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MONITORING FATIGUE AND RECOVERY

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KEY POINTS

- Appropriate load monitoring can aid in determining if an athlete is adapting to a training program and to minimize the risk of developing non-functional overreaching (fatigue lasting weeks to months), illness and/or injury.
- Research has investigated a number of external load quantifying and monitoring tools, such as power output measuring devices, time-motion analysis, as well as internal load unit measures, including perception of effort, heart rate, lactate concentration and training impulse. Dissociation between external and internal load units may reveal the state of fatigue of an athlete.
- Heart-rate recovery, neuromuscular function, biochemical/hormonal/immunological assessments, questionnaires and diaries, psychomotor speed and sleep quality and quantity are other monitoring tools utilized by high-performance programs.
- The monitoring approach taken with athletes may depend on whether the athlete is engaging in individual or team sport activities, but the importance of individualization of load monitoring cannot be overemphasized.
- Detecting meaningful changes with scientific and statistical approaches can provide confidence and certainty when implementing change.
- Appropriate monitoring of training load can provide important information to athletes and coaches; however, monitoring systems should be intuitive, provide efficient data analysis and interpretation, and enable efficient reporting of simple, yet scientifically valid feedback.

INTRODUCTION

As athletes strive to improve their performance, modifications in training load are required, and in particular, increases in frequency, duration and intensity. Training loads are managed at various times during the training cycle to either increase or decrease fatigue depending on the phase of training (i.e., baseline or competition phase). Ensuring that fatigue is adjusted appropriately is critical for both adaptations to training as well as competition performance.

To monitor is often defined as “observing and checking the progress or quality of something over a period of time” (Oxford English Dictionary Online). When considering a specific definition of monitoring for athletes, confusion may arise based on single, one-off assessments (i.e., a yearly nutrition assessment) vs. more frequent routine monitoring. For the purpose of this article an assessment of an athlete will be considered monitoring if, 1) the assessment occurs more than once and 2) the assessments occur with enough frequency to give the desired and relevant information to the athlete, coach or scientist.

Monitoring the training load of an athlete is viewed by many as important to determine if an athlete is adapting to the training program and to minimize the risk of non-functional overreaching (fatigue lasting weeks to months), injury and illness (Halson & Jeukendrup, 2004). To date, research in this area is limited and much of what we know about monitoring comes from personal experience and anecdotal information.

MONITORING LOAD

Reasons for and Against Monitoring Load

As mentioned above, there are a number of reasons why monitoring training load is becoming an increasingly modern, scientific approach to understanding athletes, training responses and competition readiness. Although published data on high-level athletes is lacking, monitoring training load can provide an explanation for changes in performance if performed using scientific principles. This can aid in enhancing the clarity and confidence regarding possible reasons for changes in performance and to minimize the degree of uncertainty associated with the changes. From this data, it is not only possible to retrospectively examine load-performance relationships, but also enable appropriate planning for training loads and competitions. Importantly, load monitoring is also implemented to try to reduce the risk of injury, illness and non-functional overreaching. Data may also be useful for team selection and determining which athletes are ready for the demands of competition.

There are also a number of benefits related to communication and relationship building with athletes, support staff and coaches. When athletes are involved in monitoring, it can enhance their feeling of involvement in the training program and they feel both empowered as well as having a sense of ownership. Data collected from monitoring training can also be useful to facilitate communication between the support staff and coaching staff. When combined, these benefits can help enhance the belief associated with the training program.

However, not all coaches and scientists engage in athlete monitoring. For some athletes/teams, insufficient resources can be a major reason for not including a system of training monitoring. Resources may be in the form of time, money or the human resources needed to collect, process and analyse the data. Further, since there are no guarantees that monitoring training load will result in successful performances, resources may be withheld. A lack of knowledge or experience with monitoring techniques can also result in an inability to implement a practical and sustainable system and/or an inability to interpret the data collected. In addition, a clear rationale identifying why the monitoring is occurring, what will be monitored, how often monitoring will occur and how the data will be interpreted and presented back to the coaching staff is required. Finally, the ability and opportunity to implement change and provide feedback is critical to a successful monitoring system, and if this does not occur, many attempts at monitoring are not sustainable.

