Recovery and Performance in Sport: Consensus Statement

Abstract

The relationship between recovery and fatigue and its impact on performance has attracted the interest of sports science for many years. An adequate balance between stress (training and competition load, other life demands) and recovery is essential to achieve continuous high-level performance of athletes. Research has focused on the examination of physiological and psychological recovery strategies to compensate external and internal training and competition loads. A systematic monitoring of recovery and the subsequent implementation of recovery routines aims to maximize performance and to prevent negative developments such as underrecovery, non-functional overreaching, the overtraining syndrome, injuries, or illnesses. Due to the inter- and intra-individual variability of responses to training, competition, and recovery strategies, a diverse set of expertise is required to address the multifaceted phenomena of recovery, performance and their interactions to transfer knowledge from sports science to sports practice. For this purpose, a symposium on *Recovery and Performance* was organized at the Technical University Munich Science and Study Center Raitenhaslach (Germany) in September 2016. A range of international experts from many disciplines and research areas gathered to discuss and share their knowledge on recovery for performance enhancement in a variety of settings. The results of this meeting are outlined in this consensus statement that provides central definitions, theoretical frameworks, as well as practical implications as a synopsis on the current knowledge of recovery and performance. While our understanding of the complex relationship between recovery and performance has significantly increased through research, we also elaborate some important issues for future investigations.

Keywords: load; monitoring; enhancement; physiological; psychological; review

Definition of central terms

Recovery is regarded as a multifaceted (e.g., physiological, psychological) restorative process relative to time. In case an individual's recovery status (i.e., their biopsychosocial balance) is disturbed by external or internal factors, fatigue as a condition of augmented tiredness due to physical and mental effort develops.[1] Through recovery, fatigue can be compensated, thereby regaining the organismic allostatic balance by re-establishing the invested resources on a physiological and psychological level.[2] Recovery is an umbrella term, which can be further characterized by different modalities of recovery such as regeneration or psychological recovery strategies.

Regeneration in sport and exercise refers to the physiological aspect of recovery and ideally follows training or competition induced physical fatigue.[3] Frequently applied and scientifically evaluated regeneration approaches encompass strategies such as cold water immersion (CWI) and sleep.[4] In contrast, mental fatigue (i.e., cognitive exhaustion) can mainly be compensated through psychological recovery strategies such as cognitive self-regulation, resource activation, and psychological relaxation techniques.[3,5]

Furthermore, Kellmann[2] distinguishes between passive, active, and pro-active approaches to recovery. Passive methods may range from the application of external methods (e.g., massage) or implementing a state of rest which is characterized by inactivity. Active recovery (e.g., cool-down jogging) involves mainly physical activities aimed at compensating the metabolic responses of physical fatigue. Pro-active recovery (e.g., social activities) implies a high level of self-determination by choosing activities in light of individual needs and preferences.[3,6]

A certain degree of fatigue resulting in functional overreaching (FO) is required for performance enhancement and can be compensated through comprehensive recovery. FO describes a short-term decrement of performance without signs of maladaptation as a consequence of intensive training. In case systematic and individualized recovery is not achieved after training and FO, a continuous imbalance of inadequate recovery and excessive demands could initiate a cascade of deleterious conditions including underrecovery and non-functional overreaching (NFO). Underrecovery and NFO represent two closely related, though slightly different concepts. While underrecovery appears to delineate a broader condition of insufficient recovery in reaction to general stress (e.g., family, media), Meeusen et al.[7] characterize NFO as training-specific negative psychological and hormonal alterations and subsequent decreased performance. Continuous underrecovery and NFO often serve as a precursor of the overtraining syndrome (OTS). An accumulation of underrecovery in terms of daily life demands together with long-term NFO in training and competition settings ultimately manifest in the OTS. The OTS is marked by physical symptoms such as continuous muscle soreness, pain sensations or clinical and/or endocrinological disturbances. Underrecovery and early-stage NFO can be compensated by a systematic application of recovery strategies and rest, alongside lifestyle-related strategies like sleep, diet, and social activities. However, recovering from the OTS requires a continuous restoration together with long rest and recovery periods lasting from weeks to months accompanied by reduced performance.

