Tools to Monitor Neuromuscular Fatigue

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Contributor: Javier Peña , Dani Moreno , Claudia Alba Jimenez , Stephanie Feleus

Neuromuscular fatigue (NMF) is a reduction in the maximal voluntary force induced by exercise, with neuromuscular function changes that are due to repeated or sustained muscular contraction, and that are produced either at the peripheral or central levels, and that can be detected for upwards of 48 h to an extended period. An accumulation of work or an incomplete force restoration can significantly influence the neuromuscular performance in both the short and long terms. Thus, fatigue management is essential for controlling the training adaptations of athletes and reducing their susceptibility to injury and illness. The main individualized monitoring tools used to describe fatigue are questionnaires and subjective assessments of fatigue, biochemical markers, sprint tests, and vertical jump tests. Among the subjective measures, the rating of the perceived exertion has been widely used because of its simplicity and high validity. In terms of the objective measures, one of the more frequently employed tools by practitioners to assess neuromuscular fatigue is the countermovement jump. Because of its high validity and reliability, it is accepted as the reference standard test in sports, in general, and particularly in team sports.

monitoring neuromuscular fatigue sports

1. Background

The accumulation of fatigue or incomplete recovery can significantly influence the team sports performance, especially during regular competition with a congested fixture calendar, which can have acute and chronic harmful effects (**Figure 1**). If the fatigue sustained by players and their recoveries are not managed correctly, athletes can potentially be placed at a higher risk of impaired performance, or at a more significant risk of injuries [1][2]. Although NMF control is necessary, the time needed to recover the neuromuscular function fully is not well established. In the long term, it has been reported that 24–48 h of recovery are necessary to return the measures of the sprint and vertical jumps to their neuromuscular function baselines. Other research shows that the vertical jump performance is reduced post-match, and that recovery requires at least 72 h [3][4][5]. This decrement in function can last for up to four days after a demanding competition [1]. Furthermore, the results imply that different individuals show relevant differences in their recovery profiles because the recovery time after a stimulus can have an individual component [6]. Therefore, personalized recovery strategies in sports are needed because some athletes benefit more from using recovery strategies than others to restore their physiological values [7]. Psychological factors also seem to play a pivotal role in recovery in the enhancement of the subsequent performance in actions such as sprints [8]. Overall, these studies reinforce the importance of individualized monitoring. To illustrate the use of tests to understand the NM status, researchers want to highlight the work from Jimenez-Reyes et al. [9], which used a vertical jump test to individualize training doses.

After fatiguing exercise, the time course and short-term recovery mechanisms are largely dependent on the properties of the previous exercise bout and the recovery time [10]. Balsom et al. [11][12] investigated the relationship between different durations of successive bouts of work, different between-set recovery times, and fatigue in two scientific works. First, they modified the working time (15, 30, and 40 m) while maintaining the recovery time between bouts. The authors concluded that a 30-s resting period is enough to recover from the 15-m repetitions, while significant performance reductions were detected in the other two distances. Second, they modified the resting time (30, 60, and 120 s) using a fixed-distance sprint (40 m), and they found that 30 s was insufficient to maintain the performance, while 60 and 120 s allowed the athletes to maintain acceleration and limit the drop in the performance in the last 10 m. Hence, aerobic metabolism plays an essential role after high-intensity intermittent training by restoring homeostasis during short-term recovery periods, which minimizes the drop in the neuromuscular performance [13].

The purpose of the review is to describe the information available about the effect of neuromuscular fatigue on the sports performance, decreasing the motor control, and, consequently, the sports injuries. The existing methods to evaluate this marker and assess fatigue in high-performance contexts are proposed for the control of the training load and a better recovery.

