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Paula J. Robson-Ansley^a, Michael Gleeson^b & Les Ansley^a

^a School of Psychology and Sport Sciences, Northumbria University, Newcastle upon Tyne

^b School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK

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Fatigue management in the preparation of Olympic athletes

PAULA J. ROBSON-ANSLEY¹, MICHAEL GLEESON², & LES ANSLEY¹

¹*School of Psychology and Sport Sciences, Northumbria University, Newcastle upon Tyne and* ²*School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK*

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Abstract

Fatigue is often a consequence of physical training and the effective management of fatigue by the coach and athlete is essential in optimizing adaptation and performance. In this paper, we explore a range of practical and contemporary methods of fatigue management for Olympic athletes. We assess the scientific merit of methods for monitoring fatigue, including self-assessment of training load, self-scored questionnaires, and the usefulness of saliva and blood diagnostic markers for indicating fatigued and under-recovered athletes, effective nutrition and hydration strategies for optimizing recovery and short-term recovery methods. We conclude that well-accepted methods such as sufficient nutrition, hydration, and rest appear to be the most effective strategies for optimizing recovery in Olympic athletes.

Keywords: *Training load, questionnaires, nutrition, hydration, short-term recovery*

Introduction

The Olympic motto *citius, altius, fortius* (faster, higher, stronger) epitomizes the goal of athletic training. As Olympic athletes strive to improve their performance, they invariably increase the frequency, volume, and intensity of training. This increase in training load is often successful and athletic performance improves. However, athletes will inevitably experience fatigue (general sensations of tiredness and accompanying decrements in physical performance) following training and competition, ranging from short-term “normal” fatigue when recovery is achieved within hours or days to longer-lasting “abnormal” fatigue where recovery is prolonged (a week or two in the case of overreaching and months or even years in the case of overtraining or unexplained, underperformance syndrome). Since performance and training will be compromised during periods of fatigue, its management is an integral component of athletic training. Athletes and coaches need to be able to monitor and effectively manage fatigue to optimize recovery in their preparation for Olympic competition. In this paper, we explore practical methods of monitoring and managing fatigue in athletes.

Tools for monitoring fatigue

It is impractical to screen Olympic athletes in the laboratory to assess daily fatigue objectively, especially when these athletes may live and train long distances from specialist facilities. Therefore, subjective fatigue assessment using psychological questionnaires is often used as a practical method of monitoring fatigue and recovery in athletes. The subjective reporting of training load, perceived stress, and psychological mood states has been shown to be a reliable indicator of adaptation to training load and may prove to be more practical and reliable than physiological and biochemical/immunological tests (Morgan, Costill, Flynn, Raglin, & O'Connor, 1988; Robson-Ansley, Blannin, & Gleeson, 2007; Rushall, 1990).

Assessment of training load

High training loads, which Olympic athletes commonly undertake, are often associated with signs of under-recovery and overreaching, which may lead to the development of underperformance syndrome (UPS) (Foster, 1998). During periods of high training loads, athletes and coaches need to be

prudent to ensure adequate recovery and, consequently, the quantification of training load is an important but complex issue. Three main approaches have been proposed to quantify training load and these are comprehensively reviewed elsewhere (Hopkins, 1991). The first is the observational approach, which involves real-time measurements such as type and duration of a training session with split times or workloads to assess intensity, or the use of video for time – motion analysis (Deutsch, Kearney, & Rehner, 2007). Real-time measurements can provide accurate information on load and increase an athlete's compliance to prescribed training but is time-consuming and potentially costly for the coach/sport scientist to be present at each training session.

The second, physiological approach involves the monitoring of variables such as heart rate, blood lactate concentration, and oxygen consumption during training sessions to obtain information on intensity of steady-state exercise. Nocturnal heart rate variability rather than resting heart rate values are better indicators of high training loads and cumulated physical fatigue (Pichot et al., 2000), although this requires monitoring of heart rate during sleep, which may prove uncomfortable and impractical for athletes in the long term. Measurement of lactate can provide an indication of training load, but variations in muscle glycogen (Sawka, Knowlton, Glaser, Wilde, & Miles, 1979) and diet (Horvath, Eagen, Fisher, Leddy, & Pendergast, 2000) can affect lactate concentration, so conditions would require standardization for repeatable measures. Oxygen consumption provides an accurate indication of exercise intensity, yet this requires costly equipment and technical expertise, which outweighs its usefulness for quantifying load during routine training.

