

Does Overtraining Exist?

An Analysis of Overreaching and Overtraining Research

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Abstract

Athletes experience minor fatigue and acute reductions in performance as a consequence of the normal training process. When the balance between training stress and recovery is disproportionate, it is thought that overreaching and possibly overtraining may develop. However, the majority of research that has been conducted in this area has investigated overreached and not overtrained athletes. Overreaching occurs as a result of intensified training and is often considered a normal outcome for elite athletes due to the relatively short time needed for recovery (approximately 2 weeks) and the possibility of a supercompensatory effect. As the time needed to recover from the overtraining syndrome is considered to be much longer (months to years), it may not be appropriate to compare the two states. It is presently not possible to discern acute fatigue and decreased performance experienced from isolated training sessions, from the states of overreaching and overtraining. This is partially the result of a lack of diagnostic tools, variability of results of research studies, a lack of well controlled studies and individual responses to training.

The general lack of research in the area in combination with very few well controlled investigations means that it is very difficult to gain insight into the incidence, markers and possible causes of overtraining. There is currently no evidence aside from anecdotal information to suggest that overreaching precedes overtraining and that symptoms of overtraining are more severe than overreaching. It is indeed possible that the two states show different defining characteristics and the overtraining continuum may be an oversimplification. Critical analysis of relevant research suggests that overreaching and overtraining investigations should be interpreted with caution before recommendations for markers of overreaching and overtraining can be proposed. Systematically controlled and monitored studies are needed to determine if overtraining is distinguishable from overreaching, what the best indicators of these states are and the underlying mechanisms that cause fatigue and performance decrements. The available scientific and anecdotal evidence supports the existence of the overtraining syndrome; however, more research is required to state with certainty that the syndrome exists.

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. Athletes may experience similar or heightened symptoms following completion of the intensified training period and may be identified as overreached. Continual training and/or non-training stress is suggested to result in a state of overtraining.^[1] To date, there are a number of investigations that have examined the effects of an intensified training period that resulted in overreaching, on numerous physiological, biochemical, psychological, immunological and hormonal variables (for a recent review, see Urhausen and Kindermann^[1]). However, information regarding overtraining is based almost entirely on anecdotal information. The majority of studies examine athletes in a state of overreaching, as it is not ethical to deliberately induce a state of overtraining.

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 with baseline levels.

As it is possible, by definition, to recover from a state of overreaching within a 2-week period,^[2,3] 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 possibly years to completely recover, in which time an athlete's career may be seriously compromised. Therefore, the usefulness and relevance of research purely investigating overreaching must be considered. In essence, it is generally thought that symptoms of overtraining, such as fatigue, performance decline and mood disturbances, are more severe than those of overreaching. However, there is no scientific evidence to either confirm or refute this suggestion. Importantly, as there is no diagnostic tool to identify an athlete as overtrained, 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, overtraining is diagnosed. Hence, there is no objective evidence that the athlete is indeed overtrained. Additionally, in the studies that induce a state of overreaching, many of the physiological and biochemical responses to the increased training are highly variable, with some measures in some studies demonstrating changes and others remaining unaltered. The aim of this review is to critically examine

literature on both overreaching and overtraining and to determine if there is sufficient and appropriately accomplished scientific evidence to indicate that the state of overtraining does indeed exist.

The lack of common and consistent terminology in the study of overtraining is one of the many problems associated with research in this area. For the purpose of this review the following definitions will be used:^[4]

- **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 overtraining in which restoration of performance capacity may take *several weeks or months*.
- **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 overtraining in which restoration of performance capacity may take from *several days to several weeks*.

These definitions suggest that the difference between overtraining and overreaching is the amount of time needed for performance restoration and not the type or duration of training stress or the degree of impairment.^[5] While this may be correct, there is currently no evidence to suggest that the nature and extent of the training that will result in these conditions is identical. In fact, it has been anecdotally suggested that overreaching may occur more in team sports and explosive/power sports whereas overtraining would be more prevalent in endurance sports. Similarly, the degree of impairment experienced in each of these states may not be similar and may indeed be expected to be significantly worse in the overtrained compared with the overreached state. The above definitions also imply that there may be an absence of psychological signs associated with the conditions. Increased mood disturbance can be used to discern the acute fatigue and decreased performance experienced following a single bout of intensive exercise and that of longer term overreaching symptoms.^[2] For these reasons, the above defini-

tions are not entirely satisfactory; however, at present they provide the most accurate description of the conditions and are commonly cited in the literature.

