



# **Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM)**

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# *Prevention, diagnosis and treatment of the Overtraining Syndrome*

## ECSS Position Statement 'Task Force'

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## Introduction.

The goal in training competitive athletes is to provide training loads that are effective in improving performance. During this process athletes may go through several stages within a competitive season of periodised training. These phases of training range from undertraining, during the period between competitive seasons or during active rest and taper, to “Overreaching” (OR) and “Overtraining” (OT) which includes maladaptations and diminished competitive performance. Literature on “Overtraining” has increased enormously; however, the major difficulty is the lack of common and consistent terminology as well as a gold standard for the diagnosis of overtraining.

In this “consensus statement” we will present the current state of knowledge on the Overtraining Syndrome (OTS) going through its definition, diagnosis, treatment, and prevention.

## Definition

Successful training must involve overload but also must avoid the combination of excessive overload plus inadequate recovery. The process of intensifying training is commonly employed by athletes in an attempt to enhance performance. As a consequence the athlete may experience acute feelings of fatigue and decreases in performance as a result of a single intense training session, or an intense training period. The resultant acute fatigue, combination with adequate rest can be followed by a positive adaptation or improvement in performance and is the basis of effective training programmes. However, if the balance between appropriate training stress and adequate recovery is disrupted, an abnormal training response may occur and a state of “Overreaching” may develop.

Many recent papers have referred to the work of Kreider et al (1998) for the definition of OT & OR.

- Overreaching : an accumulation of training and/or non-training stress resulting in *short-term* decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take from *several days to several weeks*.
- Overtraining : an accumulation of training and/or non-training stress resulting in *long-term* decrement in performance capacity with or without related physiological and

psychological signs and symptoms of maladaptation in which restoration of performance capacity may take *several weeks or months*.

As stated by several authors (Lehmann et al. 1999a, Budgett et al. 2000, Halson & Jeukendrup 2004) these definitions suggest that the difference between OT & OR is the amount of time needed for performance restoration and not the type or duration of training stress or degree of impairment. These definitions also imply that there may be an absence of psychological signs associated with the conditions. As it is possible to recover from a state of OR within a 2-week period (Lehmann et al. 1999a, Halson et al 2002, Jeukendrup et al 1992, Kreider et al 1998, Steinacker et al. 2000), it may be argued that this condition is a relatively normal and harmless stage of the training process. However, athletes who are in an ‘overtrained’ state may take months or possible years to completely recover.

The difficulty lies in the subtle difference that might exist between extreme Overreached athletes and those having an “Overtraining Syndrome” (OTS). The possibility also exists that these states (OR/OTS) show different defining characteristics and that the overtraining continuum may be an oversimplification.

To avoid misconception of terminology we here outline the terms OR, OT and the OTS based on the definitions used by Halson & Jeukendrup (2004) and Urhausen & Kindermann (2002). In these definitions “Overtraining” is used as a ‘verb’, a process of intensified training with possible outcomes of short term Overreaching (functional OR); extreme Overreaching (non-functional OR); or the Overtraining Syndrome (OTS). By using the expression ‘syndrome’ we emphasize the multifactorial aetiology and acknowledge that exercise (training) is not necessarily the sole causative factor of the syndrome.

Overreaching is often utilised by athletes during a typical training cycle to enhance performance. Intensified training can result in a decline in performance; however, when appropriate periods of recovery are provided, a ‘*Supercompensation*’ effect may occur with the athlete exhibiting an enhanced performance when compared to baseline levels. This process is often used when going on a ‘training camp’, and will lead to a temporary performance decrement, which is followed by improved performance. In this situation, the physiological responses will compensate the training related stress (Steinacker et al. 2004).

This form of short term “Overreaching” can also be called “Functional Overreaching”. When this ‘intensified training’ continues, the athletes can evolve into a state of extreme Overreaching or “Non-Functional Overreaching”, that will lead to a stagnation or decrease in performance which will not resume for several weeks or months. However, eventually these athletes will be able to fully recover after sufficient rest. “Non-Functional Overreaching” emphasizes that the evolution on the “overtraining continuum” is not only "quantitatively" determined (i.e. by the increase in training volume) but that also "qualitative" changes occur (e.g. signs and symptoms of psychological and/or endocrine distress). This is in line with findings on the "sympathetic versus parasympathetic OTS" (probably together with different resting cortisol levels and exercise-induced changes in free plasma catecholamines) (Lehmann et al. 1998), and recent neuroendocrine findings using a double exercise test (Meeusen et al 2004).

In figure 1 the different stages that differentiate normal training from OR (functional and non-functional OR) and from the OTS are presented. Training can be defined as a process of overload that is used to disturb homeostasis which results in acute fatigue leading to an improvement in performance. When training continues or when athletes deliberately use a short term period (e.g. training camp) to increase training load they can experience short term performance decrement, without severe psychological, or lasting other negative symptoms. This Functional OR (or short term OR) will eventually lead to an improvement in performance after recovery. However, when athletes do not sufficiently respect the balance between training and recovery, Non-Functional OR (extreme OR) can occur. At this stage the first signs and symptoms of prolonged training distress such as performance decrements, psychological disturbance (decreased vigour, increased fatigue), and hormonal disturbances will occur and the athletes will need weeks or months to recover. Several confounding factors such as inadequate nutrition (energy and/or carbohydrate intake), illness (most commonly upper respiratory tract infections, URTI), psychosocial stressors (work-, team-, coach-, family- related) and sleep disorders may be present. At this stage the distinction between Non-Functional OR and OTS is very difficult and will depend on the clinical outcome and exclusion diagnosis. The athlete will often show the same clinical, hormonal and other signs and symptoms. Therefore the diagnosis of OTS can often only be made retrospectively when the time course can be overseen. A keyword in the recognition of OTS might be ‘prolonged maladaptation’ not only of the athlete, but also of several biological, neurochemical, and hormonal regulation mechanisms.

PROCESS	TRAINING (overload)	INTENSIFIED TRAINING		
OUTCOME	ACUTE FATIGUE	FUNCTIONAL OR (short-term OR)	NON-FUNCTIONAL OVERREACHING (extreme OR)	OVERTRAINING SYNDROME (OTS)
RECOVERY	Day(s)	Days – weeks	Weeks – months	Months - ...
PERFORMANCE	INCREASE	Temporary performance decrement (e.g. training camp)	STAGNATION DECREASE	DECREASE

**Figure 1 :** possible presentation of the different stages of training, OR and OTS.

The borderline between optimal performance and performance impairment due to “OTS” is subtle. This applies especially to physiological and biochemical factors. The apparent vagueness surrounding OTS is further complicated by the fact that the clinical features are varied from one individual to another, non-specific, anecdotal and numerous.

## Diagnosis

Although in recent years the knowledge of central pathomechanisms of the OTS has significantly increased there is still a strong demand for relevant tools for the early diagnosis of OTS. The OTS is characterised by a “sports-specific” decrease in performance together with disturbances in mood state. This underperformance persists despite a period of recovery lasting several weeks or months. Importantly, as there is no diagnostic tool to identify an athlete as suffering from OTS, diagnosis can only be made by excluding all other possible influences on changes in performance and mood state. Therefore, if no explanation for the observed changes can be found, OTS is diagnosed. Early and unequivocal recognition of OTS is virtually impossible because the only certain sign is a decrease in performance during competition or training. The definitive diagnosis of OTS always requires the exclusion of an organic disease, e.g. endocrinological disorders (thyroid or adrenal gland, diabetes), iron deficiency with anaemia, or infectious diseases (including myocarditis, hepatitis, glandular fever). Other major disorders or feeding behaviours such as anorexia nervosa, bulimia should

also be excluded. However, it should be emphasised, that many endocrinological and clinical findings due to OR and OTS can mimic other diseases. The borderline between under- and overdiagnosis is very difficult to judge.