Finally, a useful, yet simple method of assessing training load is by obtaining a subjective estimate of an athlete's training load during or after a bout of non-steady-state exercise (including high-intensity interval training and team sport training/competition). Such a measure may be derived using a session rating of perceived exertion (sRPE), as described by Foster (1998). Daily exercise load is quantified by multiplying each day's exercise rating of perceived exertion using the category ratio scale (Borg, 1982) by total exercise duration (in minutes); the product represents in a single number the magnitude of exercise load in arbitrary units (AU). A score for training monotony (standard deviation of the weekly load) and training strain (load $\times$ monotony) can also be calculated from total weekly load and noted in a diary, which will provide further insight into the athlete's adaptation to training. This method has been used to highlight athletes who are negatively

adapting to training and at risk of developing UPS (Foster, 1998). Athletes should score the sRPE at least 30 min after exercise to ensure that the score is reflective of the entire session rather than just a score based on the final part of the session, and it is recommended that athletes maintain a weekly training load below 4000–5000 AU (Foster, 1998).

Other methods of assessing physical effort include the "training impulse" or TRIMP method (Bannister, 1991), which involves monitoring average heart rate during a session and multiplying this by the duration of the session, resulting in a TRIMP score. This method fails to reflect the physiological demands of stochastic sport, while the averaging of heart rates during intermittent exercise of a prolonged nature (e.g. football, basketball) is impractical and may not provide meaningful information. To overcome this, modified TRIMP methods have been developed using heart rate zones and total time spent in each zone multiplied by a relevant weighting (Foster et al., 2001; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003). Generally, however, the modified TRIMP methods have failed to address the physiological responses to exercise above the anaerobic threshold (Wasserman, 1987). More recently, Stagno and colleagues (Stagno, Thatcher, & van Someren, 2007) developed a modified TRIMP (TRIMP_{MOD}) method using a weighting scale to reflect a typical blood lactate response curve to increasing exercise intensity, which they suggest can be used to monitor training load in high-intensity, intermittent field sports. One further consideration when using heart rate monitors is that despite their widespread use in modern training, if an athlete were to forget to wear their monitor or the unit failed, then data for the session would be lost. A significant advantage of the sRPE method is that although it yields similar results to that of the TRIMP (with the exception of high-intensity training), it is a simpler method to employ on a regular training basis, requiring athletes to respond to a simple question to rate the global intensity of the exercise bout rather than the more technical approach of physiological monitoring.

Questionnaires

Profile of Mood States. The maladaptation to an imposed training stress is often associated with changes in disposition. Therefore, the Profile of Mood States (POMS) questionnaire (Morgan, Brown, Raglin, O'Connor, & Ellickson, 1987) has been used extensively to monitor stress on a daily basis (Fry et al., 1994; Liederbach, Gleim, & Nicholas, 1992; Morgan et al., 1988; Tharp & Barnes, 1990). Even though the global POMS score appears to have a strong positive relationship with

training load (Morgan et al., 1987, 1988), the questionnaire has been criticized for not being sport specific. However, athletes recovering from UPS reported improved mood states that paralleled an improved athletic performance (Koutedakis, Frischknecht, Vrbova, Sharp, & Budgett, 1995). A shortened POMS questionnaire has also been developed (Grove & Prappavessis, 1992) that is more practical and less time-consuming; however, its sensitivity to changes in training load may be diminished (Rietjens et al., 2005). Changes in total mood disturbance can be calculated by an athlete or coach by summing the five negative scores (fatigue, anger, depression, confusion, tension), adding 100, and subtracting the one positive mood score, vigour. If the questionnaire were completed on a regular basis during training and total mood disturbance logged in a diary, then a baseline could be established. Any elevations above that baseline could be highlighted by the athlete and discussed with the coach/sport scientist to ensure a positive adaptation to training.

Daily Analyses of Life Demands for Athletes questionnaire. The Daily Analyses of Life Demands for Athletes (DALDA) questionnaire (Rushall, 1990) has been used in several studies during periods of intensified training (Achten et al., 2004; Halson et al., 2002; Robson-Ansley et al., 2007). The DALDA is divided into two parts: Part A and Part B represent the “sources of life stress” and “symptoms of stress”, respectively. The questionnaire is normally completed by the athlete on a daily basis or on alternate days and the athlete or coach can graphically plot the day-to-day responses to the questionnaire. However, if an athlete is struggling with daily completion of the questionnaire, research suggests that its completion on a weekly basis may not reduce its sensitivity to changes in training load (Robson-Ansley et al., 2007). Peaks in the sum of the “worse-than-normal” responses that remain elevated for several days may indicate an athlete who has overreached and is at risk of developing UPS (Rushall, 1990). The DALDA appears to be a sensitive indicator that is responsive to changes in training load, with researchers reporting significant increases in the “symptoms of stress” inventory before a fall in innate immune function was detected during a 2-week period of intensified training (Robson-Ansley et al., 2007). When training resumed to normal levels, the worse-than-normal scores in the symptoms of stress inventory returned to baseline (Robson-Ansley et al., 2007). The DALDA may also be a useful daily tool for developing an athlete’s self-awareness of sources and symptoms of physical and psychological stressors from both the sporting and non-sporting

environment, especially in the case of impending Olympic competition.