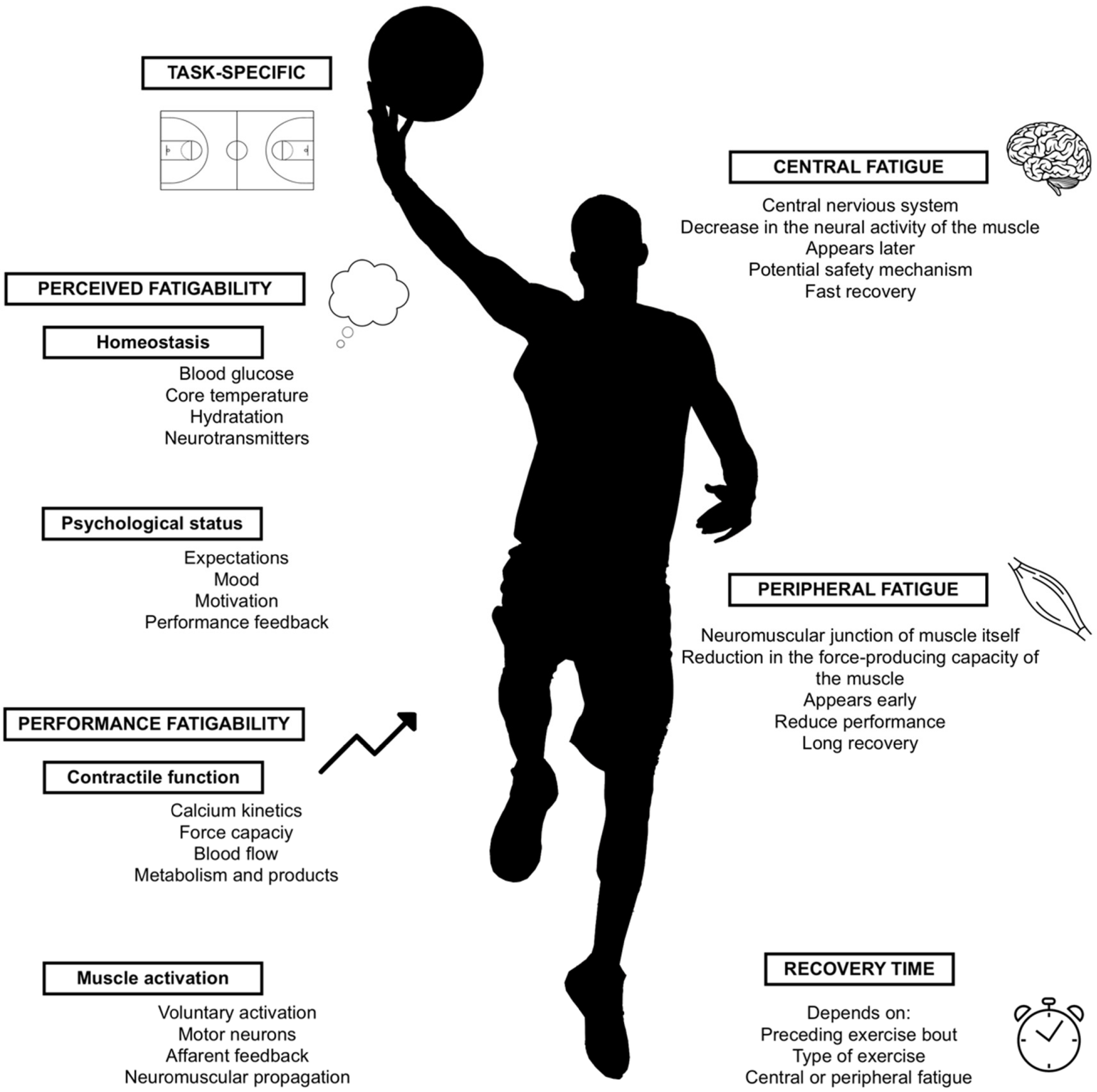

Figure 1. Sources and types of fatigue.

2. Athlete Self-Report Measures: Questionnaires and Subjective Assessments of Fatigue

The management of fatigue is essential for controlling the athletes' training adaptations, for ensuring that they are ready for competition, and for reducing their susceptibility to injury and illness. In team sports, a reliable tool to monitor fatigue should be sensitive to the training loads and their magnitudes, and should differentiate the acute responses to exercise from the chronic changes [14].