In addition, the term overtraining and overreaching will be considered the product or outcome, while intensified training will be considered the process. This is to avoid confusion surrounding the use of the term overtraining as both the outcome and the process of this state.

The process of intensified training leading to overreaching and/or overtraining is often viewed as a continuum^[6] (see figure 1). The continuum suggests that increased stress, or overload, results in a disruption of homeostasis and a temporary decrease in function.^[7] The stress may arise from training, psychological stress or illness. The resultant acute fatigue can cause a positive adaptation or improvement in performance provided appropriate recovery is allowed. This is considered a normal training response and this progressive increase in training load followed by sufficient recovery results in enhanced 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 (see figure 1).

According to this continuum, if athletes undergo periods of intensified training in the absence of appropriate recovery, they may not respond positively to the training and progressive fatigue and decreased performance ensues. Once a state of over-

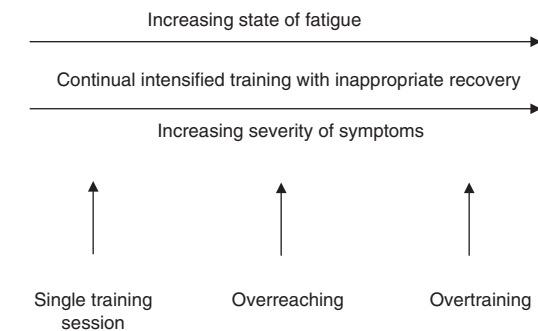


Fig. 1. The overtraining continuum.

reaching has occurred, one of two outcomes may occur. Firstly, the athlete/coach/sport scientist may recognise the symptoms associated with overreaching and provide appropriate rest and recovery for the athlete. Following this, full recovery may occur and the process of overreaching may have stimulated a supercompensation effect and performance may increase to a level higher than that previously attained.^[7] The second possible suggested outcome following overreaching is the progressive development of a state of overtraining. The reduced performance ability that occurs as a consequence of overreaching may be the stimulus for an increase in training in an attempt to improve the diminished performances. Alternatively, the reduced performance may be unrecognised. If high levels of training persist and/or rest and recovery is inadequate, the more serious state of overtraining is thought to develop. Other contributing stressors include frequent competition, monotonous training, psychosocial stressors, illness/ infection and heavy travel schedules.^[5]

While the fundamentals of the overtraining continuum appear logical, there is no evidence to confirm that overreaching will develop into overtraining and that symptoms of overtraining are worse than those of overreaching. An example of this ambiguity is evidenced by the theories of Israel,^[8] which suggest that two types of overtraining exist. One type is suggested to be the result of sympathetic nervous system dominance and the other characterised by parasympathetic dominance.^[8] Again, this theory is often presented in reviews and discussions on overtraining.^[6,9-12] However, while it is commonly thought that the parasympathetic form may be a more advanced stage of overtraining and that this type is subsequent to the sympathetic form, there are no data available to suggest that this occurs. Indeed, there is no scientific evidence to indicate that overreaching itself precedes overtraining.

Selye^[13] proposed the notion that the body's stress response is triphasic in nature and that the body's ability to resist stress is finite. Continual exposure to a given stressor or stressors according to Selye, initially results in a decline in general resis-

tance (Alarm Reaction Stage). As adaptation is acquired, the body's resistance to the stressor rises above normal (Stage of Resistance). However, under continual exposure to the stressor, resistance drops to below normal levels and a Stage of Exhaustion ensues.^[13] Selye observed this pattern of behaviour using a variety of stimuli that included forced muscular work.

It is often suggested that overtraining is the result of an accumulation of stressors that exceed an athlete's finite resistance capacity, similar to that which Selye observed.^[14] Selye stated that "stress shows itself as a specific syndrome, yet it is non-specifically induced", therefore, environmental, physical and/or emotional stressors may result in a variety of nonspecific responses.^[13] This theory appears plausible and may correspond nicely with Israel's theory of sympathetic and parasympathetic forms of overtraining; however, further research to substantiate or counter this notion is required.

It is evident that research in the area of overtraining is lacking in a variety of aspects. Generally, there is a lack of well controlled investigations that include appropriate measures of performance as well as baseline and recovery periods of assessment. Changes in performance and recovery time are presently two of the only methods to both diagnose overreaching and overtraining and to try to partition the two conditions. However, a large proportion of investigations do not include such measures. Therefore, it is impossible to determine if athletes in these studies were overreached, as it is possible to have a positive adaptation to intensified training. There are also issues inherent to the lack of diagnostic tools to indicate a state of overreaching or overtraining as well as a variety of definitions in use to describe the conditions.