Potential Load Monitoring Measures

In order to gain an understanding of the training load and its effect on the athlete, a number of potential markers are available to athletes, coaches and scientists. However, very few of these markers have strong scientific evidence supporting their use and there is yet to be a single, definitive marker described in the literature. To assess fatigue, it would appear that the best test in terms of ecological validity would be a maximal performance test replicating the athlete's event/competition. However, there are numerous difficulties regarding maximal testing in athletes. Maximal tests may add to existing fatigue in an athlete, which may be problematic around competition phases. A taper may also be required to determine true performance capabilities, which is often impractical. Athletes may also lack motivation when fatigued to produce a maximal effort that is not for competitive purposes. For many sports, in particular team sports, it is also extremely difficult to replicate or even define maximal performance (Taylor, 2012). Finally, if maximal performance only is assessed, little information can be gained regarding the potential mechanism(s) of fatigue. Table 1 outlines a number of variables that can be used to monitor training load and the resultant fatigue.

Internal Versus External Load

When monitoring training load, the load units can be thought of as either external or internal. Traditionally, external load has been the foundation of most monitoring systems. External load is defined as the work completed by the athlete measured independently of his or her internal characteristics (Wallace et al., 2009). An example of external load in road cycling would be the power output achieved for a given duration of time (e.g., 400 W for 30 min). While external load is important in understanding work completed and capabilities and capacities of the athlete, the internal load, or the relative physiological and psychological stress imposed, is also critical in determining the training load and subsequent adaptation. As both external and internal loads have merit for understanding the athlete's training load, a combination of both may be important for training

Table 1: Variables that can be used to monitor training load and subsequent fatigue. RPE - Rating of Perceived Exertion; REST-Q - Recovery Stress Questionnaire; VAS - Visual Analogue Scale.

VARIABLE	UNITS/DESCRIPTORS
Frequency	Sessions per Day, Week, Month
Time	Seconds, Minutes, Hours
Intensity	Absolute, Relative
Type	Modality, Environment
Maximal Effort	Max Mean Power, Jump Height
Repeat Efforts	Number of Efforts, Quality of Efforts
Training Volume	Time, Intensity
Perception of Effort	RPE
Perception of Fatigue and Recovery	Questionnaires; REST-Q, VAS
Illness	Incidence, Duration
Injury	Type, Duration
Biochemistry and Hormone Analysis	Baseline, Response to Exercise
Technique	Movement Deviations
Body Composition	Total Body Weight, Fat Mass, Fat-Free Mass
Sleep	Quality, Quantity, Routine
Psychology	Stress, Anxiety, Motivation
Sensations	Hopeful, Neutral, Hopeless

monitoring. Indeed, it may be the relationship between external and internal loads that help in revealing fatigue. For example, using the cycling external load mentioned above, the power output may be maintained for the same duration; however, depending on the fatigue state of the athlete, this may be achieved with a high or low heart rate or a high or low perception of effort. It is this uncoupling or divergence of external and internal loads that may differentiate between a fresh and a fatigued athlete (Pyne & Martin, 2011).

METHODS OF MONITORING EXTERNAL LOAD

To gain an understanding of external training load, there are a number of technologies available to athletes and coaches. In the sport of cycling, power output measuring devices such as SRM™ and PowerTap™ allow the continuous measurement of work rate (power output) (Jobsen et al., 2009). Training and competition can be recorded and data can be analysed to provide information on a number of parameters including average power, normalised power, speed and accelerations. Cycling power output can be converted into a Training Stress Score™ (TSS™) via commercially available software (Pyne & Martin, 2011) and allows the quantification of training based on relative intensity, duration and frequency.