Performance can be defined as the accomplishment of goals by meeting or exceeding predefined standards.[8] The multidimensional concept of performance is linked to physiological and psychological influences in a reciprocal manner. The concept describes individual or collective patterns of behavior depending on a set of skills, abilities, and specific performance conditions. Performance is therefore determined by the development of specific skills and abilities to adapt to unexpected environmental influences, and the continuous and reliable delivery of these skills and abilities in competitive situations.[3,8] Performance in turn can be affected by physiological capacities, such as endurance, strength, speed, or flexibility.[1,9] Psychologically, factors such as concentration, motivation, and volition may also affect performance.[5]

Recovery and fatigue can be considered on a continuum, and are jointly affected by physiological and psychological influences of restoration and depletion. An imbalance of long-term fatigue and insufficient recovery initiates an unfavorable development, resulting in negative consequences such as underrecovery, NFO, or the OTS. Ultimately, a long-term decrement of performance and well-being may manifest.[7]

Assessment of recovery

Due to the multifactorial nature of recovery, the assessment of the recovery-fatigue continuum should be relative to the demands of the sport. While performance measures represent the most sports-specific outcomes, other physiological and psychological measures provide integral information on an athlete’s recovery and biophysical balance.

Performance can be characterized by competition outcomes or the perceptions of the coaching staff, though often important maximal physical capacities are used as surrogates.[4] However, imposing a maximal sport-specific task to test the readiness to perform may be deemed counterproductive. Given the practical constraints and ambiguity of performance measures, sports scientists rely on feasible and simple measures, such as tests of peak power in jumping-lifting tasks or sub-maximal efforts in set-intensity tasks.[10] These measures exemplify convenient proxies where established gold-standard measures of performance are not available or are impractical. In light of these limitations, it is crucial to understand the ecological and construct validity of the proxy performance task together with measurement accuracy (i.e., sensitivity and specificity). This knowledge is critical for developing a performance-relevant task to interpret the state of recovery and fatigue.[10] A thorough understanding of recovery can only be garnered from controlled testing in recovered and fatigued states (i.e., sensitivity to load), regardless of laboratory or field environments. More importantly, tests require practicality in combination with athlete belief of the task relevance to competitive performance outcomes.

Physiological markers are used to infer the extent of disruption of allostasis caused by the training or competition loads. These physiological measures of recovery should interfere minimally with the training process and be based on a clear physiological rationale related to the recovery-fatigue continuum. A common method involves the monitoring of the autonomic nervous system via measures of heart rate (HR) and/or heart rate variability (HRV) at rest or following exercise.[11] This method has been of increasing interest due to the non-invasive, time-efficient, and inexpensive applicability to a large number of athletes.[12] Correct interpretations need to consider variations in the training phase and/or load, as well as the individual error of measurement and the smallest worthwhile change.[12] Alterations in blood-based variables also characterize a prevalent approach as blood lactate is often assessed to monitor recovery and fatigue, although its appropriateness is still debated.[12] Several markers of damage, inflammation or stress, such as creatine kinase (CK), urea nitrogen, salivary cortisol, free-testosterone and/or IGF-1 have further been investigated. CK has been proposed as a reliable marker in team sports,[4,13] while urea nitrogen provides promising results in endurance-based sports.[13] However, their usefulness on a regular basis remains unclear, as these measures are prone to a large inter- and intra-individual variability in both baseline values and the post-exercise response.[13,14] To overcome this shortcoming, gradual individualization of reference ranges based on a Bayesian approach has been proposed.[15]

Despite the importance of performance and physiological markers, the perception of an athlete's readiness to perform describes a critical determinant of recovery. Commonly applied psychological measures of individual responses to acute and chronic training load encompass the Rating of Perceived Exertion (RPE[16]), the Profile of Mood States (POMS[17]), and the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport[18]). RPE and its derivative, the session-RPE[19], represent measures of intensity (rather than load) whilst the POMS can be rather categorized as a reflective response measure to training load and other stimuli.