In essence, it is generally thought that symptoms of OTS, such as fatigue, performance decline, and mood disturbances, are more severe than those of OR. However, there is no scientific evidence to either confirm or refute this suggestion. Hence, there is no objective evidence that the athlete is indeed suffering from the OTS. Additionally, in the studies that induced a state of overreaching, many of the physiological and biochemical responses to the increased training were highly variable, with some measures in some studies demonstrating changes and others remaining unaltered, most likely, because conditions and the degree of OR and OTS differ and were not comparably described. This is also probably because the signs and symptoms of OTS are individual and it is not feasible and certainly unethical to 'overtrain' an athlete in such a way that he/she will develop the OTS. Therefore, prospective studies are lacking and only few data exist on OTS.

One approach to understanding the aetiology of OTS involves the exclusion of organic diseases or infections and factors such as dietary caloric restriction (negative energy balance) and insufficient carbohydrate and/or protein intake, iron deficiency, magnesium deficiency, allergies, etc. together with identification of initiating events or triggers. One of the most certain triggers is a training error resulting in an imbalance between load and recovery. Other possible triggers might be the monotony of training, too many competitions, personal and emotional (psychological) problems and emotional demands of occupation. Less commonly cited possibilities are altitude exposure and exercise-heat stress. Scientific evidence is not strong for most of these potential triggers. Many triggers such as glycogen deficiency or infections may contribute to OR or OTS but might not be present at the time the athlete presents to a physician. Furthermore, identifying these possible initiating events has not revealed the mechanism of OTS.

Athletes and the field of sports medicine in general would benefit greatly if a specific, sensitive simple diagnostic test existed for the diagnosis of OTS. At present no test meets this criterion, but there certainly is a need for a combination of diagnostic aids to pinpoint possible markers for OTS. Especially there is a need for a detection mechanism for early triggering factors.

Increased training loads as well as other chronic stresses can influence the neuroendocrine system chronically. However, at this time it is not yet clear which mechanism eventually leads to the OTS. Probably because of this, and because there are several possible hypotheses, several recent review articles have focused on hypothetical explanations for the mechanism behind OTS. Although these theories have potential, until more prospective studies are carried out where a longitudinal follow up of athletes (who may develop the OTS) is performed, or specific diagnostic tools are developed, these theories remain speculative.

## Assessment of Overtraining

OTS reflects the attempt of the human body to cope with physiological and other stressors. Several studies have revealed that OTS represents the sum of multiple life stressors, such as physical training, sleep loss, exposure to environmental stresses (e.g. exposure to heat, humidity, cold, high altitude) occupational pressures, change of residence and interpersonal difficulties. Thus OTS can be understood partly within the context of the General Adaptation Syndrome (GAS) of Seyle (1936). Concomitant to this “stress-disturbance” the endocrine system is called upon to counteract the stress situation. The primary hormone products (adrenaline, noradrenaline and cortisol) all serve to redistribute metabolic fuels, maintain blood glucose, and enhance the responsiveness of the cardiovascular system. Repeated exposure to stress may lead to different responsiveness to subsequent stressful experiences depending on the stressor as well as on the stimuli paired with the stressor, either leading to an unchanged or increased or decreased neurotransmitter and receptor function (Meeusen 1999). Behavioural adaptation (neurotransmitter release, receptor sensitivity, receptor binding etc.) in higher brain centres will certainly influence hypothalamic output (Lachuer et al 1994). Lehmann et al. (1993, 1999b) introduced the concept, that hypothalamic function reflects the state of OR or OTS because the hypothalamus integrates many of the stressors. It has been shown that acute stress not only increases hypothalamic monoamine release, but consequently corticotrophic releasing hormone (CRH) and adrenocorticotrophic hormone (ACTH) secretion (Shintani et al 1995). Chronic stress and the subsequent chronically elevated adrenal glucocorticoid secretion could play an important role in the desensitisation of higher brain centres response to acute stressors, since it has been shown that in acute and chronic stress the responsiveness of hypothalamic CRH neurons rapidly falls (Barron et al, 1985, Lehmann et al. 1993, Cizza et al, 1993, Urhausen et al. 1998a).



The lack of definitive diagnostic criteria for the OTS is reflected in much of the 'overreaching' and 'overtraining research' by a lack of consistent findings. There are several criteria that a reliable marker for the onset of the OTS must fulfil: the marker should be sensitive to the training load and ideally, be unaffected by other factors (e.g. diet). Changes in the marker should occur prior to the establishment of the OTS and changes in response to acute exercise should be distinguishable from chronic changes. Ideally, the marker should be relatively easy to measure and not too expensive. However, none of the currently available or suggested markers meets all of these criteria.

## HORMONES

For several years it has been hypothesised that a hormonal mediated central dysregulation occurs during the pathogenesis of the OTS, and that measurements of blood hormones could help to detect the OTS (Lehmann et al. 1993, Fry et al 1991, 1997; Keizer 1998; Kuipers et al 1988; Urhausen et al 1995, 1998a, Steinacker et al. 2000), 2004, Meeusen et al 2004). The results of the research devoted to this subject is far from unanimous, mostly because of the difference in measuring methods, and/or detection limits of the analytical equipment used. Testing of central hypothalamic/pituitary regulation requires functional tests which are considered invasive and require diagnostic experience, the tests are time consuming and expensive.

For a long time the plasma testosterone/cortisol ratio was considered as a good indicator of the overtraining state. This ratio decreases in relation to the intensity and duration of training and it is evident that this ratio indicates only the actual physiological strain of training and can not be used for diagnosis of OR or OTS (Lehmann et al. 1998, 1999b, 2001, Urhausen et al 1995; Meeusen 1999).

Most of the literature agrees that OR and OTS must be viewed on a continuum with a disturbance, an adaptation, and finally a maladaptation of the hypothalamic pituitary adrenal axis (HPA) and all other hypothalamic axes (Keizer 1998; Lehmann et al 1993, 1998, 1999b, 2001) Meeusen 1998, 1999; Meeusen et al 2004, Urhausen et al 1995, 1998b). For example, the HPA adaptation to normal training is characterised by increased ACTH/cortisol ratio only during exercise recovery (due to decreased pituitary sensitivity to cortisol) (Lehmann et al.

1993, 1999b, Duclos et al. 1997, 1998), and by modulation of tissue sensitivity to glucocorticoids (Duclos et al., 1999, 2003). However, it should be emphasized that during a resting day, in endurance-trained athletes 24 h cortisol secretion under non-exercising conditions is normal (Lehmann et al. 1999b, Lancaster et al 2004; Duclos et al., 1999, 2003). Accordingly, morning plasma cortisol and 24 h urinary free cortisol (UFC) in resting endurance-trained men are similar to those of age-matched sedentary subjects (Kern et al., 1995; Duclos et al., 1997). Since UFC represents an integrated measure of the 24 h cortisol secretion, this is in accordance with the previously reported normal diurnal HPA axis rhythm in endurance-trained men (Duclos et al., 1997). Finally, endurance-trained men maintain the seasonal rhythmicity of cortisol excretion; as in sedentary men the highest concentrations of urinary cortisol, morning plasma cortisol and saliva cortisol are observed during autumn and winter compared with spring and summer.