In team sports, time-motion analysis (TMA), including global positioning system (GPS) tracking and movement pattern analysis via digital video (such as ProZone™) are becoming increasingly popular to monitor athletes (Taylor, 2012), particularly during competitions. Typically, when using TMA for monitoring, arbitrary speed thresholds are set (Lovell & Abt, 2013). These categories may include walking, jogging, running, striding, sprinting, etc. (Aughey, 2011). The reliability of GPS for monitoring movement is influenced by factors such as sample rate, velocity, duration of task and the type of task (Aughey, 2011). From the available literature, it appears that the higher the velocity of movement, the lower the GPS reliability (Aughey, 2011). Further, the reliability is also reduced when assessing tasks that require changes of direction and GPS does not quantify the load of jumping, kicking a ball and tackling actions (Aughey, 2011).

Neuromuscular Function

Measures of neuromuscular function such as jump tests (countermovement/squat jump), sprint performance and isokinetic and isoinertial dynamometry are often utilized in the team sport environment (Twist & Highton, 2013). These assessments have become popular due to the simplicity of administration and the minimal amount of additional fatigue induced. Common variables from jump test measurements include mean power, peak velocity, peak force, jump height, flight time, contact time and rate of force development (Taylor, 2012; Twist & Highton, 2013).

METHODS OF MONITORING INTERNAL LOAD

Perception of Effort

The rating of perceived exertion (RPE) is one of the most common means of assessing internal load. The use of RPE is based on the notion that athletes can monitor their physiological stress during exercise as well as retrospectively provide information regarding their perceived effort post training or competition. Evidence suggests that RPE correlates well with heart rate during steady-state exercise and high-intensity interval cycling training, but not as well during short-duration high-intensity soccer drills (Borresen & Lambert, 2009). Further, a meta-analysis of the literature reported that while RPE is a valid means of assessing exercise intensity, the validity may not be as high as previously thought (Chen et al., 2002).

Session RPE

Foster (1998) developed the Session RPE method of quantifying training load and it involves multiplying the athlete's RPE (on a 1-10 scale) by the duration of the session (in min). This simple method has been shown in the literature to be valid and reliable (Foster, 1998). While the session RPE method may be simple, valid and reliable, the addition of heart rate monitoring may aid in understanding some of the variance not explained by the session RPE method.

Heart Rate

Monitoring heart rate is one of the most common means of assessing internal load in athletes. The use of heart rate monitoring during exercise is based on the linear relationship between heart rate and oxygen uptake and the intensity of steady-state exercise (Hopkins, 1991); however, the percentage of maximum heart rate is often used to both prescribe and monitor intensity (Borresen & Lambert, 2008). Due to the daily variation in heart rate (up to 6.5%), controlling for factors such as hydration, environment and medication is important (Bagger et al., 2003). Heart rate measurements in isolation may have limited value, but combined with other measurements can become more powerful (Achten & Jeukendrup, 2003).

Heart Rate–Perception of Effort Ratio

The examination of physiological and perceptual indicators of load, at a fixed submaximal intensity, can provide information on the state of fatigue in the athlete. The combination of heart rate and perception of effort measures (HR-RPE ratio) may aid in elucidating fatigue (Martin & Andersen, 2000). For example, the internal load of a cyclist who has a reduced submaximal heart rate in combination with an elevated perception of effort may be quite different from a cyclist with a normal HR-RPE ratio (Pyne & Martin, 2011).

Training Impulse (TRIMP)

The training impulse (TRIMP) is often considered a useful means of assessing training load (Pyne & Martin, 2011) and is a unit of physical effort that is calculated using training duration, maximal heart rate, resting heart rate and average heart rate during the exercise session (Morton et al., 1990). Further derivations of Banister's initial TRIMP model have been developed. These include Edwards' TRIMP, which uses accumulated time in five arbitrary heart rate zones multiplied by a weighting factor (Edwards, 1993). Lucia's TRIMP model is similar to the Edwards derivation; however, there are three heart rate zones which are based on individually determined lactate thresholds and onset of blood lactate accumulation (Lucia et al., 2000). Further, the use of an individualised TRIMP (iTRIMP) has been developed for use in runners (Manzi et al., 2009) and recently tested in soccer players (Akubat et al., 2012). The use of the iTRIMP reduces issues associated with arbitrary zones and generic weightings.