The RESTQ-Sport gauges the frequency of both current stress symptoms and recovery-associated activities/states of the previous three days/nights and addresses both nonspecific and sport-specific areas of stress and recovery. The questionnaire includes 76 statements divided into seven general stress scales (e.g., *General Stress*), five general recovery scales (e.g., *Physical Recovery*), three sport-specific stress scales (e.g., *Emotional Exhaustion*), and four sport-specific recovery scales (e.g., *Self-Regulation*). In addition, the Rating-of-Fatigue (ROF) scale[20], the Acute Recovery and Stress Scale (ARSS)[21] as well as the Short Recovery and Stress Scale (SRSS)[21] have recently been developed as short and economic measures of recovery and stress. While the ROF may serve as an innovative instrument to register fatigue in various settings, the ARSS and SRSS qualify for a longitudinal assessment of the acute recovery-stress state in applied settings.[22] Overall, psychological measures of athlete recovery are characterized by their sensitivity and feasibility and represent an important component of the recovery-fatigue monitoring process.[14] Within the larger scope of a conceptual framework of recovery assessment, the primary challenge stems from the multifaceted nature of the recovery-fatigue continuum. Any single physiological or psychological parameter will only highlight an isolated aspect of recovery and fatigue. Multivariate approaches should be employed to assess post-exercise recovery, combining physiological and psychological measures on a formal or informal level.

Training-recovery-performance models

Monitoring of the recovery-fatigue continuum represents the first step towards performance enhancement. Based on a systematic and comprehensive monitoring of training and competition loads, interventions need to be derived and established to maximize performance. Both training and recovery activities can be manipulated by coaches to produce specific physiological and psychological outcomes. While recovery may refer to short-term, mid-term or long-term restoration, a clear categorization based on specific time frames cannot be provided due to the high intra- and inter-individual variability of the recovery process. The required amount of time for recovery from training-induced fatigue and stress may differ within and between the different organismic systems of the human body.[2] Meeusen et al.[7] suggest that short-term recovery interventions (e.g., power nap) are applied during periods of heavy or intensified training to allow athletes to maintain training quality and physical performance levels. While this approach has shown to be effective in the short-term,[1] the efficacy of this approach over the longer term and in combination with other mid- or long-term recovery interventions (e.g., extended periods of night sleep) remains unknown. Muscle damage, metabolic responses, inflammation, and associated fatigue resulting as a consequence of intensified training are considered to be important drivers of adaptation, although chronic use of short-term recovery activities[2] may blunt these effects.

At present, it remains unclear if the long-term application of short-term recovery interventions positively affects performance. Recovery interventions between sessions may lead to greater recovery in athletes (i.e., less soreness and fatigue) and increased subsequent training quality.[23,24] In contrast, even negative effects may occur due to repeated blunting of training adaptations. Recent studies have shown that recovery interventions (e.g., CWI) may diminish physiological and performance adaptations to resistance training,[25] while others have indicated performance benefits[1] and amplified physiological responses with endurance exercise tasks.[26] CWI resulted in acceleration of parasympathetic reactivation compared to active recovery after a constant velocity exhaustive test in athletes participating in intermittent sports (e.g., football, basketball).[27] The conflicting results may be attributed to differences in training status, exercise mode (e.g., resistance vs. endurance), specific outcome measures, and the CWI interventions used in these studies. Potential short-term recovery benefits, but undetermined long-term adaptation and performance effects, also apply to other popular recovery interventions (e.g., contrast water therapy, stretching, whole body cryotherapy, compression garments, massage, intermittent pneumatic compression, electrostimulation, sauna, far-infrared therapy). The outcomes emphasize that the efficacy of specific recovery interventions needs to be determined in the context of the athlete, their schedule, and the current and long-term training goals.