The psychobiological state by prolonged periods of demanding cognitive activity (or mental fatigue) affects the individual perception of fatigue [15]. Mental fatigue drives athletes to downregulate their exercise capacity, which is known to be the maximum amount of physical exertion that an athlete can sustain [16]. Therefore, measuring these subjective markers is necessary to better understand NMF and recovery [17]. A recent survey on the use of fatigue-monitoring tools on high performance athletes in team-sport settings describes a high acceptance of the self-report questionnaires in various disciplines and competition levels to assess overall well-being [18]. The validated self-report forms are custom-designed forms, such as the Profile of Mood States Questionnaire (POMS), or the Recovery-Stress Questionnaire for Athletes (REST-Q), which are among the most widely used, and which may assist staff in monitoring the complex psychophysiological stress associated with high degrees of fatigue and poor recoveries [17]. The most regularly used is the rating of perceived exertion (RPE). The RPE is derived from a psychophysical process combining multiple sensations and feelings of physical stress, discomfort, and fatigue during exercise or physical activity [19]. Impellizzeri et al. [20] correlated the RPE with various methods to determine the internal training load, and they observe that it is a good indicator for it. This method may assist in the development of specific periodization strategies for individuals and teams. However, something relevant is that when questionnaires are implemented daily, their length should be considered. Many team sports practitioners prefer shorter and simpler questionnaires to minimize time constraints, which is more time-efficient when they have to be completed daily [17][21][22]. Implementing daily wellness questionnaires into an athlete monitoring program, such as the PAR-Q, requires time, but the RPE is a quick way to know the NM statuses of the athletes. A current study shows that a customized wellness questionnaire that encompasses the sleep quality, fatigue, muscle soreness, and mood on a 1–5 Likert scale produced an acceptable interday reliability, with a coefficient of variation (CV) of 6.9% [21]. Against this, some coaches raise concerns about the subjectivity and individual dimensions of these measures, as well as the scope for athletes to manipulate the responses to facilitate favorable outcomes [17]. Brito, Hertzog, and Nassis, in an article published in 2016 that assesses how the contextual variables influenced the training loads of highly trained soccer players under the age of 19, and they identified that the fatigue scores were inaccurate when using the sessional RPE (sRPE), and detected meaningful differences during the season. The individual fatigue scores that were reported varied significantly inside the microcycles [23]. The explanation for these inaccuracies may come from the fact that the perception of effort is very multidimensional and is determined by physiological, psychological, and experiential factors, as was determined by Morgan in a classic piece of research on the psychological components of the effort sense that was published in 1994 [24]. Moreover, the assessment of fatigue can be provided by the coach [25]. The performance markers can assist the coaching staff when an athlete is in a state of fatigue or recovery. There are available a multitude of fatigue markers to inform the coaching staff, and while the research in this area is plentiful, no single reliable diagnostic marker has been identified.

3. Biochemical Markers

The acute responses and recovery times after practices and competitions can be assessed using diverse biochemical, hormonal, and immunological markers that are measured from the blood or saliva [17]. The endocrine system plays a relevant role when periodizing the workloads of athletes, which involves optimizing the training adaptations and avoiding further fatigue [26].

The most used biochemical markers to evaluate the responses to different workloads, training stresses, and recoveries are testosterone and cortisol [21]. Testosterone is an anabolic hormone, which plays a critical role in muscle hypertrophy and muscle glycogen synthesis [27], and it is also a neural facilitator that could affect the motor unit excitability [28]. Cortisol is a stress hormone, and is an indicator of the endocrine system's response to exercise [26]. The independent responses to cortisol and testosterone have been widely studied, along with the changes in the anabolic–catabolic balance, or the testosterone:cortisol ratio (T:C), which are often observed [25]. The T:C ratio represents the imbalance between the anabolic and catabolic states, or the response to the training load, and it has been widely employed as a physiological signal to determine the anabolic and catabolic activity during increased workload periods [29]. It is hypothesized that an increase in the training load will decrease the T:C ratio, which shows an imbalance in the anabolic and catabolic responses [30]. A lowered T:C ratio means that players endure a catabolic hormonal profile for up to 24 h after a game. Thus, the relationship between testosterone and cortisol has been used as evidence of increased anabolic and catabolic activity during periods with high training loads, with the data indicating that decreases of 30% or over are the relevant markers of overreaching [29]. Creatine kinase (CK) is another relevant fatigue marker in athletes and players [21][25]. The CK enzyme is stored inside the muscle cells, but it is often released into the bloodstream after heavy exercise, which indicates muscle damage. Although the evidence appears compelling for CK's use as a fatigue-monitoring tool in team sports, large individual variability in the resting CK levels exists, which makes it problematic to measure the changes induced by training [21]. CK has also shown large individual variability, with a high day-to-day variation of nearly 27% [17]. After all, several measures display low reliability and substantial intraindividual differences, which makes it challenging to obtain accurate measurements [25]. Moreover, the time, cost, and expertise required for the data collection and analysis are all high, the analysis is time-consuming, and there is generally a relatively long lag time to obtain feedback. These methodological limitations limit their use in high-performance environments and potentially impair the usefulness of such markers in a cyclic fatigue-monitoring system. The precise control of the previous exercise, the time of the day, the diet, the presence of injuries, the inconvenience of taking venipuncture blood samples, the possible unwillingness of some players to be subjected to invasive tests, and the relatively high cost associated with laboratory analysis, make this method difficult to implement in a practical training environment [25]. Moreover, the temporal relationships to the neuromuscular performance are not well established yet, and the multifaceted nature of fatigue makes it difficult to rely on a single biochemical, hormonal, or immunological marker [17].