Lactate Concentrations

Blood lactate concentrations are sensitive to changes in exercise intensity and duration (Beneke et al., 2011). However, there are a number of potential limitations to the use of regular monitoring of lactate concentrations during training and competition. These include inter- and intra-individual differences in lactate accumulation and differences in lactate accumulation depending on ambient temperature, hydration status, glycogen content, previous exercise, the amount of muscle mass utilized and sampling procedures (time and site) (Borresen & Lambert, 2008).

Lactate–Perception of Effort Ratio

Similar to the HR-RPE ratio, the lactate to RPE ratio may be useful in determining internal load and identifying fatigue in athletes

(Snyder et al., 1993). Again, changes in these parameters at a fixed submaximal workload may be useful to identify physiological and perceptual changes in internal load.

Heart-Rate Recovery (HRR)

Heart-rate recovery (HRR) is the rate at which the heart rate declines at the cessation of exercise and has been suggested to be a marker of autonomic function and training status in athletes (Daanen et al., 2012). HRR can be calculated over varying time frames, usually between 30 s to 2 min, with the difference between the end of exercise heart rate and heart rate at 60 s post exercise being most commonly used.

In a recent review on HRR and monitoring changes in training status, it was suggested that HRR improves with increased training status, remains unchanged when there is no change in training status and decreases when training status is reduced (Daanen et al., 2012). It was then concluded that with the exception of overreaching (where research is conflicting), HRR could be used to monitor the accumulation of fatigue in athletes. However, the considerations mentioned above regarding standardisation of factors that may influence heart rate, are also relevant for HRR.

Biochemical/Hormonal/Immunological Assessments

Some research has been conducted examining a range of biochemical, hormonal and immunological responses to exercise, primarily in a bid to monitor fatigue and minimize excessive fatigue and illness. It is beyond the scope of this article to review the literature in this area; however, in short, the use of biochemical, hormonal and/or immunological measures as indicators of internal load is currently not justified based on the limited research in this area. In addition, these measures can be costly, time consuming and not practical in an applied environment (Shetler et al., 2001).

Questionnaires and Diaries

Questionnaires and diaries can be a relatively simple and inexpensive means of determining the training load and subsequent responses to training. However, both questionnaires and diaries rely on subjective information, which may need to be corroborated with physiological data (Borresen & Lambert, 2009). It is possible for athletes to manipulate data and/or over- or under-estimate training load. Importantly, the frequency of questionnaire administration and length of questionnaire should be considered to maximize compliance and avoid questionnaire "fatigue". There are a number of questionnaires identified in the literature which have been utilised by high-performance sport programs (Taylor, 2012). These include the Profile of Mood States (POMS) (Morgan et al., 1987), The Recovery-Stress Questionnaire for Athletes (REST-Q-Sport) (Kellmann & Kallus, 2000), Daily Analysis of Life Demands for Athletes (DALDA) (Rushall, 1990) and the Total Recovery Scale (TQR) (Kentta & Hassmen, 1998).

While questionnaires can provide simple and often useful subjective information, factors such as frequency of administration, time taken to complete the question, sensitivity of the questionnaire, type of response required (written answers or circling responses), time of day of completion and the amount of time required for appropriate feedback, should be considered.

Sleep

Sleep loss or deprivation can have significant effects on performance, motivation, perception of effort and cognition as well as numerous other biological functions. Monitoring sleep quality and quantity can be useful for early detection and intervention before significant performance and health decrements are observed. The use of simple diaries indicating hours of sleep and perceived sleep quality can be useful. Other non-invasive methods such as actigraphy (wrist watch device utilizing accelerometry) can provide more detailed information over shorter periods (7-14 d). Actigraphy can provide data on bedtime, wake time, sleep onset latency (time taken to fall asleep), wake during sleep, sleep efficiency (estimate of sleep quality), as well as provide information on sleep routines. Due to the increasing knowledge regarding the importance of sleep, monitoring and assessment of sleep is becoming popular with elite athletes, coaches and support staff (Halson, 2014).

