz, B. C., King, M. E., Haas, L. A., & Branch, J. D. (1998). Relationship between % heart rate reserve and % $\dot{V}O_2$ reserve in treadmill exercise. *Medicine and Science in Sports and Exercise*, *30*, 318 – 321.

Thomas, J. R., & Nelson, J. K. (2001). *Research methods in physical activity* (4th edn.). Champaign, IL: Human Kinetics.

Tomlin, D. L., & Wenger, H. A. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Medicine*, *31*, 1 – 11.

Tumilty, D. (1993). Physiological characteristics of elite soccer players. *Sports Medicine*, *16*, 80 – 96.

Van Gool, D., Van Gerven, D., & Boumans, J. (1988). The physiological load imposed on soccer players during real match-play. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), *Science and football* (pp. 51 – 59). London: E & FN Spoon.

Viru, A., & Viru, M. (2000). Nature of training effects. In W. Garrett & D. Kirkendall (Eds.), *Exercise and sport science* (pp. 67 – 95). Philadelphia, PA: Lippincott Williams & Williams.

Wislöff, U., Helgerud, J., & Hoff, J. (1998). Strength and endurance of elite soccer players. *Medicine and Science in Sports and Exercise*, *30*, 462 – 467.