In OTS, a decreased rise in pituitary hormones (ACTH, growth hormone, GH, luteinising hormone, LH and follicle stimulating hormone, FSH) in response to a stressful stimulus is reported (Barron et al 1985; Lehmann et al 1999a, 1993, 1998, 1999b; Urhausen et al 1995, 1998; Wittert et al 1996). But behind the seemingly uniform acute hormonal response to exercise, explaining the disturbance to the neuroendocrine system caused by the OTS is not that simple. Whether peripheral metabolic hormones can be used for OR/OTS diagnosis is currently under discussion. A nutrient-sensing signal of adipose tissue is represented by leptin (Simsch et al. 2002) which has like the glucoregulatory hormone insulin, interleukin-6 (IL-6) and the metabolic growth factor insulin-like growth-factor I (IGF-I) decrease with training induced catabolism like in OR. These signalling molecules have profound effects on the hypothalamus and are involved in the metabolic hormonal regulation of exercise and training (Steinacker et al. 2004).

Meeusen et al (2004) recently published a test protocol with two consecutive maximal exercise tests separated by 4 hours. With this protocol they found that in order to detect signs of OTS and distinguish them from normal training responses or Functional OR, this method may be a good indicator not only of the recovery capacity of the athlete but also of the ability to normally perform the second bout of exercise. The use of 2 bouts of maximal exercise to study neuroendocrine variations showed an adapted exercise-induced increase of ACTH, prolactin (PRL) and GH to a two exercise bout (Meeusen et al 2004). The test could be therefore used as an indirect measure of hypothalamic-pituitary capacity. In a Functional OR

stage a less pronounced neuroendocrine response to a second bout of exercise on the same day is found, (De Schutter et al 2004, Meeusen 2004), while in a Non-Functional OR stage the hormonal response to a two bout exercise protocol shows an extreme increased release after the second exercise trigger (Meeusen 2004). With the same protocol it has been shown that athletes suffering from OTS have an extremely large increase in hormonal release in the first exercise bout, followed by a complete suppression in the second exercise bout (Meeusen et al 2004). This could indicate a hypersensitivity of the pituitary followed by an insensitivity or exhaustion afterwards. Previous reports that used a single exercise protocol found similar effects (Meeusen et al 2004). It appears that the use of two exercise bouts is more useful in detecting overreaching for preventing overtraining. Early detection of overreaching may be very important in the prevention of overtraining.

#### Problems with hormonal data:

- Many factors affect blood hormone concentrations these include factors linked to sampling conditions and/or conservation of the sampling: stress of the sampling, intra- and inter-assay coefficient of variability,
- Food intake (nutrients composition and/or pre- vs post meal sampling) can modify significantly either the basal concentration of some hormones (cortisol, DHEA-S, total testosterone) or their concentration change in response to exercise (cortisol, GH)
- Pulsatility of the secretion of some hormones which modulates the tissue sensitivity to these hormones
- In female athletes the hormonal response will depend on the phase of the menstrual cycle
- Aerobic and resistance protocols typically stimulate different endocrinologic responses
- Hormone concentrations at rest and following stimulation (exercise = acute stimulus) respond differently
- Diurnal and seasonal variations of the hormones
- Stress-induced measures (exercise, pro-hormones, etc) need to be compared with baseline measures from the same individual
- Poor reproducibility and feasibility of some techniques used to measure some hormones (for example free testosterone by RIA instead of the reference method – reserved to some highly specialised centres - equilibrium dialysis)

## PERFORMANCE TESTING

In athletes who have been diagnosed as having the OTS, several signs and symptoms have been associated with this imbalance between training and recovery. However, reliable diagnostic markers for distinguishing between well-trained, OR and athletes having the OTS are lacking. A hallmark feature of the OTS is the inability to sustain intense exercise, a decreased sports-specific performance capacity when the training load is maintained or even increased (Urhausen et al. 1995, Meeusen et al 2004). Athletes suffering from OTS are usually able to start a normal training sequence or a race at their normal training pace but are not able to complete the training load they are given, or race as usual. The key indicator of OTS can be considered an unexplainable decrease in performance. Therefore, an exercise / performance test is considered to be essential for the diagnosis of OTS (Budgett et al. 2000, Lehmann et al. 1999a, Urhausen et al 1995).

It appears that both the type of performance test employed and the duration of the test are important in determining the changes in performance associated with OTS. Debate exists as to which performance test is the most appropriate when attempting to diagnose OR & OTS. In general, time to fatigue tests will most likely show greater changes in exercise capacity as a result of OR & OTS than incremental exercise tests (Halsen and Jeukendrup 2004). Additionally they allow the assessment of substrate kinetics, hormonal responses, and submaximal measures can be made at a fixed intensity and duration. In order to detect subtle performance decrements it might be better to use sports specific performance tests.

### Problems with performance testing

- Baseline measures are often not available and therefore, the degree of performance limitation may not be exactly determined
- The intensity and reproducibility of the test should be sufficient to detect differences (max test; time trial )
- Necessity of highly standardized conditions from one test to another and from one laboratory to another
- Many performance tests are not sport-specific
- Submaximal ergometric test results do not seem to produce significant results (Urhausen et al 1998a), but repeated maximal tests required for assessment of an individual baseline measure, are difficult to obtain in athletes.

## MOOD STATE

There is general agreement that the OTS is characterised by psychological disturbances and negative affective states. Several questionnaires such as the Profile of Mood State [POMS] (Morgan et al 1988; Raglin et al 1994, O'Connor 1997, O'Connor et al 1989, Rietjens et al 2005); Recovery-Stress Questionnaire [RestQ-Sport] (Kellmann 2002); Daily Analysis of Life Demands of Athletes [DALDA] (Halsen et al 2002), and the "self-condition scale" (Urhausen et al. 1998b) have been used to monitor psychological parameters in athletes. It is important to register the current state of stress and recovery, and to prospectively follow the evolution for each athlete individually (Morgan et al 1988, Kellmann 2002). The great advantage of psychometric instruments is the quick availability of information (Kellmann 2002), especially since psychological disturbances coincide with physiological and performance changes, and are generally precursors of neuroendocrine disturbances. In OTS the depressive component is more expressed than in OR (Armstrong and Van Heest 2002). Changes in mood state may be a useful indicator of OR and OTS; however, it is necessary to combine mood disturbances with measures of performance.

### Problems with mood state tests

- Other psychological parameters different from mood state (attention focussing, anxiety) might also be influenced
- Measures always need to be compared with baseline status of the athlete
- The lack of success induced by a long term decrement of performance could explain by itself the depression in OTS
- The differences between self assessment and questionnaires given by an independent experimenter
- The timing of the mood state assessment is important. Questionnaires should be used in standardised conditions (same time and day) to avoid pre- vs post-exercise; morning vs evening variation
- Some coaches are sceptical of using questionnaires for data assessment because they doubt the honesty of answers

## PHYSIOLOGY

There have been several proposals as to which physiological measures might be indicative of OR or OTS. Reduced maximal heart rates after increased training may be the result of reduced sympathetic nervous system activity, of a decreased tissue responsiveness to catecholamines, of changes in adrenergic receptor activity, or may simply be the result of a reduced power output achieved with maximal effort. Several other reductions in maximal physiological measures (oxygen uptake, heart rate, ...) might be a consequence of a reduction in exercise time and not related to abnormalities *per sé*, and it should be noted that changes of resting heart rate are not consistently found in athletes suffering from the OTS.

Heart rate variability (HRV) analysis has been used as a measure of cardiac autonomic balance, with an increase in HRV indicating an increase in vagal (parasympathetic) tone relative to sympathetic activity (Uusitalo et al. 2000). Numerous studies have examined the effects of training on indices of HRV, but to date few studies have investigated HRV in overreached or OTS athletes, with studies showing either no change (Achten & Jeukendrup 2003; Hedelin et al 2000a; Uusitalo et al. 1998), inconsistent changes (Uusitalo et al. 2000) or changes in parasympathetic modulation (Hedelin et al. 2000b).