While researchers have investigated the use of questionnaires over relatively short periods of training (weeks and months), there is scant information on the regular daily use of questionnaires over years of training. However, in the clinical setting, a high compliance was reported in patients completing a daily quality of life questionnaire over 52 weeks (Bush et al., 2005). The maintenance of a high compliance to the regular completion of questionnaires would depend on factors such as the length and nature of the questionnaire, type of response required (tick box or sentences), and incidence of feedback to the athlete. Data on the long-term use and adherence to completing regular questionnaires/diaries by athletes would provide valuable information on the sensitivity and reliability of these methods.

Performance tests

In general, athletes exhibiting UPS are unable to sustain normal training and have a diminished sports-specific performance capacity (Meeusen et al., 2006). Although they are usually able to start a normal training sequence or a race at their normal training pace, they are unable to complete the training load they are given or race as usual. Therefore, a performance test is considered to be essential for the diagnosis of UPS. Such a test can also help to confirm normal recovery following a period of intensified training designed to induce overreaching (Budgett et al., 2000). An additional complication in interpreting performance test data in athletes suffering from UPS is, of course, the gradual loss of training adaptation that will ensue when the athlete follows medical advice to reduce training load, avoid intense exercise, and take more rest. Performance tests are, therefore, more useful to establish that an athlete has recovered from a period of intensified training (i.e. deliberate overreaching) within a matter of days or weeks than for determining when they have recovered from a confirmed episode of UPS that has persisted for a few months or more.

Debate exists as to which performance test is most appropriate when attempting to diagnose UPS. In general, time-to-fatigue tests will most likely show greater changes in exercise capacity as a result of UPS than incremental exercise tests (Halson & Jeukendrup, 2004). Additionally, since time-to-fatigue tests are performed at a fixed intensity, they allow the comparison of substrate kinetics, hormonal responses, and other physiological variables. To detect subtle performance decrements, especially in Olympic athletes, it is advisable to make the performance tests sport specific (Coutts, Reaburn, Piva, & Rowsell, 2007).

Blood/saliva screening

Many researchers have attempted to identify a biochemical, haematological or immunological marker that could be used to distinguish between well-trained healthy athletes, overreached athletes, and athletes with UPS, but no single, reliable diagnostic marker has yet been found. For several years it has been hypothesized that a hormonally mediated central dysregulation occurs during the pathogenesis of the UPS, and that measurements of blood hormones could help to detect the syndrome (Lehmann et al., 1993; Steinacker et al., 2000). For example, the plasma cortisol/testosterone ratio is generally considered to be a good indicator of the overreached state. This ratio increases in relation to the intensity and duration of training and therefore provides an indication of responses to the training load but cannot be used for diagnosis of UPS (Urhausen, Gabriel, & Kindermann, 1995). Cortisol and testosterone concentrations can also be measured in saliva, which provides the possibility for regular, non-invasive monitoring of hormonal status in response to changes in training loads to prevent the development of overreaching (Gleeson, Allgrove, & Reddin, 2007).

Meeusen et al. (2004) published a test protocol that assessed the neuroendocrine response to two consecutive incremental, maximal exercise tests separated by 4 h. The protocol showed an adapted exercise-induced increase of adrenocorticotrophic hormone (ACTH), prolactin, and growth hormone to the two exercise bouts (Meeusen et al., 2004); in an early overreaching state, a less pronounced neuroendocrine response to a second bout of exercise on the same day is found (De Schutter, Buyse, Meeusen, & Roelands, 2004; Meeusen et al., 2004), whereas in a late overreaching stage, the hormonal response to a two-bout exercise protocol shows an extreme increased release after the second exercise trigger (Meeusen et al., 2004). Athletes suffering from UPS exhibit an excessive increase in hormonal release in the first exercise bout, followed by a complete suppression in the second exercise bout (Meeusen et al., 2004); this finding could indicate a hypersensitivity of the pituitary followed by an insensitivity or exhaustion. One almost consistent finding, at least in endurance and strength-endurance athletes suffering from UPS, is an attenuated maximal lactate concentration, while submaximal concentrations remain unchanged or slightly reduced (Meeusen et al., 2006).

Increased creatine kinase and/or urea measured in the blood under standardized, resting conditions may provide information concerning elevated

muscular and/or metabolic strain, but they are not suitable to indicate overreaching or the presence of UPS (Urhausen, Gabriel, & Kindermann, 1998). Similarly, although the saliva concentration of immunoglobulin A may fall with sustained periods of intensive training, it is not a reliable marker of overreaching, in part due to large within-participant day-to-day variation (Gleeson et al., 2007; (Halsen, Lancaster, Jeukendrup, & Gleeson, 2003). The concentration of plasma glutamine (and more recently its ratio to glutamate) has been suggested as a possible indicator of excessive training stress (Smith & Norris, 2000; Halsen et al., 2003). In a recent study of intensified training in rugby players, although there was no single reliable biochemical marker of overreaching, the glutamine/glutamate ratio and shuttle running performance were found to be useful markers of training intolerance (Coutts et al., 2007). Other immune measures such as neutrophil phagocytic activity, natural killer cell cytolytic activity, lymphocyte cytokine and antibody production, are generally too time-consuming and expensive to be of practical use. While blood parameters (e.g. blood cell counts and haemoglobin concentration, serum C-reactive protein, creatinine, liver enzymes, glucose, ferritin, sodium, potassium, etc.) cannot detect overreaching or UPS *per se*, they are helpful in providing information on the actual health status of the athlete; therefore, they are useful in the "exclusion diagnosis" when it comes to deciding if an athlete can be diagnosed as suffering from UPS.