In concordance with established periodization approaches in training, recovery activities should also be periodized and modified to meet the individuals' specific needs. While there is little empirical information regarding the periodization of recovery interventions, fundamental assumptions are important to guide an individualized recovery approach. Recovery activities can be tailored to the nature of the present stressors, with greater need for mid- and long-term psychological recovery interventions following mentally fatiguing tasks. After activities that induce a high level of muscle damage, recovery should be adapted accordingly, resulting in interventions (e.g., change of environment, exercise, sleep) to reduce pain, inflammation, and soreness. If amplification of training stress (i.e., increased fatigue) is indicated, increased training load and fewer recovery activities might be prescribed during periods when performance capacity is less important (e.g., preseason/preparatory training periods). Conversely, lower training loads and targeted recovery activities may be required before competitions to initiate dissipation of training fatigue to facilitate maximum performance.

An improved understanding of athletes' individual interactions between training, recovery, and performance may assist coaches/scientists in determining the necessity of specific recovery activities. These interactions can be generally explained by the fitness-fatigue model which describes the relationship between training load, positive (fitness) adaptations, and negative (fatigue) adaptations.[28] According to this model, performance can be estimated from the difference between the fitness and fatigue reactions to training. An athlete's fitness is thereby operationalized by the positive influence of long-term training, while the negative response is explained by the acute fatigue responses to recent training stimuli. Due to the inter- and intra-individual responses to fitness and fatigue, direct monitoring of fitness and fatigue responses has emerged as common aspect of scientific support for high performance athletes.[3] The appropriate application and interpretation of available monitoring tools fosters a goal-oriented processing of the obtained information to guide decisions on training content and recovery activities for individual athletes. Additional work is required in this area to link athlete monitoring to meaningful recovery activities for individual athletes in a reliable manner. Furthermore, holistic training-recovery-performance models using an integrated and idiographic psychophysiological approach are advocated.[3]

Monitoring approaches for training and recovery

Athletes and coaches are taking an increasingly scientific approach to designing training programs and monitoring adaptation. Training load and recovery monitoring can contribute to assess an athlete's adaptation and ensure an adequate recovery-stress balance. The actual aim is to enhance performance and minimize the risk of developing NFO, the OTS, illness, and/or injury.[29,30]

Training monitoring should include assessment of both external and internal loads. The external training load defines an objective measure of the work that an athlete completes during training or competition. The internal load describes the biological stress imposed by the training session and is characterized by the disturbance in homeostasis of the physiological and metabolic processes during the training session.[9]

To gain an understanding of the training load and its effect on the athlete, a number of training load indicators have been introduced, but strong scientific evidence supporting their applicability is often lacking.[31] Monitoring tools to quantify external loads include for example power output measuring devices and time-motion analysis. Internal load measures encompass the perception of effort, oxygen uptake, HR derived assessments, blood lactate, training impulse, neuromuscular function, biochemical/hormonal/immunological assessments, questionnaires and diaries, psychomotor speed, as well as sleep quality and quantity.[14,32] An incongruence between external and internal load units may reveal the current recovery-fatigue continuum of an athlete.[1]