Hedelin et al (2000a) increased the training load of 9 canoeists by 50% over a 6-day training camp. Running time to fatigue,  $\text{VO}_2\text{max}$ , submaximal and maximal heart rates and maximal blood lactate production all decreased in response to the intensified training; however, all indices of HRV remained unchanged. On average, there were no significant changes in low frequency power, high frequency power, total power or the ratio of low to high frequency power, both in the supine position and after head-up tilt. Similarly, Uusitalo et al (1998) reported no change in intrinsic heart rate and autonomic balance in female athletes following 6-9 weeks of intensified training. This involved the investigation of autonomic balance assessed by pharmacological vagal and  $\beta$ -blockade. In addition, both the time domain and power spectral analysis in the frequency domain were calculated during rest and in response to head-up tilt. Results suggest that HRV in the upright position had a tendency to decrease in response to intensified training in the subjects who were identified as “overtrained” (Uusitalo et al. 2000). This may indicate vagal withdrawal and/or increased sympathetic activity. However, between-subject variability was high in this investigation. Finally, Hedelin et al (2000) reported increased HRV and decreased resting heart rate in a single “overtrained”

athlete when compared to baseline measures. In comparison to normally responding subjects examined during the same period, the “overtrained” subject exhibited an increase in high frequency and total power in the supine position during intensified training, which decreased after recovery. The increase in high frequency power was suggested to be most likely the result of increased parasympathetic activity (Hedelin et al 2000).

Highly controlled and monitored studies that examine possible changes in HRV following OR are lacking. However, a very recent study (Halsen et al. 2005) investigated whether 7 days of intensified training that results in OR is accompanied by changes in HRV. The main finding of this study was that time and frequency domain measures of HRV in both upright and supine positions, were significantly elevated above normal values after intensified training. This suggests an increase in the relative contribution of parasympathetic to sympathetic nervous system activity. However, as with so many of the other physiological measures, it cannot be certain that changes observed during OR are reflected in athletes suffering from the OTS.

#### Problems with physiological measures

- HRV seems a promising tool in theory but needs to be standardised when tested and does not provide consistent results.
- The present data do not allow to distinguish between changes in physiological measures resulting from functional OR, non-functional OR and OTS.

## BIOCHEMISTRY

In prolonged training glycogen stores get close to full depletion, glycogenolysis and glucose transport are downregulated in muscle and liver as well as the liver production of insulin-like growth-factor I, and catabolism is induced. Although this is one of the likely triggers of OTS, muscle glycogen is typically normal when athletes are examined (Lehmann et al. 1999b). Blood glucose is also not typically altered. Resting blood glucose / insulin ratio may indicate mild insulin resistance (Steinacker et al. 2004).

Blood lactate measurements can be dependent on the actual training status of the individual. Other factors that are equally important when discussing changes in blood lactate concentrations are the glycogen status and possible decreases in muscle and liver stores due to

increased training. One almost consistent overall finding, at least in endurance and strength-endurance athletes having OTS, is a diminished maximal lactate concentration while submaximal values remain unchanged or slightly reduced.

Individually increased blood concentrations of Creatine Kinase (CK) and/or urea measured under standardised conditions at rest, may provide information concerning an elevated muscular and/or metabolic strain, but they are not suitable to indicate an OR or OTS state (Urhausen et al 1998a).

The concentration of plasma glutamine has been suggested as a possible indicator of excessive training stress (Rowbottom et al 1995). However, not all studies have found a fall during periods of increased training and overtraining (Walsh et al 1998) and altered plasma glutamine concentrations are not a causative factor of immunodepression in OTS.

Although most of the blood parameters (e.g. blood count, CRP, SR, CK, urea, creatinine, liver enzymes, glucose, ferritin, sodium, potassium, etc. ) are not capable of detecting OR or OTS, they are helpful in providing information on the actual health status of the athlete, and therefore useful in the “exclusion diagnosis”.

#### Problems with biochemistry testing

- Lactate differences are sometimes subtle (lying within the measuring error of the apparatus) and depend on the modus of the exercise test used.
- No lactate changes reported in strength athletes.
- Glutamine may fall with increased training load but low plasma glutamine concentration is not a consistent finding in OTS.

#### IMMUNE SYSTEM

There are many reports on URTI due to increased training, and also in OR and OTS athletes. It seems feasible that intensified training (leading to OR or OTS) may increase both the duration of the so-called “open window” and the degree of the resultant immunodepression. The amount of scientific information to substantiate these arguments is, however, limited.

It might just be that the increased URTI incidence is likely to reflect the increase in training, regardless of the response of the athlete to the increased physical stress. URTI might be one of the ‘triggering’ factors that can lead to the induction of OTS.



Several studies that have investigated the effects of short periods (typically 1-3 weeks) of intensified training on resting immune function and on immunoendocrine responses to endurance exercise indicate that several indices of neutrophil function appear to be sensitive to the training load. A 2-week period of intensified training in already well-trained triathletes was associated with a 20% fall in the bacterially-stimulated neutrophil degranulation response (Robson et al 1999). In another study, neutrophil and monocyte oxidative burst activity, mitogen-stimulated lymphocyte proliferation and percentage and number of T-cells producing interferon- $\gamma$  were lower at rest following one week of intensified training in cyclists (Lancaster et al 2003). Other leukocyte functions including T-lymphocyte CD4<sup>+</sup>/CD8<sup>+</sup> ratios, lymphocyte antibody synthesis and natural killer cell cytotoxic activity have been shown to be lower following increases in the training load in already well-trained athletes (Verde et al 1992). Several studies have documented a fall in salivary IgA concentration with intensified training and some, though not all have observed a negative relationship between salivary IgA concentration and occurrence of URTI (Gleeson 2000). Thus, with sustained periods of heavy training, several aspects of both innate and adaptive immunity are depressed. Several studies have examined changes in immune function during intensive periods of military training (Carins and Booth 2002; Tiollier et al 2005). However, this often involves not only strenuous physical activity, but also dietary energy deficiency, sleep deprivation and psychological challenges. These multiple stressors are likely to induce a pattern of immunoendocrine responses that amplify the exercise-induced alterations.

Studies that have examined athletes exposed to a long-term training periods (e.g. over the course of a 5-10 month competitive season) have shown a general trend of depression of both systemic and mucosal immunity (Baj et al 1994; Bury et al 1998; Gleeson et al 1995, 1999; Gleeson 2000; Gleeson 2005). Although elite athletes are not clinically immune deficient, it is possible that the combined effects of small changes in several immune parameters may compromise resistance to common minor illnesses such as URTI. Protracted immune depression linked with prolonged training may determine susceptibility to infection, particularly at times of major competitions. However, it might just be that the increased URTI incidence reflects the increased stress associated with increased training, regardless of the response of the athlete to the increased physical stress. Whether immune function is seriously impaired in athletes suffering from OTS is unknown as there is insufficient scientific data

available. However, anecdotal reports from athletes and coaches of an increased infection rate with OTS (Smith 2000) have been supported by a few empirical studies (Kingsbury et al 1998; Reid et al 2004). In a cohort study of highly trained athletes prior to the Olympic Games, over 50% of the athletes who reported symptoms of “overtraining” presented with infection compared with none of the athletes in the overreached group (Kingsbury et al 1998). In junior rowers, studied during and following a training camp (functional OR), 40 % of the male subjects had URTI (Steinacker et al. 2002). In the study by Reid et al (2004) 41 competitive athletes with persistent fatigue and impaired performance had a thorough medical examination which identified medical conditions with the potential to cause fatigue and/or recurrent infections in 68% of the athletes. The most common conditions were humoral immune deficiency and unresolved viral infections. Evidence of Epstein-Barr virus reactivation was detected in 22% of the athletes tested. Thus, it seems plausible that a significant number of athletes who are diagnosed as suffering from OTS may represent cases of unresolved infection.