General fatigue management strategies*Rest*

One of the most obvious methods for managing fatigue and enhancing recovery is adequate passive rest and obtaining sufficient sleep. It is generally recommended that athletes should have at least one passive rest day each week, as the absence of a recovery day, especially during intensified training periods, is closely related to the onset of signs of overreaching and under-recovery (Bruin, Kuipers, Keizer, & Vander Vusse, 1994). A passive rest day can also act as a 'time-out' period for athletes and prevent them from becoming totally preoccupied with their sport during Olympic preparation and possibly encourage them to pursue a different (passive) interest. Such distractions from the daily routine of training may alleviate boredom and reduce stress perception. Common sense must prevail when prescribing rest; for example, if an athlete has undergone excessive training or is exhibiting abnormal levels of fatigue, longer periods of passive recovery may be required.

Sleep

Sleep is an essential part of fatigue management, as persistent sleep loss can negatively impact on the quality of a training session and general well-being. The primary need for sleep has been hypothesized as being neurally based rather than a requirement for restitution of other biological tissues (Horne & Pettitt, 1984). Therefore, cognitive functions are likely to be impaired, especially the ability to concentrate. Sleep loss can also negatively impact on mood state and the motivation to exercise and complete training sessions competently (Reilly & Edwards, 2007). Research suggests that athletes are able to overcome the effects of sleep deprivation and perform supra-maximal exercise, but they become less motivated to maintain a high level of performance in sustained exercise or in repeated exercise bouts that commonly occur in training (Reilly & Piercy, 1994). Sleep deprivation studies have shown that while gross motor functions can remain unaffected by three nights of partial sleep deprivation (Reilly & Piercy, 1994), the performance of fine motor skills deteriorates (Froberg, Karlsson, Levi, & Lidberg, 1975).

To date, it remains largely unknown whether sleep supports host defence or modifies immune responses to infectious agents. In humans, for example, acute sleep deprivation of up to 55 h has only minor effects on endotoxin-induced host responses. In contrast, there is preliminary and yet inconsistent evidence that sleep deprivation might impair antibody formation in response to viral challenges (Dimitrov, Lange, Nohroudi, & Born, 2007; Schuld, Haack, Hinze-Selch, Mullington & Pollmacher, 2005). To date, only one study has investigated the effects of sleep deprivation on immune responses to exercise (Ricardo et al., 2009). This very recent study reported that 30 h of sleep deprivation did not affect leukocyte trafficking, neutrophil function or salivary responses either at rest or after strenuous treadmill running in recreationally active men.

Individuals have different requirements for sleep and to prescribe the dose of sleep that a highly trained athlete requires would be erroneous. The general advice is to sleep for the amount of time that is required to feel wakeful during the day, which may vary considerably between individuals (Horne & Pettitt, 1984). Poor sleep may be compensated by short post-lunchtime naps. Napping for 30 min with a 30-min post-nap recovery period has been shown to improve sprint performance and reaction time following a night of reduced sleep (Waterhouse, Atkinson, Edwards, & Reilly, 2007). The ability to nap for short periods during the day may be a useful skill for athletes to develop, as for many individuals a disturbed night's sleep before an important

competition is common. However, caution should be taken, since longer daytime naps will result in longer post-sleep inertial periods and resumption of optimal performance may take longer. In the case of disturbed night sleep from noise that may occur at training camps or Olympic village venues, the use of earplugs should be recommended (Robertson, Loughran, & MacKenzie, 2006). There are also practical implications; for example, when selecting accommodation in hotels, it is sensible to get a room away from a busy street and not close to entrances, stairs, lifts or hotel bars and restaurants, although this may not be possible when athletes are allocated rooms in the Olympic village. Full recovery from a period of sleep loss can be attained after a full night of undisturbed sleep (Reilly & Piercy, 1994).

Nutrition

The key point in relation to nutrition for an athlete is that diet affects both health and performance: the foods and drinks that are consumed in training and competition will affect how well an individual can train and compete. A good diet will help support consistent intensive training without the athlete succumbing to excessive fatigue, illness or injury. Good food choices can also promote adaptations to the training stimulus, enhance recovery between workouts, and speed tissue repair from minor injuries (Hawley, Tipton, & Millard-Stafford, 2006). Athletes need to be aware of their nutritional goals and of how they can select an eating strategy to meet those goals. Getting the right amount of dietary energy to stay healthy and to perform well is very important. Even at the point of the Olympics, athletes need to maintain their normal diet as closely as possible even with the nutritional temptations on offer within the Olympic food halls. However, it is important to remember that athletes are different, and there is no single diet that meets the needs of all athletes at all times. Individual needs also change across the season and athletes must be flexible to accommodate this demand.

