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Review

Monitoring training load and fatigue in soccer players with physiological markers

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ABSTRACT

The quantification and monitoring of training load (TL) has been the topic of many scientific works in the last fifteen years. TL monitoring helps coaches to individually prescribe, follow-up, analyse, adjust and programme training sessions. In particular, the aim of the present review was to provide a critical literature report regarding different physiological markers of TL monitoring, particularly in soccer, as the load is specific to individual sports. Therefore, the interests and limitations of heart rate (HR), HR variability (HRV) and biochemical variables (blood, urinary and hormonal variations) were analysed, with a special focus on daily measures (before, during and after training) and monitoring throughout a whole season. It appears that the most relevant markers were the resting HR before training, HR reserve during training, HRV during rest days, blood lactate, and blood and salivary immunological status in follow-ups throughout the season. Urinary markers indicative of the players' hydration status also deserve attention. However, these objective markers should be considered with a subjective marker of TL such as the rating of perceived exertion to give a more precise quantification of TL and its perception. Future research could be directed towards urinary marker analysis and the analysis of specific markers of TL, which could be related to injury occurrence and to performance during competition.

1. Introduction

Soccer is characterized by high neuromuscular demands with accelerations, decelerations, changes in direction, jumps and tackles [1]. In elite soccer, one to three matches can be played in a 7-day period. Thus, elite soccer programmes are designed by coaches and staff to prepare the players to repeat these high neuromuscular demand efforts several times a week during a whole season (usually 9 to 11 months of continuous training and competition [1]). While designing training programmes appears to be the first step of training management, monitoring the impact of the sessions on players appears be the second important step towards being successful in the training process. Indeed, both training and matches induce physiological changes that are important to assess. Thus, monitoring these changes would give coaches an indication of the individual internal training load (TL) so that adjustments could be made to the training regimen [2,3]; therefore, overtraining could be avoided, fitness and performance could be optimized [2], and the occurrence of injury and illness could be reduced [4,5]. Additionally, a player's turnover could be managed when necessary.

Subjective measures such as the rating of perceived exertion (RPE) [6], for which players are asked to grade their own perceived load, could be used to quantify fatigue and TL. The latter parameter could also be assessed based on objective measures using both external (e.g., distance covered at different speeds, number of sprints, and accelerations) [7] and internal (e.g., heart rate, oxygen uptake, and blood, urinary and salivary markers) [8] indicators of training intensity. Within the present review, we specifically aimed to present the different

Abbreviations: A, Adrenaline; ANS, Autonomic nervous system; C, Cortisol; CK, Creatine kinase; Cn, Cortisone; HDL, High-density lipoprotein; HF, High frequency; HIT, High-intensity training exercise; HR, Heart rate; HR_{max}, Maximal heart rate; HR_R, Recovery heart rate; HR_{res}, Reserve heart rate; HR_{rest}, Resting heart rate; HRV, Heart rate variability; IgA, Immunoglobulin A; LDL, Low-density lipoprotein; LF, Low frequency; NA, Noradrenaline; rMSSD, The square root of the mean of the sum of the squares of differences between adjacent normal R-R intervals; RPE, Rating of perceived exertion; SD, Standard deviation; sIgA, Salivary IgA; SSG, Small-sided games; T, Testosterone; TC, Total cholesterol; TL, Training load; TRIMP, Training impulse; URTI, Upper respiratory tract infection; VO_2, Oxygen uptake

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physiological indicators. Therefore, heart rate measures at different times before, during and after soccer efforts/sessions will be introduced and criticised. Following this discussion, different markers obtained from blood, salivary and urinary sampling will be described to present their contributions and limitations in a training monitoring process in soccer players.

2. Heart rate

Heart rate (HR) can be used to monitor TL as follows: (i) during exercise with exercise HR (HR_{ex}), percentage of maximal HR ($\%HR_{max}$), and percentage of reserve HR ($\%HR_{res}$); (ii) just after exercise with recovery HR (HR_R); and (iii) to monitor TL and the state of fatigue at rest by the means of HR variability (HRV) and resting HR (HR_{rest}) [9,10]. HR is the most common physiological parameter used in soccer as it has been validated as an indicator of workload in different types of exercises and sessions in soccer [11–13]. In general, while making individual comparisons, a lower HR correlates with a better fitness level in the player tested [2]. Indeed, during exercise it would mean that for a given intensity or at rest, the heart would not need to beat as fast due to better efficiency of heart pumping mechanisms such as an increase in stroke volume, cardiac muscle hypertrophy and/or an improvement in oxygen transport mechanisms [14–16]. In the same way, during post-exercise, it would mean that the player recovers faster from a given exercise intensity. Within the HR measurement, changes in HRV have also been examined and reviewed by several authors as a relevant and practical tool to monitor TL and fatigue in athletes [1,17–19]. HRV can be measured from the variation in the R-R intervals on an electrocardiogram. For instance, HRV is represented in a time domain in milliseconds, or in a frequency domain, which is the frequency at which the length of the R-R interval changes [9,19]. In this frequency domain, the contribution of parasympathetic activity prevails in high frequency (HF) power peaks (0.15–0.40 Hz) [11], and both sympathetic and parasympathetic systems contribute to low frequency (LF) power peaks (0.04–0.15 Hz) [20]. The ratio LF:HF is another index to measure HRV to reflect autonomic reactivity, with high values of this ratio reflecting sympathetic dominance [21]. The square root of the mean of the sum of the squares of differences between adjacent normal R-R intervals (rMSSD) is the usual cardiac parasympathetic activity-related index as it is not affected by breathing [22]. Another usual index calculated as a vagal-related HRV index is the standard deviation (SD) of instantaneous beat-to-beat R-R interval variability [23], which can be measured from Poincaré plots (SD1) [24].