There are only a few reports of differences in immune function status in “overtrained” athletes compared with healthy trained athletes (e.g. Mackinnon and Hooper 1994; Gabriel et al 1998) and most studies on “overtrained” athletes have failed to find any differences (Rowbottom et al 1995; Mackinnon et al 1997). Circulating numbers of lymphocyte subsets change with exercise and training. With heavy training, the T-lymphocyte CD4<sup>+</sup>/CD8<sup>+</sup> (helper/ suppressor) ratio falls. However, this has not been shown to be different in athletes diagnosed as suffering from OTS compared with healthy well-trained athletes. One study (Gabriel et al 1998) has shown that the expression of other proteins on the cell surface of T-lymphocytes does seem to be sensitive enough to distinguish between the majority of “overtrained” athletes and healthy athletes. The expression of CD45RO on T-helper CD4<sup>+</sup> cells (but not the circulating numbers of CD45RO<sup>+</sup> T-cells) was significantly higher in athletes suffering from OTS compared with healthy well-trained controls. Using this indicator, “overtraining” could be classified with high specificity and sensitivity. However, CD45RO is a marker of T-memory cells and activated T cells. Thus, higher expression of CD45RO on T cells may merely be indicative of the presence of acute infection, which is, of course, a possible cause of the underperformance. Fry et al (1994) reported a significant increase in activation markers (CD25, HLA-DR) in blood lymphocytes of “overtrained” athletes. Unresolved viral infections are not routinely assessed in elite athletes, but it may be worth investigating this in individuals experiencing

fatigue and underperformance in training and competition. Thus, infection might be one of the ‘triggering’ factors that can lead to the induction of OTS or in some cases the diagnosis of OTS cannot be differentiated from a state of post-viral fatigue such as that observed with episodes of glandular fever.

In conclusion, it is clear that the immune system is extremely sensitive to stress - both physiological and psychological - and thus, potentially, immune variables could be used as an index of stress in relation to exercise training. The current information regarding the immune system and overreaching confirms that periods of intensified training result in depressed immune cell functions with little or no alteration in circulating cell numbers. However, although immune parameters change in response to increased training load, these changes do not distinguish between those athletes who successfully adapt to overreaching and those who maladapt and develop symptoms of OTS. Furthermore, at present it seems that measures of immune function cannot really distinguish OTS from infection or post-viral fatigue states.

#### Problems with immunological testing

- Timing of the test (time of the day; time since last exercise session)
- Lack of consistency of the data in literature
- Time consuming and very expensive (for functional measures)

## Prevention

One general confounding factor when reviewing literature on OTS is that the definition and diagnosis of OR & OTS is not standardised. One can even question if in most of the studies subjects were suffering from OTS. Because the OTS is difficult to diagnose, authors agree that it is important to prevent OTS (Foster et al 1988, Kuipers 1996, Uusitalo 2001). Moreover, because the OTS is mainly due to an imbalance in the training recovery ratio (too much training and competitions and too little recovery), it is of utmost importance that athletes record daily their training load, using a daily training diary or training log (Foster et al 1998, Foster et al 1988, Foster 1998). The four methods, most frequently used to monitor training and prevent overtraining are: retrospective questionnaires, training diaries, physiological screening and the direct observational method (Hopkins 1991). Also the psychological screening of athletes (Berglund & Safstrom 1994, Hooper et al 1995, Hooper &

McKinnon 1995, McKenzie 1999, Raglin et al 1991, Urhausen et al 1998b, Morgan et al 1988, Kellmann 2002, Steinacker et al. 2002) and the Ratings of Perceived Exertion (RPE) (Acevedo et al 1994, Callister et al 1990, Foster et al 1996, Foster 1998, Hooper et al 1995, Hooper & McKinnon 1995, Kentta & Hassmen 1998, Snyder et al 1993) have received more and more attention nowadays.

Hooper et al. (1995) used daily training logs during an entire season in swimmers to detect staleness (OTS). The distances swum, the dry-land work time and subjective self-assessment of training intensity were recorded. In addition to these training details the swimmers also recorded subjective ratings of quality of sleep, fatigue, stress and muscle soreness, body mass, early morning heart rate, occurrence of illness, menstruation and causes of stress. Swimmers were classified as having the OTS if their profile met five criteria. Three of these criteria were determined by items of the daily training logs: fatigue ratings in the logs of more than 5 (scale 1-7) lasting longer than 7 days, comments in the page provided in each log that the athlete was feeling that he/she responded poorly to training and a negative response to a question regarding presence of illness in the swimmer's log, together with normal blood leukocyte count.

Foster et al. (1996, 1998) have determined training load as the product of the subjective intensity of a training session using 'session RPE' and the total duration of the training session expressed in minutes. If these parameters are summated on a weekly bases it is called the total training load of an individual. The 'session RPE' has been shown to be related to the average percent heart rate reserve during an exercise session and to the percentage of a training session during which the heart rate is in blood lactate derived heart rate training zones. With this method of monitoring training they have demonstrated the utility of evaluating experimental alterations in training and have successfully related training load to its performance (Foster et al 1996). However, training load is clearly not the only training related variable contributing to the genesis of OTS. So additionally to the weekly training load, daily mean training load as well as the standard deviation of training load were calculated during each week. The daily mean divided by the standard deviation was defined as the monotony. The product of the weekly training load and monotony was calculated as strain. The incidence of simple illness and injury was noted and plotted together with the indices of training load,

monotony and strain. They noted the correspondence between spikes in the indices of training and subsequent illness or injury and thresholds that allowed for optimal explanation of illnesses were computed (Foster 1998).

One of the disadvantages of the traditional ‘paper & pencil’ method is that data collection can be complicated, and that immediate feedback is not always possible. Another problem is that when athletes are on an international training camp or competition, immediate ‘data computing’ is not possible. It might therefore be useful to have an ‘on-line’ training log which has specific features in detecting not only slight differences in training load, but also the subjective parameters (muscle soreness, mental and physical well being) that have been proven to be important in the detection of the OTS.

## Conclusion

A difficulty with recognising and conducting research into athletes with OTS is defining the point at which OTS develops. Many studies claim to have induced OTS but it is more likely that they have induced a state of OR in their subjects. Consequently, the majority of studies aimed at identifying markers of ensuing OTS are actually reporting markers of excessive exercise stress resulting in the acute condition of overreaching and not the chronic condition of OTS. The mechanism of the OTS could be difficult to examine in detail maybe because the stress caused by excessive training load, in combination with other stressors might trigger different “defence mechanisms” such as the immunological, neuroendocrine and other physiological systems that all interact and probably therefore cannot be pinpointed as the “sole” cause of OTS. It might be that as in other Syndromes (e.g. chronic fatigue syndrome, or burnout) the psychoneuroimmunology (study of brain-behavior-immune interrelationships) might shed a light on the possible mechanisms of OTS, but until there is no definite diagnostic tool, it is of utmost importance to standardise measures that are now thought to provide a good inventory of the training status of the athlete. It is very important to emphasise the need to distinguish the OTS from overreaching and other potential causes of temporary underperformance such as anaemia, acute infection, muscle damage and insufficient carbohydrate intake.