4. Surface Electromyography

Electromyography (EMG) refers to the collective electric signal from the muscles controlled by the nervous system that is produced during muscle contraction [31]. The EMG signal results from many physiological, anatomical, and technical factors. Proper detection methods may manage the effects of some of these factors, but others are not easily regulated with the current technology, and their potential effects on the signals may only be surmised and considered [32]. There are two types of EMG signals: surface EMG and intramuscular EMG. Surface EMG (sEMG) is preferable when obtaining information about the time or intensity of the superficial muscle activation with noninvasive electrodes [31]. The sEMG signal is used as an indicator of the muscle activation for its relationship to the force produced by a muscle, and as an index of the fatigue processes occurring within a muscle [32]. Thus, sEMG signals are related to the skeletal musculature's biochemical and physiological changes during fatiguing contractions [33]. It is also applicable to the study of static actions that require a muscular effort of a postural type, but its use is limited to those involving dynamic movements. Dynamic actions have to be synchronized with the recording of the other measurement systems that provide the cinematic data as a camera [34]. Its principal advantages are its noninvasiveness, its applicability in situ, the real-time fatigue monitoring during the performance of the defined work, the ability to monitor the fatigue of a particular muscle, and the correlations with the biochemical and physiological muscle changes during the fatiguing [33]. It is evident that sEMG has several advantages, but it has severe reliability problems, and it is still challenging to validate the relationships observed between the sEMG parameters and the physiological events. The lack of standards for the sensors, configurations, electrode placement, and recording protocols has adversely affected the possibility of its integration into the team sport context [35].

5. Sprinting Ability

Sprint tests have been widely used to describe the NMF of athletes and their performances in various sports, and most of them use similar sprint distances, such as 5, 10, and 20 m [6][17][21][36][37][38][39]. Very large correlations have been found between the speed loss and the lactate (r = 0.83) and ammonia (r = 0.86) concentrations when the metabolic responses to the sprint training are focused on maintaining a maximal speed until a given speed loss is reached [9]. These findings support the use of sprint tests as an excellent tool for determining the fatigue responses because of their agreement with the physiological gold-standard measures. Different sprint distances have been studied to improve understanding of how NMF and performance interact. Thus, the type of sprinting (running, rowing, skiing, or leg or arm cycling), the number of sprints, the length of each sprint, the time to recover between sprints, and the work-to-rest ratios of a sprint have been analyzed. These factors may vary the sprint performance, thus affecting the NMF interpretation. Using task-specific parameters may help to understand the development of NMF when responding to a repeated sprint exercise in a given sport [40]. Hence, many authors agree that this drill is the most task-specific measure of NMF [17][36][38][39]. According to Marrier et al. [38], in team sports, such as rugby sevens, sprint accelerations and decelerations are more frequent than vertical jumps (VJ). Sprint tests rely primarily on the concentric muscle action, whereas the VJ fundamentally relies on a stretch-shortening cycle (SSC) [39]. A running test could be more sensitive to neuromuscular status changes than a jump test because of the higher task-specific nature. Garret et al. [36] observed this trend in Australian Football, a predominantly running sport. Surprisingly, the authors found similar results between the sprint test and the vertical jump tests, which shows an alternative method of assessing the neuromuscular function in high-performance athletes. In basketball, the sprint speed has been identified as a relevant attribute; specifically, 5 m of sprint time showed a moderate inverse relationship to the playing time in the NCAA Division II competition. Thus, monitoring the athletes' acceleration abilities can be a more suitable method of identifying fatigue, in opposition to the maximal speed. The sprint performance could be considered a valid tool for the assessment of NMF in sports where sprints are specific to the task [9]. Since it does not cause excessive fatigue, it is easy to administer as a part of the warm-up, and it can be applied to large groups of athletes concurrently in a different number of environments and settings, i.e., indoors and outdoors, which increases its ecological validity [36]. However, some authors report that the sprint performance was less sensitive as a fatigue marker compared with the CMJ, which suggests that its use to profile recovery is limited [6].

6. Vertical Jump Tests

The benefit of vertical jumps as a practical measure of NMF is indicated by the high degree of the adoption of these testing procedures in high-performance sports settings. These tests have been used in many studies to investigate the recovery times from demanding practices or competitions [18]. Vertical jump tests are practical, well accepted by elite players, and are valid and reliable, which makes them potentially valuable for detecting and quantifying fatigue in in-field conditions [41].

Several Vertical Jump Tests Exist [42], and among them, the countermovement jump (CMJ) is more frequently used to assess the jumping performance and the neuromuscular status. The CMJ is one of the main tools used to examine the level of the neuromuscular status in elite sports. Because of its reliability and validity, the CMJ test has become the “gold standard” test for monitoring neuromuscular fatigue in high-performance sports settings [43]. Apart from the jump height, the vast number of variables exhibiting acceptable reliability suggests that the CMJ strategy and the output remain stable during and across multiple days. This stability may be attributed to the athletes regularly performing multiple jumps and SSC activities, such as COD through training and competition, which results in more reproducible movement patterns.

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