TEAM SPORTS VERSUS INDIVIDUAL SPORT ATHLETES

The nature of load monitoring required, or indeed possible, may vary greatly between team sport and individual sport athletes. Monitoring in team sports is often perceived to be more challenging due to the diverse range of training activities (e.g., general conditioning, resistance training, interval training and skill-based conditioning) commonly employed. Further, the assessment of skilled performance and "cognitive load" or fatigue that influences decision-making is important for team sport performance and poses many challenges for accurate assessment.

When monitoring team sport athletes, some of the most useful measures involve physiological changes, assessment of movement patterns and indicators of skills, with these measures being as sport specific as possible (Pyne & Martin, 2011). Movement patterns can be assessed by time-motion analysis or GPS tracking. Other difficulties when assessing team sport competition performance include the influence of team tactics (including the opposing team), environmental conditions, team cohesion, home or away competition and travel.

In individual sports such as cycling, swimming and triathlon, the fatigue is often the result of high training loads, and the management of these loads through monitoring can be particularly important (Pyne & Martin, 2011). Load monitoring is often based on training volume, duration and intensity alongside indicators of perceptual fatigue such as RPE.

UTILIZING A SYSTEMS-BASED APPROACH

With the increasing amounts of data available from monitoring devices such as GPS, digital video, SRM devices, in combination with internal load measurements such as heart rate, questionnaires and perceptions of fatigue, comes the requirement to incorporate this information into a database and data management system that results in efficient access to meaningful information. According to Pyne & Martin (2011), "a systems-based approach that integrates well-chosen diagnostic tests, with smart sensor technology, and a real-time database and data management system, is the future for fatigue management in elite sport." There are now a number of commercially available athlete monitoring systems such as Training Peaks™, Kinetic Athlete and Smartabase, which allow for integration of data and simple reporting tools that are becoming increasingly popular in high-performance sport.

KEY FEATURES OF A SUSTAINABLE MONITORING SYSTEM

An effective and sustainable monitoring system is critical to ensure that data are effectively captured and reported. Table 2 identifies several key features of such a system.

Table 2. Key Features of a Sustainable Monitoring System.
Ease of use/intuitive design
Efficient result reporting
Can be used with or without Internet connection, i.e., able to be utilized effectively remotely
Data should be able to be translated into simple outcomes, such as effect sizes
The system should be flexible and adaptable for different sports and athletes
Identification of a meaningful change should be simple and efficient
Should include an assessment of cognitive function
Be able to provide both individual responses and group responses

PRACTICAL APPLICATIONS

- Monitoring tools should be sport specific and more than one tool may be used to ensure accurate information is provided.
- Monitoring should occur frequently enough to provide the necessary information; however, not so often that compliance is reduced. Weekly measurements are common in high-performance programs.
- The feedback provided to coaches and athletes should be given as soon as possible after data collection, be easy to interpret and include simple indicators of whether any change in measures are meaningful and/or whether an intervention is required.
- Monitoring should be sustainable from a financial and human resource perspective, be a simple addition to the training program and take minimal time for the athlete to complete.

CONCLUSION

Utilizing scientific principles for load monitoring can be an important means of reducing the risk of non-functional overreaching, illness and injury. With many athletes exposed to high training loads and high training and competition stress, it is necessary to manage risks associated with the possible negative outcomes and to maintain optimal physiological and psychological health and well-being of the athlete. While a range of potential measures of external and internal load have been described, numerous factors are involved in determining the reasons for and against load monitoring, the specific type of monitoring necessary for the sport and the individual and ensuring change is evaluated in an appropriate manner. If accurate and easy to interpret feedback is provided to the athlete and coach, load monitoring can result in enhanced knowledge of training responses, aid in the design of training programs, provide a further avenue for communication between support staff and athletes and coaches and ultimately enhance an athlete's performance.

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