Carbohydrate is the key macronutrient for energy supply. Athletes must be conscious of foods that can help meet their carbohydrate needs and make these a focus of their diet. Carbohydrate provides an important but relatively short-lived supply of fuel for exercise that must be refilled each day from carbohydrate foods in the diet. The athlete's daily eating plan needs to provide enough carbohydrate to fuel his or her training programme and to optimize the recovery of muscle and liver glycogen stores between training sessions. An inadequate carbohydrate intake can lead to an earlier onset of over-reaching symptoms including altered mood state, hormonal changes, and impaired performance

during periods of intensified training (Achten et al., 2004; Halson, Lancaster, Achten, Gleeson, & Jeukendrup, 2004). General targets can be provided for carbohydrate needs, based on the athlete's body mass (BM) and the demands of his or her training programme. The broad recommendations for carbohydrate (CHO) ingestion to optimize fatigue management and maximize recovery following training sessions are: 1 g CHO · kg BM⁻¹ · h⁻¹ as soon as possible (e.g. within 4 h) after exercise; 5–7 g CHO · kg BM⁻¹ · day⁻¹ for recovery within 24 h from light- to moderate-intensity training; 7–10 g CHO · kg BM⁻¹ · day⁻¹ for recovery from moderate- to heavy-endurance training; 10–12 g CHO · kg BM⁻¹ · day⁻¹ for daily recovery from extreme exercise training sessions (more than 4 h · day⁻¹) (Burke, Kiens, & Ivy, 2004; Burke, Loucks, & Broad, 2006). However, actual needs are specific to the individual athlete and should be fine-tuned with consideration of the athlete's total energy requirements, specific training needs, and feedback from his or her training performance. It is important to realize that not all athletes need a high carbohydrate intake every day – carbohydrate intake can be scaled up and down according to the fuel requirements of training or competition. The measurement of ketones in urine may provide a useful indicator of inadequate carbohydrate intake, as ketone production and circulating and urinary concentrations of ketones rise when fatty acids are incompletely oxidized, a metabolic event that arises when body carbohydrate availability is low and fats are mobilized from adipose tissue stores as an alternative fuel. Measurement of urinary ketones can be done at the same time as the estimation of hydration status using a urine colour chart or an osmometer.

When the period between successive training sessions is less than about 8 h, carbohydrate intake should begin as soon as possible after the first session to maximize the effective recovery time and a series of high- carbohydrate snacks and drinks during the early recovery phase is an effective practical solution when “proper meals” are not available. During longer recovery periods (12–24 h), the pattern and timing of carbohydrate intake do not appear to be critical, and eating can be organized according to what is practical and comfortable for each athlete (Burke et al., 2004). There is no difference in glycogen synthesis when carbohydrate is consumed in liquid form or as solid foods. It is valuable to choose nutrient-rich carbohydrate sources and to add other foods to recovery meals and snacks to provide a good source of protein and other nutrients. These nutrients may assist in other recovery processes, and in the case of protein may promote additional glycogen recovery when carbohydrate intake is below targets (Burke et al., 2004) or when

frequent snacking is not possible. Foods rich in carbohydrate and with a moderate to high glycaemic index (GI) provide a readily available source of carbohydrate for glycogen synthesis, and should be the major fuel choices in recovery meals. Examples of moderate- to high-GI foods include most breakfast cereals, rice, bread, sugar, jam, honey, potatoes, fruit juices, mangoes, grapes, raisins, sports drinks, and soft drinks.

Evidence from several recent studies on the influence of pre-exercise muscle glycogen on the transcription rate of several genes involved in training adaptation has indicated that skeletal muscle adaptations to endurance training may be enhanced when athletes exercise in a carbohydrate -depleted state (see Hawley et al., 2006). Thus, it is reasonable to suggest that there may be some benefit to using performing training sessions twice each day with no carbohydrate intake between the first and second bout. However, it should be borne in mind that a high-carbohydrate diet is still required to meet the demands of a heavy training schedule and that this so-called practice of “train-low, compete-high” with regard to carbohydrate intake is likely to increase the possibility of an athlete becoming overreached.