The physical demands of intensified training are not the only elements in the development of OTS. It seems that a complex set of psychological factors are important in the development of OTS, including excessive expectations from a coach or family members, competitive stress, personality structure, social environment, relationships with family and friends, monotony in training, personal or emotional problems, and school- or work- related demands. While no single marker can be taken as an indicator of impending OTS, the regular monitoring of a combination of performance, physiological, biochemical, immunological and psychological variables would seem to be the best strategy to identify athletes who are failing to cope with the stress of training.

We therefore propose a “Check List” that might help the physicians to decide on the diagnosis of OTS and to exclude other possible causes of underperformance (see figure 2).

### Considerations for coaches and physicians

Until a definitive diagnostic tool for OTS is present, coaches and physicians need to rely on performance decrements as verification that OTS exists. However, if sophisticated laboratory techniques are not available, the following considerations may be useful :

- Maintain accurate records of performance during training and competition. Be willing to adjust daily training intensity/volume, or allow a day of complete rest, when performance declines, or the athlete complains of excessive fatigue.
- Avoid excessive monotony of training
- Always individualise the intensity of training
- Encourage and regularly reinforce optimal nutrition, hydration status and sleep
- Be aware that multiple stressors such as sleep loss or sleep disturbance (e.g. jet lag), exposure to environmental stressors, occupational pressures, change of residence, and interpersonal or family difficulties may add to the stress of physical training
- Treat OTS with rest ! Reduced training may be sufficient for recovery in some cases of overreaching
- Resumption of training should be individualised on the basis of the Signs & Symptoms because there is no definitive indicator of recovery
- Communication with the athletes (maybe through an on-line training diary) about their physical, mental and emotional concerns is important.

- Include regular psychological questionnaires to evaluate the emotional and psychological state of the athlete
- Maintain confidentiality regarding each athlete's condition (physical, clinical and mental).
- Importance of regular health checks performed by a multidisciplinary team (physician, nutritionist, psychologist...)
- Allow the athlete time to recover after illness/injury
- Note the occurrence of URTI and other infectious episodes; the athlete should be encouraged to suspend training or reduce the training intensity when suffering from an infection
- Always rule out an organic disease in a cases of performance decrement.
- Unresolved viral infections are not routinely assessed in elite athletes, but it may be worth investigating this in individuals experiencing fatigue and underperformance in training and competition.

Moreover, when OTS is suspected, it is also of utmost importance to standardize the criteria used for diagnosis and/or, at least, as tools for the diagnosis of OTS are lacking, to standardize the criteria of exclusion of OTS (see figure 1 for the definition and figure 2) .

## Diagnosis of OTS – checklist (figure 2)

### Performance - fatigue

Is the athlete suffering from :

- Unexplainable Underperformance
- Persistent Fatigue
- Increased sense of effort in training
- Sleep disorders
- ...

### Exclusion Criteria

Are there confounding diseases ?

- Anaemia
- Epstein Barr virus
- Other infectious diseases
- Muscle damage (high CK)
- Lyme disease
- Endocrinological diseases (diabetes, thyroid, adrenal gland, ...)
- Major disorders of feeding behaviour
- Biological abnormalities (increased SR, increased CRP, creatinine, ferritin, increased liver enzymes, ...)
- Injury (musculoskeletal system)
- Cardiological symptoms
- Adult-onset asthma
- Allergies
- ...

### Are there training errors ?

- Training volume increased (>5%) (hrs/wk, km/wk)
- Training intensity increased significantly
- Training monotony present
- High number of competitions
- In endurance athletes : Decreased performance at “anaerobic” threshold
- Exposure to environmental stressors (altitude, heat, cold, ...)
- ...

### Other confounding factors :

- Psychological signs and symptoms (disturbed POMS, RestQ-sport, RPE, ...)
- Social factors (family, relationships, financial, work, coach, team, ...)
- Recent or multiple Time zone travel
- ...

### Exercise test

- Are there baseline values to compare with? (Performance, Heart Rate, Hormonal, Lactate,...)
- Maximal exercise test performance
- Submaximal or sports specific test performance
- Multiple performance tests
- ...



## References

1. **Acevedo E, Rinehardt K, Kraemer R.** Perceived exertion and affect at varying intensities of running. *Res Q Exerc Sport*, 65(4):372-6 1994
2. **Achten J, Jeukendrup AE.** Heart rate monitoring: applications and limitations. *Sports Med* 33:517-538, 2003.
3. **Armstrong L, VanHeest J.** The unknown mechanisms of the overtraining syndrome. Clues from depression and Psychoneuroimmunology. *Sports Med* 32: 185-209, 2002
4. **Baj Z, Kantorski J, Majewska E, Zeman K, Pokoca L, Fornalczyk E, Tchorzewski H, Sulowska Z, Lewicki R.** Immunological status of competitive cyclists before and after the training season. *Int J Sports Med* 15: 319-324, 1994.
5. **Barron G, Noakes T, Levy W, Smidt C, Millar R.** Hypothalamic dysfunction in overtrained athletes, *J Clin Endocrin Metabol.* 60: 803-806, 1985
6. **Berglund B, Safstrom H,** Psychological monitoring and modulation of training load of world-class canoeists. *Med Sci Sports Exerc*, 26:1036-40 1994
7. **Budgett R, Newsholme E, Lehmann M, Sharp C, Jones D, Peto T, Collins D, Nerurkar R, White P.** Redefining the overtraining syndrome as the unexplained underperformance0 syndrome. *Br J Sports Med* 34: 67-68, 2000.
8. **Bury T, Marechal R, Mahieu P, Pirnay F.** Immunological status of competitive football players during the training season. *Int J Sports Med* 19: 364368, 1998.
9. **Callister R, Callister R, Fleck S, Dudley G.** Physiological and performance responses to overtraining in elite judo athletes. *Med Sci Sports Exerc*, 22(6):816-24 1990
10. **Carins J, Booth C.** Salivary immunoglobulin-A as a marker of stress during strenuous physical training. *Aviat Space Environ Med.*3: 1203-1207, 2002.
11. **Cizza G, Kvetnansky R, Tartaglia M, Blackman M, Chrousos G, Gold P.** Immobilisation stress rapidly decreases hypothalamic corticotropin-releasing hormone secretion in vitro in the male 344/N fischer rat. *Life Sci.* 53: 233-240, 1993
12. **De Schutter, Buyse L, Meeusen R, Roelands B.** Hormonal responses to a high-intensity training period in Army recruits. *Med Sci Sports Exerc* 36: S295, 2004.
13. **Duclos, M., Corcuff, J.-B., Arsac, L., Moreau-Gaudry, F., Rashedi, M., Roger, P., Tabarin, A., Manier, G.** Corticotroph axis sensitivity after exercise in endurance-trained athletes. *Clin Endocrinol* 8, 493-501, 1998.