Once coaches and sport scientists have chosen their monitoring tools based on validity, reliability, accessibility, and acceptance by their athletes, criteria to determine changes in load, performance, or recovery need to be established to build a reliable decision-making process.[33] Change can be defined as a valid confirmation of an improvement or a deterioration of a measure over a given time span due to interventions.[34] Reliability outlines a key feature in tracking change and reflects the degree to which repeated measures vary for individuals and can be assimilated as measurement error. Several statistical approaches can account for measurement error in the follow-up of athletes, including the smallest worthwhile change or the Z-score.[34] Alternatively, if repeated measurements of the respective athlete are available, group based reference ranges may be developed using Bayesian methods.[15] In case the individual history of data is not available (e.g., when athletes transfer between teams), an alternative reference is needed. Under these circumstances, the mean of a healthy group can be calculated with upper and lower boundaries based on the standard deviation. This provides information on how an individual compares to the rest of the group. However, coaches and sport scientists should be aware that the choice of appropriate monitoring tools and statistical procedure only delineates a cornerstone of their follow-up system. Monitoring systems should be intuitive, provide efficient strategies for data analysis and interpretation, and enable efficient reporting and visualizing of simple, yet scientifically valid feedback.[1] Concurrent assessments of the various quantification methods allow researchers and practitioners to evaluate the recovery-stress balance, adjust individual training programmes and determine the relationships between external load, internal load, and athletes' performance.[32]

Consequences for coaches and athletes

Strategies to enhance recovery should be implemented as a means to compensate internal and external loads. Since recovery-related activities often take place outside the formal training setting, the evaluation of individual differences appears to be extremely difficult for coaches and may even result in a mismatch between coaches' and athletes' perception of recovery.[35] It seems that coaches tend to overestimate the need for recovery of their athletes. This misjudgment increases the longer athletes and coaches are separated, which highlights the importance of coordinated and prospective recovery monitoring. The establishment of an effective monitoring routine ideally results in meaningful individualized interventions that consider the potpourri of psychophysiological demands placed on athletes in different training and non-training situations as well as in competition settings. Factors such as the type of sport, the training phase of the year,[36] type of training performed and level of participation[37] exemplify situations athletes are confronted with.[38] Traditional ways of training and competing have revolved around work-based training, with performance challenges solved by simply increasing training load. However, periodization of the season should be addressed especially during the competition and tapering phases to reach high levels of preparedness within athletes.[39] Recovery should be programmed as an integral component of training via the implementation of recovery microcycles and recovery strategies.[39] Since psychological problems are frequently related to underrecovery, the integration of efficient recovery into athletes' training and competition routines appears to be a buffer against psychological problems such as burnout and depression.[3]

In this context, sleep plays an essential role in recovery with regard to physical and psychological recovery as well as general well-being. Athletes should understand their sleep needs and should be educated regarding aspects such as sleep hygiene and potential positive effects of sleep extension.[40] Furthermore, a range of specific recovery methods are available and could be systematically incorporated into the athlete's training program at various times to foster recovery on different levels. Individual and situation-specific recovery strategies should be selected to address the recovery needs of the athlete in line with their psychological perception of the value.[2] Self-regulation skills play an important role in the process of recovery enhancement and should be learned and practiced to facilitate the realization and efficiency of recovery programs within sports.[5]

Considering the implementation of recovery strategies in team settings, an individualized approach to the use of recovery modalities should be promoted. Athletes should engage in a combination of recovery modalities since this method appears to result in the most rapid rates of recovery and continuous high-level performance.[3,5] Behavioral and cognitive underpinnings of all parties involved (i.e., coaches, athletes, researchers, policy makers, and healthcare professionals) should be considered when designing recovery interventions. The ideal recovery routine would consist of a positive perception of recovery while also addressing the appropriate physiological and psychological mechanisms necessary to effectively recover from training.

In applied settings, successful implementation of a system to identify and monitor the recovery-fatigue continuum depends on cooperation of a multidisciplinary team. The commitment and agreement regarding the elements and strategies of monitoring should be acquired from participating parties (e.g., coaches, sport scientist, sport psychologist, etc.) to ensure a high quality of the overall process. Coaches should consider monitoring and recovery management as a reasonable addition to their training routine. Communication represents a key factor in this interplay, while regular meetings and the exchange of ideas may foster an atmosphere of compliance and meaningfulness to obtain a common goal. With regard to their athletes, coaches should be aware that engagement in recovery activities should be contemplated as supportive instead of burdening. The improvement of performance is not achieved through a high quantity of recovery activities, but rather through a high quality, well-matched, and individualized approach to recovery. A cycle to improve recovery might encompass: debriefing, smiling (or laughing), restoring, and restarting.