Training with inadequate carbohydrate intake may also compromise immune function, leading to increased susceptibility to opportunistic infections (Gleeson, Nieman, & Pedersen, 2004). The size of the glycogen stores in muscle and liver at the onset of exercise influences the hormonal and immune response to exercise. When individuals begin prolonged exercise with low glycogen stores, the magnitude of the stress hormone and anti-inflammatory cytokine response is markedly increased (Gleeson, 2006; Gleeson, Blannin, Walsh, Bishop, & Clark, 1998). Thus, athletes deficient in carbohydrate are placing themselves at risk from the known immunosuppressive effects of cortisol. An important aspect of recovery nutrition as far as the immune system is concerned is the optimal replenishment of muscle and liver glycogen stores in time for the next exercise session, as described previously.

Increased oxygen free-radical formation that accompanies the dramatic rise in oxidative metabolism during exercise could also inhibit immune responses (Peters, 1997). There have also been concerns expressed about the potential problem of poor air quality in Beijing at the time of the 2008 Olympic Games due to high levels of pollution and it has been suggested that antioxidant supplementation could help to protect athletes against potentially harmful effects. Sustained endurance training appears to be associated with an adaptive up-regulation of the antioxidant defence system (Powers, DeRuisseau, Quindry, & Hamilton, 2004), although this may be insufficient to protect athletes who train extensively,

particularly in environments where levels of air pollutants are high. Some studies on South African distance runners have indicated that vitamin C supplementation ($\sim 1000 \text{ mg} \cdot \text{day}^{-1}$) reduces the incidence of upper respiratory tract illness and inflammation after endurance events (Peters, 2000), although other researchers have been unable to replicate these findings (Himmelstein, Robergs, Koehler, Lewis, & Qualls, 1998; Nieman et al., 1997; Nieman, Peters, Henson, Nevines, & Thompson, 2000). Several studies have, however, shown that chronic high-dose antioxidant supplementation is associated with a lower interleukin-6 and cortisol response to prolonged exercise (Davison & Gleeson, 2006; Fischer et al., 2004), which offers another possible mechanism for the findings of Peters (2000). On balance, the available evidence is not strong enough to suggest that athletes will benefit from the use of antioxidant supplements and the potential dangers of excessive intake must be considered – over-supplementation can diminish the body's natural defence system (Powers et al., 2004). Ensuring that the diet contains plenty of fresh fruits and vegetables seems the wisest option to ensure a high and varied antioxidant intake.

Protein foods are important for building and repairing muscles, but a varied diet containing everyday foods will generally supply more than enough protein. Well-chosen vegetarian diets can also meet protein needs. A varied and wholesome nutrient-rich diet that meets energy needs and is based largely on vegetables, fruits, beans, legumes, grains, animal meats, oils, and carbohydrate should ensure an adequate intake of vitamins and minerals, although there is no harm in taking a single daily multivitamin supplement as “insurance”. Such a supplement is useful when food choices may be limited, such as when travelling or faced with unfamiliar foods in a foreign country, but athletes are cautioned against the indiscriminate use of other dietary supplements. Adequate intake of protein and avoiding micronutrient deficiencies are essential to maintain health and an optimally functioning immune system to protect against infection and ensure rapid healing from injuries.

Enhanced protein balance is a desirable goal of the recovery phase to overturn the increased rates of protein breakdown that occur during and after exercise, and to promote protein synthesis, net protein gain, repair, and adaptation following the exercise stimulus (Hawley et al., 2006; Tipton & Wolfe, 2004). Recently, researchers have focused on the acute response to training sessions of both endurance and resistance exercise modes. These studies indicate that the intake of protein, with the addition of carbohydrate to enhance the insulin response (insulin inhibits protein breakdown and

promotes amino acid as well as glucose uptake into muscle), enhances net tissue protein gain during the recovery phase after training (Hawley et al., 2006; Tipton & Wolfe, 2004). There is some evidence that the response is enhanced when these nutrients are provided soon after exercise (Rasmussen, Tipton, Miller, Wolf, & Wolfe, 2000) or in the case of a resistance exercise bout, perhaps immediately before training (Tipton et al., 2001). Further work is required to fine-tune guidelines for the optimum amount, type, and timing of intake of these nutrients, and to confirm that these eating strategies lead to better achievement of the goals of training, namely increased muscle hypertrophy, strength, and endurance. In the meantime, it appears sensible to focus on the total balance of the diet and the timing of protein – carbohydrate meals and snacks in relation to training, rather than high dietary protein intakes *per se*. The current consensus is that no athletes require protein intakes greater than $1.7 \text{ g protein} \cdot \text{kg BM}^{-1} \cdot \text{day}^{-1}$ (Burke & Maughan, 2007). Special sports foods such as sports bars and liquid meal supplements can provide a compact and convenient way to consume carbohydrate and protein when everyday foods are unavailable or are too bulky and impractical to consume. There is little justification for using protein-only powders or amino acid supplements.