14. **Duclos, M., Corcuff, J.-B., Rashedi, M., Fougere, V., Manier, G.** Trained versus untrained men: different immediate post-exercise responses of pituitary-adrenal axis. *Eur J Appl Physiol* **75**, 343-350, 1997.
15. **Duclos, M., Gouarne, C., Bonnemaïson, D.** Acute and chronic effects of exercise on tissue sensitivity to glucocorticoids. *J Appl Physiol* **94**, 869-875, 2003.
16. **Duclos, M., Minkhar, M., Sarrieau, A., Bonnemaïson, D., Manier, G., Mormede, P.** Reversibility of endurance training-induced changes on glucocorticoid sensitivity of monocytes by an acute exercise. *Clin Endocrinol* **1**, 749-756, 1999.
17. **Foster C, Daines E, Hector L, Snyder A, Welsh R.** Athletic performance in relation to training load. *Wisconsin Med J*, 95:370-374, 1996
18. **Foster C, Snyder A, Thompson N and Kuettel K.** Normalisation of the blood lactate Profile. *Int J Sports Med* 9:198-200, 1988
19. **Foster C.** Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*, 30(7):1164-8 1998
20. **Fry A, Kraemer W.** Resistance exercise overtraining and overreaching. *Sports Med.* 23: 106-129, 1997
21. **Fry R, Morton A, Keast D.** Overtraining in athletes, *Sports Med.* 12: 32-65, 1991
22. **Fry RW, Grove JR, Morton AR, Zeroni PM, Gaudieri S, Keast D.** Psychological and immunological correlates of acute overtraining. *Br J Sports Med* 28: 241-246, 1994.
23. **Gabriel HH, Urhausen A, Valet G, Heidelberg U, Kindermann W..** Overtraining and immune system: A prospective longitudinal study in endurance athletes. *Med Sci Sports Exerc* 30: 1151-1157, 1998.
24. **Gleeson M, McDonald WA, Cripps AW, Clancy RL, Fricker PA..** The effect on immunity of long-term intensive training in elite swimmers. *Clin Exp Immunol.* 102 : 210-216, 1995.
25. **Gleeson M, McDonald WA, Pyne DB, Cripps AW, Francis JL, Fricker PA, Clancy RL.** Salivary IgA levels and infection risk in elite swimmers. *Med Sci Sports Exerc* 31: 67-73, 1999.
26. **Gleeson M.** Immune function and exercise. *Eur J Sport Sci* 2005 (in press)
27. **Gleeson M.** Mucosal immune responses and risk of respiratory illness in elite athletes. *Exerc Immunol Rev.*6: 5-42, 2000.
28. **Halsen S, Jeukendrup A.** Does Overtraining exist ? An analysis of overreaching and overtraining research. *Sports Med* 34: 967-981, 2004

29. **Halsen SL, Bridge MW, Meeusen R, Busschaert B, Gleeson M, Jones DA, Jeukendrup AE.** Time course of performance changes and fatigue markers during intensified training in trained cyclists. *J Appl Physiol* 93(3): 947-956, 2002
30. **Halsen SL, Lancaster GI, Gleeson M, Jeukendrup AE.** Heart rate variability and hormonal indices of endocrine function in overreaching. *Med Sci Sports Exerc* (in press), 2005.
31. **Hedelin R, Kentta G, Wiklund U, Bjerle P, Henriksson-Larsen K.** Short-term overtraining: effects on performance, circulatory responses, and heart rate variability. *Med Sci Sports Exerc* 32: 1480-1484, 2000a.
32. **Hedelin R, Wiklund U, Bjerle P, Henriksson-Larsen K.** Cardiac autonomic imbalance in an overtrained athlete. *Med Sci Sports Exerc* 32: 1531-1533, 2000b.
33. **Hooper S, Mackinnon L.** Monitoring overtraining in athletes. Recommendations. *Sports Med*, 20(5):321-7 1995.
34. **Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW.** Markers for monitoring overtraining and recovery. *Med Sci Sports Exerc*, 27(1):106-12 1995
35. **Hopkins W,** Quantification of training in competitive sports. *Methods and Applications. Sports Med*, 12:161-83 1991
36. **Jeukendrup AE, Hesselink MK, Snyder AC, Kuipers H, Keizer HA.** Physiological changes in male competitive cyclists after two weeks of intensified training. *Int J Sports Med* 13: 534-541, 1992
37. **Keizer H.** Neuroendocrine aspects of overtraining. In : *Overtraining in Sport* (Kreider, Fry, O'Toole eds.) Human Kinetics, Champaign Illinois. pp. 145-167, 1998
38. **Kellmann M** (ed). Enhancing recovery: preventing underperformance in athletes. Human Kinetics; Champaign IL, 2002.
39. **Kentta G, Hassmen P.** Overtraining and Recovery. *Sports Med*, 26(1):1-16 1998
40. **Kern, W., Perras, B., Wodick, R., Fehm, H. L., and Born, J.** Hormonal secretion during nighttime sleep indicating stress of daytime exercise. *J Appl Physiol* 79, 1461-1468, 1995.
41. **Kingsbury KJ, Kay L, Hjelm M.** Contrasting plasma amino acid patterns in elite athletes: association with fatigue and infection. *Br J Sports Med* 32: 25-33, 1998.
42. **Kreider R, Fry AC, O'Toole M.** Overtraining in sport: terms, definitions, and prevalence. In: Kreider R, Fry AC, O'Toole M, editors. *Overtraining in sport*. Champaign (IL): Human Kinetics, 1998: vii-ix
43. **Kuipers H, Keizer H.** Overtraining in elite athletes, *Sports Med*. 6: 79-92, 1988

44. **Kuipers H.** How much is too much? Performance aspects of overtraining. *Res Q Exerc Sport* 67(s3) :65-69 1996
45. **Lachuer J, Delton I, Buda M, Tappaz M.** The habituation of brainstem catecholaminergic groups to chronic daily restraint stress is stress specific like that of the hypothalamo-pituitary-adrenal axis. *Brain Res.* 638: 196-202, 1994
46. **Lancaster GI, Halson SL, Khan Q, Drysdale P, Wallace F, Jeukendrup AE, Drayson MT, Gleeson M.** Effect of acute exhaustive exercise and a 6-day period of intensified training on immune function in cyclists. *J Physiol* 548.P: O96, 2003.
47. **Lancaster, G.I., Halson, S.L., Khan, Q., Drysdale, P., Jeukendrup, A.E., Drayson, M.T., Gleeson, M.** The effects of acute exhaustive exercise and intensified training on type 1/type 2 T cell distribution and cytokine production. *Exerc Immunol Rev.* **10**: 91-106, 2004.
48. **Lehmann M, Foster C, Dickhuth HH, Gastmann U.** Autonomic imbalance hypothesis and overtraining syndrome. *Med Sci Sports Exerc* 30: 1140-1145, 1998.
49. **Lehmann M, Foster C, Gastmann U, Keizer H, Steinacker J.** Definitions, types, symptoms, findings, underlying mechanisms, and frequency of overtraining and overtraining syndrome. In: Lehmann M, Foster C, Gastmann U, Keizer H, Steinacker J (eds). *Overload, performance incompetence, and regeneration in sport.* Kluwer Academic/Plenum publishers, New York. pp 1-6, 1999a
50. **Lehmann M, Foster C, Netzer N, Lormes W, Steinacker J.M., Liu Y, Opitz-Gress A, Gastmann U.** Physiological responses to short- and long-term overtraining in endurance athletes. In : *Overtraining in Sport* (Kreider, Fry, O'Toole eds.) Human Kinetics, Champaign Illinois. pp. 19-46, 1998
51. **Lehmann M, Gastmann U, Baur S, Liu Y, Lormes W, Opitz-Gress A, Reissnecker S, Simsch C, Steinacker JM.** Selected parameters and mechanisms of peripheral and central fatigue and regeneration in overtrained athletes. In: Lehmann M, Foster C, Gastmann U, Keizer H, Steinacker J (eds). *Overload, performance incompetence, and regeneration in sport.* Kluwer Academic/Plenum publishers, New York. pp 7-25, 1999b
52. **Lehmann M, Knizia K, Gastmann U, Petersen KG, Khalaf AN, Bauer S, Kerp L, Keul J.** Influence of 6-week, 6 days per week, training on pituitary function in recreational athletes. *Br J Sports Med* 27:186-192 1993
53. **Lehmann M, Petersen KG, Liu Y, Gastmann U, Lormes W, Steinacker JM.** Chronische und erschöpfende Belastungen im Sport - Einfluss von Leptin und Inhibin.