Physiologists and medical and technical personnel can use HR monitoring before, during and after training. It is possible to perform the monitoring every day including during the athletes' rest days. The following sections provide information about contributions and limitations when using HR and HRV and all their related markers in the monitoring process.

2.1. HR before training

2.1.1. Resting heart rate (HR_{rest})

HR_{rest} is defined as the lowest measure of HR taken from a 10-min lying position or immediately upon awakening [10]. Sleeping HR is defined as the lowest measure recorded during an entire night of sleep monitoring [9]. Measured in a seated or lying position, a decrease in HR_{rest} is suggested to be associated with an increase in the predominance of parasympathetic control [25]. It is well known that a decrease in HR_{rest} is a common response to endurance training; however, changes in HR_{rest} might also be influenced by environmental factors, thus its use as a marker of endurance TL or training adaptation is limited [2]. HR_{rest} is known to be a valid tool to detect short-term fatigue [26] even in soccer [27,28], but it is still questionable as a tool to detect a state of overtraining. Indeed, similar HR measures between normal and overtrained states were found in several studies, and some others reported an increase in HR_{rest} in overtrained individuals [9]. HR_{rest} might be the easiest marker to assess because it does not require sophisticated monitoring equipment and any further analysis. However, its use might be limited to the estimation of general fatigue without reporting day-to-day variations in TLs.

2.1.2. Resting heart rate variability (HRV)

Resting HRV is usually measured in a seated position for 5 min immediately after awakening in the morning to reduce external confounding factors (noise, light, and temperature). It is measured using a single marker such as Ln rMSSD (please see list of abbreviations), which is the most reliable HRV variable [1,29]. High Ln rMSSD has been associated with a high perception of fatigue and low fitness [30] and correlated with physical activity [31]. With respect to the timeline of a full season, lower values were observed during pre-season [32,33] and at the end of the season [33], which are periods where the fatigue is reported to be higher. More recently, it was observed that LF measures of HRV that were measured from a standing position were significantly altered at the end of a professional pre-season period [28]. Resting HRV as an indicator of cardiac parasympathetic activity could thus be used to monitor both acute and chronic training adaptations.

However, in the day-to-day monitoring process, resting HRV has some limitations; it can help identify a global state of fatigue, but it cannot measure different levels of fatigue [30]. Interesting results of swimmers highlighted the influence of pre-competitive stress on rMSSD, SD1 and HF, the measures of which were significantly lower in comparison to those associated with standardized training sessions [34]. Cognitive activity and the emotional state might therefore influence HRV indicators. Furthermore, a recent study of professional players in the English Premier League reported that no changes in resting HRV could be detected over a period of a week [35], which confirms that this tool remains of limited interest to date for practitioners on the field in training settings.

2.2. HR during exercise

2.2.1. Heart rate during exercise (HR_{ex}, %HRmax, %HRres)

HR has been well studied, and it has been demonstrated that HR is correlated to exercise VO_2 and to metabolic thresholds [9,10,19]. HR could be monitored easily during all types of training including high-intensity training exercises (HIT) or during small-sided games (SSG) [10]. To monitor HR during exercise, several markers should to be considered as follows:

- HR_{ex}: exercise HR, expressed in beats per minute, is the marker of the cardiac implication at a given time;
- Maximal heart rate (HR_{max}): the highest individual measure observed for the player when exercising;
- HR_{rest}: the lowest measure observed for the player at rest;
- Reserve heart rate (HR_{res}): calculated using the following formula: $HR_{res} = HR_{max} - HR_{rest}$[36], i.e., the difference between HR_{max} and HR_{rest}.

To indicate the relative individual cardiac implication, HR_{ex} can be expressed in $\%HR_{max}$ using the following formula: $(HR_{ex} / HR_{max}) \times 100$. HR_{ex} can also be expressed in $\%HR_{res}$ using the following formula: $[(\text{mean } HR_{ex} - HR_{rest}) / (HR_{max} - HR_{rest})] \times 100]$. When calculating HR_{res}, the biorhythm variations are considered and therefore allow for inter-individual comparisons within a group of soccer players for different types of training [10].

HR_{ex}, expressed as $\%HR_{max}$ or $\%HR_{res}$, is a good marker for individual relative exercise intensity; a low HR correlates with a more physically fit player for a given standard sub-maximal exercise bout [37]. However, the increase in HR during exercise should not be systematically interpreted as a decline in fitness or a marker of fatigue [38]. It is important to know that during HIT, HR responses are