Hydration

Maintaining hydration status is important for performance, especially in a very hot and humid environment such as Beijing; at the London Olympics in 2012, this might be of less concern. Fluid intake before, during (where appropriate), and after exercise is especially important in hot climates. Specific attention to salt replacement following exercise is required in circumstances when sweat losses are high. Replacement of water and salts lost in sweat is an essential part of the recovery process. Athletes should aim to drink about 1.2–1.5 litres of fluid for each kilogram of body mass lost in exercise sessions (Shirreffs, Armstrong, & Cheuvront, 2004). Drinks should contain sodium (the main electrolyte lost in sweat) if no food is eaten at this time. Sports drinks and oral rehydration solutions that contain electrolytes are helpful, but many foods can supply the salt that is needed. A little extra salt may usefully be added to meals when sweat losses are high, but salt tablets should be used with caution. Recovery after exercise should be seen as part of the preparation for the next exercise session, and all athletes, including strength and power athletes, will perform below their best if they are not well hydrated when they begin exercise (Shirreffs et al., 2004). Athletes should not consume excessive amounts of alcohol

during the recovery period or during competition (even if celebrating another athlete's Olympic success!), since it is likely to interfere with their ability or interest to follow guidelines for appropriate post-exercise eating and drinking (Shirreffs & Maughan, 2006).

Short-term fatigue management

For many athletes, the need to train or compete in more than one session per day means that short-term fatigue management and recovery, in terms of hours, is essential in allowing the athlete to perform at a higher training load during, or realize the full potential from, a subsequent training session. Additionally, minimizing fatigue may also protect against injury (Melnik & Gollhofer, 2007). The importance of short-term fatigue management is evidenced by the investment in purpose-built facilities by teams and national sporting bodies. However, at Olympic venues, athletes may not have access to the recovery facilities that they use during training. The issue as to the most effective fatigue recovery management strategy is clouded by the plethora of claims made for the efficacy of different recovery modalities, many of which lack rigorous scientific evidence. There is even some evidence that common recovery strategies (e.g. limb cooling and active recovery) may hamper the training adaptation effect (Levenhagen et al., 2001; Yamane et al., 2006). Although there has been a fair amount of research into the effectiveness of recovery strategies, there is an absence of literature assessing their effectiveness in elite athletes, who may respond differently from sub-elite or untrained individuals (Barnett, 2006). Moreover, the applicability to elite athletes of the outcome variables used in most of the recovery studies (either lactate clearance or muscle soreness) has been questioned (Barnett, 2006). Currently, the most popular fatigue management and recovery modalities can be grouped as physical therapy, cryotherapy, hydrotherapy, and active recovery.

Physical therapy

Physical therapy encompasses massage, stretching, and compression garments. Massage is probably the oldest method of treating fatigued muscles (Veith, 2002). However, there is little scientific evidence to support the use of massage in improving recovery or subsequent performance. Even the commonly held belief that blood flow to the muscle is enhanced with massage, and that this is the mechanism through which recovery is enhanced, appears to be errant (Hinds et al., 2004). Although Hemmings and colleagues (Hemmings, Smith, Graydon, & Dyson, 2000) did report an improved perception of recovery

following a massage bout, there was no improvement in physiological markers or subsequent performance. Stretching is often used pre-exercise to minimize injury, although this notion is not corroborated by research (Thacker, Gilchrist, Stroup, & Kimsey, 2004). In fact, stretching appears to be detrimental to performance in sports requiring explosive power (Nelson, Driscoll, Landin, Young, & Schexnayder, 2005; Shrier, 2004) and at the very least does not improve running economy (Nelson, Kokkonen, Eldredge, Cornwell, & Glickman-Weiss, 2001; Jones, 2002). Based on the available evidence, therefore, stretching is probably not advisable as a recovery modality between sessions.

Compression garments are gaining popularity to aid in both performance and recovery. Although there have been a limited number of studies into the efficacy of compression garments in accelerating recovery, there is some evidence that they may minimize muscle damage or trauma that occurs during heavy exercise (Kraemer et al., 2001) or impact sport (Gill, Beaven, & Cook, 2006). Furthermore, Chatard et al. (2004) have reported improved performance of elderly sportsmen (maximum work in a 5-min cycling bout) in a subsequent bout of exercise following the use of elastic stockings during an 80-min recovery period between the bouts.

Cryotherapy

Ice treatment is a commonly practised form of recovery. Howatson and colleagues (Howatson, Gaze, & van Someren, 2005; Howatson & van Someren, 2003) have repeatedly shown that ice massage on its own is ineffective in maintaining muscle function following eccentric exercise (even though the plasma creatine kinase response was attenuated). Although used in conjunction with active recovery, ice treatment did improve shoulder strength following a simulated game of baseball pitching (Yanagisawa et al., 2003).

Hydrotherapy

The proposed benefits from hydrotherapy are derived from either the effect of hydrostatic pressure or temperature, or a combination of both. The compression force exerted by water on an immersed body causes the displacement of fluids away from the periphery and towards the core (Lollgen, Nieding, Koppenhagen, Kersting, & Just, 1981). It has been suggested that this fluid shift enhances recovery by increasing the rate at which metabolic waste products leave the muscle (Nakamura, Takahashi, Shimai, & Tanaka, 1996). The removal of metabolic by-products may also be enhanced by the increased blood flow through the muscles due to the resultant

increased cardiac output (Lollgen et al., 1981) and peripheral vasodilatation (Bonde-Petersen, Schultz-Pedersen, & Dragsted, 1992).