Conclusion

The measurement and monitoring of recovery and fatigue in training and competition contexts is a complex task. Expertise in physiology, psychology, and sport science is required to enable a high quality of the overall process. We propose some general recommendations which may contribute to successful implementation of a monitoring routine to maintain and enhance recovery in sports. During the planning phase of the monitoring routine, training and competition related goals should be set in close cooperation with athletes and the coaching staff. Recovery should be prescribed in light of the current period of the season depending on the nature of the applied training stimulus (e.g., muscle damaging vs. cognitively fatiguing vs. metabolically demanding). This approach connects to the topic of individualization of recovery monitoring in sports. Individualized measurement of recovery should be followed by an individualization of recovery methods according to athletes' situation-specific needs.

Therefore, the individualization process represents one of the most pivotal and challenging tasks in current monitoring research and practical environments. Periodization of training loads and recovery activities to promote adaptation and/or performance outcomes over longer periods (i.e., > 6 months) can only be achieved by referring to individual long-term data. Based on those collected data, tools and screenings to direct the selection of evidence-based recovery activities can be developed. Future recovery studies should develop holistic models to derive practical rules for diagnostic, intervention and evaluation purposes.

References

1. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med.* 2014;44:139-147.
2. Kellmann M. *Enhancing recovery: Preventing underperformance in athletes.* Champaign, IL: Human Kinetics; 2002.
3. Kellmann M, Beckmann J, eds. *Sport, recovery and performance: Interdisciplinary insights.* Abingdon: Routledge; 2018.
4. Nédélec M, Mc Call A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer. Part I – Post-match fatigue and time course of recovery. *Sports Med.* 2012;42: 997-1015.
5. Beckmann J, Elbe A. *Sport psychological interventions in competitive sports.* Newcastle, UK: Cambridge Scholars Publishing; 2015.
6. Venter RE, Potgieter JR, Barnard JG. The use of recovery modalities by elite South African team athletes. *S Afr J Res Sport Phys Educ Recreation.* 2010;32:133-145.
7. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc.* 2013;45:186-205.
8. Portenga ST, Aoyagi MW, Cohen AB. Helping to build a profession: A working definition of sport and performance psychology. *J Sport Psychol Action.* 2017;8:47-59.
9. Lambert MI. Quantification of endurance training and competition loads. In: Mujika I, ed. *Endurance Training: Science and Practice*. Vitoria-Gasteiz, Basque Country: Iñigo Mujika S.L.U.; 2012:211-228.
10. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. The Influence of changes in acute training load on daily sensitivity of morning-measured fatigue variables in elite soccer players. *Int J Sports Physiol Perform.* 2017;12:107-113.
11. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sports Med.* 2013;43:773-781.
12. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front Physiol.* 2014;5:1-19.

13. Hecksteden A, Skorski S, Schwindling S, et al. Blood-borne markers of fatigue in competitive athletes - results from simulated training camps. *PloS one.* 2016;11:e0148810.

14. Saw AE, Main LC, Gastin PB. Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *Br J Sports Med.* 2016;50:281-291.

15. Hecksteden A, Pitsch W, Julian R, et al. A new method to individualize monitoring of muscle recovery in athletes [published online ahead of print December 14, 2016]. *Int J Sports Physiol Perform.*

16. Borg G. *Borg's Perceived Exertion and Pain Scale.* Champaign, IL: Human Kinetics; 1998.

17. McNair DM, Lorr M, Droppleman LF. *Revised manual for the Profile of Mood States.* San Diego, CA: Educational and Industrial Testing Service; 1992.

18. Kellmann M, Kallus KW. The Recovery-Stress Questionnaire for Athletes. In: Kallus KW, Kellmann M, eds. *The Recovery-Stress Questionnaires: User manual*. Frankfurt: Pearson; 2016:89-134.

19. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15:109-115.