[Chronic and exhausting training in sports – influence of leptin and inhibin] Dtsch Z Sportmed 51, 234 – 243, 2001.

54. **Mackinnon LT, Hooper S, Jones S, Gordon R, Bachmann A.** Hormonal, immunological, and haematological responses to intensified training in elite swimmers. Med Sci Sports Exerc 29: 1637-1645, 1997.

55. **Mackinnon LT, Hooper S.** Mucosal (secretory) immune system responses to exercise of varying intensity and during overtraining. Int J Sports Med 15: S179-S183, 1994.

56. **McKenzie D.** Markers of excessive exercise. Can J Appl Physiol, 24(1):66-73 1999

57. **Meeusen R, Piacentini M.F., Busschaert B., Buyse L., De Schutter G., Stray-Gundersen J.** Hormonal responses in athletes: the use of a two bout exercise protocol to detect subtle differences in (over)training status. Eur J Appl Physiol. 91 :140-146, 2004

58. **Meeusen R.** “Overtraining and the neuroendocrine system”. Med Sci Sports Exerc 36: S45, 2004.

59. **Meeusen R.** Overtraining and the central nervous system, the missing link ? In: Lehmann M, Foster C, Gastmann U, Keizer H, Steinacker J (eds). *Overload, performance incompetence, and regeneration in sport*. Kluwer Academic/Plenum publishers, New York. pp 187-202, 1999

60. **Meeusen R.** Overtraining, indoor & outdoor. Vlaams tijdschrift voor Sportgeneeskunde & Sportwetenschappen 19: 8-19, 1998

61. **Morgan W, Costill D, Flynn M, Raglin J, O'Connor P.** Mood disturbance following increased training in swimmers, Med Sci Sports Exerc 20: 408-414, 1988

62. **O'Connor P, Morgan W, Raglin J, Barksdale C, Kalin N.** Mood state and salivary cortisol levels following overtraining in female swimmers. Psychoneuroendocr 14: 303-310, 1989

63. **O'Connor P.** Overtraining and staleness. In: *Physical activity & Mental Health*. W.P. Morgan (ed). Taylor & Francis, Washington, USA, pp 145-160, 1997

64. **Raglin J, Morgan W, O'Connor P,** Changes in mood state during training in female and male college swimmers. Int J Sports Med 12:585-9 1991

65. **Raglin J, Morgan W.** Development of a scale for use in monitoring training-induced distress in athletes. Int J Sports Med, 15: 84-88, 1994

66. **Reid VL, Gleeson M, Williams N, Clancy RL.** Clinical investigation of athletes with persistent fatigue and/or recurrent infections. Br J Sports Med 38: 42-45, 2004.

67. **Rietjens GJ, Kuipers H, Adam JJ, Saris WH, Breda van E, Hamont van D, Keizer H.** Physiological, biochemical and psychological markers of overreaching. *Int J Sport med* 26:16-26; 2005.
68. **Robson PJ, Blannin AK, Walsh NP.** The effect of an acute period of intense interval training on human neutrophil function and plasma glutamine in endurance-trained male runners. *J Physiol* 515.P: 84-85P, 1999.
69. **Rowbottom DG, Keast D, Goodman C, Morton A.** The haematological, biochemical and immunological profile of athletes suffering from the Overtraining Syndrome. *Eur J Appl Physiol* 70: 502-509, 1995
70. **Selye H.** A syndrome produced by diverse nocuous agents. *Nature*, 138: 32, 1936
71. **Shintani F, Nakaki T, Kanba S, Sato K, Yagi G, Shiozawa M, Aiso S, Kato R, Asai M.** Involvement of interleukin-1 in immobilisation stress-induced increase in plasma adrenocorticotrophic hormones and in release of hypothalamic monoamines in rat. *J Neurosci* 15: 1961-1970, 1995
72. **Simsch C, Lormes W, Petersen KG, Liu Y, Hackney AC, Lehmann M, Steinacker JM.** Training intensity influences leptin and thyroid hormones in highly trained rowers. *Int J Sports Med* 23: 422-427, 2002.
73. **Snyder A, Jeukendrup A, Hesselink M, Kuipers H, Foster C.** A physiological/psychological indicator of overreaching during intensive training. *Int J Sports Med*, 14:29-32 1993.
74. **Smith LL.** Cytokine hypothesis of overtraining: a physiological adaptation to excessive stress? *Med Sci Sports Exerc* 32: 317-331, 2000.
75. **Steinacker JM , Lormes W, Liu Y, Opitz-Gress A, Baller B, Günther K, Gastmann U, Petersen KG, Lehmann M, Altenburg D.** Training of Junior Rowers before World Championships. Effects on performance, mood state and selected hormonal and metabolic responses. *J Phys Fit Sports Med* 40: 327-335, 2000
76. **Steinacker JM, Lehmann M .** Clinical findings and mechanisms of stress and recovery in athletes. In: M. Kellmann (ed) *Enhancing Recovery: Preventing Underperformance in Athletes*. 103 - 118, Champaign, Il: Human Kinetics, 2002.
77. **Steinacker JM, Lormes W, Reissnecker S, Liu Y.** New aspects of the hormone and cytokine response to training. *Eur J Appl Physiol* 91: 382–93, 2004
78. **Tiollier E, Gomez-Merino D, Burnat P, Jouanin JC, Bourrillhon C, Filaire E, Guezennec CY, Chennaoui M.** Intense training: mucosal immunity and incidence of respiratory infections. *Eur J Appl Physiol* 93: 421-428, 2005.

79. **Urhausen A, Gabriel H, Kindermann W.** Blood hormones as markers of training stress and overtraining. *Sports Med.* 20: 251-276, 1995
80. **Urhausen A, Gabriel H, Kindermann W.** Impaired pituitary hormonal response to exhaustive exercise in overtrained endurance athletes. *Med Sci Sports Exerc.* 30: 407-414, 1998a
81. **Urhausen A, Gabriel H, Weiler B, Kindermann W.** Ergometric and psychological findings during overtraining: a long-term follow-up study in endurance athletes. *Int J Sports Med,* 19:114-20 1998b
82. **Urhausen A, Kindermann W.** Diagnosis of Overtraining – What Tools do we have ? *Sports Med* 32: 95-102, 2002.
83. **Uusitalo A.** Overtraining. Making a difficult diagnosis and implementing targeted treatment. *The Physician and Sportsmedicine* 29:35-50 2001
84. **Uusitalo AL, Uusitalo AJ, Rusko HK.** Exhaustive endurance training for 6-9 weeks did not induce changes in intrinsic heart rate and cardiac autonomic modulation in female athletes. *Int J Sports Med* 19:532-540, 1998.
85. **Uusitalo AL, Uusitalo AJ, Rusko HK.** Heart rate and blood pressure variability during heavy training and overtraining in the female athlete. *Int J Sports Med* 21:45-53, 2000.
86. **Verde T, Thomas S, Shephard RJ.** Potential markers of heavy training in highly trained endurance runners. *Brit J Sports Med* 26: 167-175, 1992.
87. **Walsh, NP, Blannin AK, Robson PJ, Gleeson M.** Glutamine, exercise and immune function: links and possible mechanisms. *Sports Med* 26: 177-191, 1998
88. **Wittert G, Livesey J, Espiner E, Donald R.** Adaptation of the hypothalamopituitary adrenal axis to chronic exercise stress in humans. *Med Sci Sports Exerc.* 28: 1015-1019, 1996