The effects of immersion in cold water ($\leq 15^{\circ}\text{C}$) (Bonde-Petersen et al., 1992) appear to be due mainly to the reduction of acute inflammation (Cote, Prentice, Hooker, & Shields, 1988). However, it has been argued that reducing the inflammatory response may be detrimental to tissue adaptation and repair (Yamane et al., 2006). Furthermore, the reduction in neural conduction velocity that occurs with tissue cooling (Abramson et al., 1966) and the resulting decrease in contractile speed of the muscle (Rutkove, 2001) probably outweigh any benefit derived from the reduced perception of fatigue as a result of the analgesic effect of the cold water.

The benefits of immersion in hot water ($> 36^{\circ}\text{C}$) (Bonde-Petersen et al., 1992) on recovery from fatigue are not very well supported by scientific evidence. Indeed, the pro-inflammatory effect of heat may in fact prolong recovery time (Cote et al., 1988). Furthermore, there are severe (sometimes fatal) consequences associated with hot water immersion on the cardiovascular system (Turner, Pennefather, & Edmonds, 1980).

Another frequently used hydrotherapeutic modality of recovery from fatigue is contrast baths. This involves alternating immersion in hot and cold water. The mechanism generally attributed with the supposed benefit of contrast therapy is the oscillation in the deep tissue temperature that enhances venous return and speeds the rate of metabolite removal (Cochrane, 2004). However, several authors have reported that intramuscular temperature does not fluctuate with alternating temperature exposures (Higgins & Kaminski, 1998; Myrer, Draper, & Durrant, 1994) and the only researchers to have looked at acute recovery from exercise found that

contrast therapy offered no benefits over passive recovery (Coffey, Leveritt, & Gill, 2004).

Active recovery

There is overwhelming evidence that active recovery speeds up lactate removal (Ahmaidi et al., 1996; Taoutaou et al., 1996); however, the efficacy of active recovery in facilitating short-term recovery and improving subsequent performance is questionable (Coffey et al., 2004; Spencer, Bishop, Dawson, Goodman, & Duffield, 2006). Perhaps what should concern athletes is the potential for active recovery to slow glycogen resynthesis (Fairchild et al., 2003) and disrupt the important immediate post-exercise carbohydrate ingestion strategy (see Nutrition section) (Barnett, 2006; Levenhagen et al., 2001).

Overview

As Olympic athletes strive to improve their performance, they will inevitably experience varying fatigue, which will require effective management and monitoring by both the athlete and coach. Our aim in this review was to explore a range of practical and contemporary methods of fatigue management in athletes, although it is by no means an exhaustive list (Table I). Self-reports by the means of questionnaires such as the POMS and DALDA questionnaires appear to be practical and effective subjective methods of indicating changes in training-related stress and overreached athletes. Reliable salivary or blood diagnostic markers for identifying fatigued and under-recovered athletes are lacking, although the plasma cortisol/testosterone ratio is considered a good indicator of the overreached state. There is little scientific support for most common short-term recovery methods and further rigorous

Table I. Summary of methods for monitoring and managing fatigue in the preparation of Olympic athletes.

Monitoring tools	
Self-scored questionnaires	Effective in the short term. Insufficient data on long-term use
Training load assessment	Subjective assessment provides a simple but effective method
Performance tests	Need to be sport specific. Time to fatigue tests currently favoured
Blood/saliva screening	Cannot detect underperformance syndrome, but may be useful in monitoring health status
General fatigue management	
Rest	Alleviates boredom and reduces stress perception
Sleep	Nervous system restoration; improves/maintains motivation and skill
Nutrition	Adequate and timely carbohydrate intake optimizes glycogen recovery and maintains immune function. Protein/carbohydrate intake enhances muscle gain
Hydration	Particularly important in hot climates such as Beijing. Salt replacement usually obtained through food
Short-term fatigue management	
Physical therapy	No evidence for massage or stretching. Compression garments may confer benefits
Cryotherapy	No evidence of benefit on its own
Hydrotherapy	No evidence of benefit; may be detrimental
Active recovery	No evidence of benefit; may be detrimental

scientific testing is required to establish definitive benefits, especially as some modalities may be detrimental to recovery. In conclusion, sufficient nutrition, hydration, and rest appears to be the most effective strategy for optimizing recovery. With an effective strategy for the monitoring and management of fatigue, athletes should be able to optimize training sessions and realize their true potential in the Olympic arena. Although Olympic athletes have access to sport science support, athletes on the fringes of reaching national standard may not, so it is imperative that these potential Olympians are not lost due to poor monitoring and management of fatigue.

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