20. Micklewright D, St Clair Gibson A, Gladwell V, Al Salman A. Development and validity of the rating-of-fatigue scale. *Sports Med.* 2017;47:2375-2393.

21. Nässi A, Ferrauti A, Meyer T, Pfeiffer M, Kellmann M. Development of two short measures for recovery and stress in sport. *Eur J Sport Sci.* 2017;17:894-903.

22. Pelka M, Schneider P, Kellmann M. Development of pre- and post-match morning recovery-stress states during in-season weeks in elite youth football [published online ahead of print October 4, 2017]. *Sci Med Football.*

23. Vaile J, O'Hagan C, Stefanovic B, Walker M, Gill N, Askew CD. Effect of cold water immersion on repeated cycling performance and limb blood flow. *Br J Sports Med.* 2011;45:825-829.

24. Stanley J, Peake JM, Buchheit M. Consecutive days of cold water immersion: Effects on cycling performance and heart rate variability. *Eur J Appl Physiol.* 2013;113:371-384.

25. Roberts LA, Raastad T, Markworth JF, et al. Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. *J Physiol.* 2015;593:4285-4301.

26. Ihsan M, Watson G, Choo HC, et al. Postexercise muscle cooling enhances gene expression of PGC-1alpha. *Med Sci Sports Exerc.* 2014;46:1900-1907.

27. Bastos FN, Vanderlei LC, Nakamura FY, et al. Effects of cold water immersion and active recovery on post-exercise heart rate variability. *Int J Sports Med.* 2012;33:873-879.

28. Banister EW, Calvert TW, Savage MV, Bach T. A systems model of training for athletic performance. *Aust J Sports Med Exerc Sci.* 1975;7:57-61.

29. Brink MS, Visscher C, Arends S, Zwerver H, Post W, Lemmink KAPM. Monitoring stress and recovery: New insights for the prevention of injuries and illnesses in elite youth soccer players. *Br J Sports Med.* 2010;44:809-815.

30. Heidari J, Mierswa T, Kleinert J, et al. Parameters of low back pain chronicity among athletes: Associations with physical and mental stress. *Phys Ther Sport.* 2016;21:31-37.

31. Jaspers A, Brink MS, Probst SGM, Frencken WGP, Helsen WF. Relationships between training load indicators and training outcomes in professional soccer. *Sports Med.* 2017;47:533-544.

32. Mujika I. Quantification of training and competition loads in endurance sports: Methods and applications. *Int J Sports Physiol Perform.* 2017;12:9-17.

33. Saw AE, Kellmann M, Main LC, Gastin PB. Athlete self-report measures in research and practice: Considerations for the discerning reader and fastidious practitioner. *Int J Sports Physiol Perform.* 2017;12:127-135.

34. Dvir Z. Difference, significant difference and clinically meaningful difference: The meaning of change in rehabilitation. *J Exerc Rehabil.* 2015;11:67-73.

35. Doeven SH, Brink MS, Frencken WGP, Lemmink KAPM. Impaired player-coach perceptions of exertion and recovery during match congestion [published online ahead of print January 17, 2017]. *Int J Sports Physiol Perform.*

36. Bresciani G, Cuevas MJ, Garatachea N, et al. Monitoring biological and psychological measures throughout an entire season in male handball players. *Eur J Sport Sci.* 2010;10:377-384.

37. Creswell SL, Eklund RC. Changes in athlete burnout over a thirty-week rugby year. *J Sci Med Sport.* 2006;9:125-134.

38. Grobbelaar HW, Malan DDJ, Steyn BJM, Ellis SM. Factors affecting the recovery-stress, burnout and mood state scores of elite student rugby players. *S Afr J Res Sport Phys Educ Recreation.* 2010;32:41-54.

39. Bompa TO, Haff GG. *Periodization: Theory and methodology of training.* 5th ed. Champaign, IL: Human Kinetics; 2009.

40. Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: The effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Med.* 2015;45:161-186.