Some of the major concerns associated with investigations in this area include the following:

- Different terminology and definitions exist, which hinder the ability to compare the results of research studies.
- No single definitive diagnostic tool exists, which results in the diagnosis of overreaching and overtraining in differing ways.

- Numerous studies do not report or measure performance. As a reduction in performance is one of the only methods to definitively diagnose overreaching and overtraining, and hence to determine if an athlete has positively or negatively adapted to the training, it is essential that investigations report and measure performance appropriately.
- A lack of performance measures during intensified training periods means we know little about the time course of changes in performance and related markers that may be used to identify overreaching. Most studies that do measure performance simply test before and after intensified training, not during.
- The quantity and quality of the intensified training is often not reported or measured. Therefore, the duration and intensity of training required to induce a state of overreaching is unknown.
- Responses to intensified training are likely to be individual and differences may exist between different sporting activities.
- As it is not possible to intentionally induce a state of overtraining in an athlete, it is necessary to perform overreaching studies. Therefore, there is a lack of investigations on overtrained as opposed to overreached athletes.

1. Incidence of Overtraining

The incidence of overtraining among a variety of athletes appears to be relatively high. Over a 1-year period, Morgan et al.^[15] reported that of 400 swimmers who trained up to 14000 m/day, 5–10% were 'stale'. Both O'Connor et al.^[16] and Hooper et al.^[17] reported similar incidences of overtraining in swimmers over a 6-month period. Hooper et al.^[17] reported three of 14 swimmers as 'stale', based on a failure to improve performance over a designated time period and consistent elevated fatigue ratings. However, although high fatigue ratings may be indicative of overreaching, a failure to improve performance may alternatively suggest that the training volume and intensity was not sufficient to induce a positive adaptation. Similarly, O'Connor et al.^[16] classified three of 11 swimmers as 'stale'; however, perform-

ance changes were not described. In a study of 170 college swimmers over a 4-year period, Raglin and Morgan^[18] classified 6.8% of swimmers as 'stale' each season. However, on average, 32.1% of the swimmers studied showed signs of training 'distress' each season and 45.9% were 'distressed' in more than one training session. Again, performance was not assessed.

Koutedakis and Sharp^[19] examined 257 elite athletes who were members of British National Teams and/or Olympic squads in a variety of sports over a 12-month training season. Thirty-eight cases (15%) of athletes were classified as overtrained and in 50% of these cases a state of overtraining was said to have developed in the 3-month competition phase. The incidence rate was slightly higher in male (17%) as opposed to female athletes (11%). Interestingly, when sports were divided into predominantly aerobic and anaerobic events, there was no significant difference in incidence of overtraining over the study period. Athletes were diagnosed as overtrained if they were experiencing feelings of constant fatigue and unexplained underperformance; however, performance was not measured or reported.

As can be seen from the above studies relating to the incidence of overtraining, it is extremely difficult to interpret the reported findings for two major reasons. First, the terminology used is inconsistent and the term 'staleness' gives no indication of whether the athlete is fatigued, overreached or overtrained. Secondly, as there is no diagnostic test for overtraining and performance measures are often not made, whether the athletes are actually overtrained is questionable.

Despite this relatively high suggested incidence of overtraining, it remains that there is very little scientific evidence describing this condition. Cross-sectional studies on athletes suggested to be overtrained are extremely rare and therefore there is little information detailing symptoms. In addition, these studies do not provide information on the development of overtraining. A practical and ethical method of trying to gain an understanding of the early signs and symptoms of overtraining has commonly been

to intensify training and induce a state of overreaching. However, as mentioned in the introductory section, there are a number of problems associated with previous research in this area.

2. Overreaching Research

In an attempt to develop an understanding of the mechanisms of overtraining as well as markers that may provide an early indication of impending overtraining, a number of aspects thought to be associated with overtraining have been investigated. These include changes in performance, mood state, physiology, biochemistry, glycogen depletion, the immune system, hormones and autonomic balance. The lack of definitive diagnostic criteria for overtraining is reflected in much of the overreaching and overtraining research by a lack of consistent findings. Additionally, almost all suggested markers are based on findings of a relatively small number of investigations that have induced overreaching and not overtraining. It is necessary to critically examine the findings and conclusions of these studies so that they may be interpreted accurately.

2.1 Performance

A number of research studies have intentionally increased training volume and/or intensity to induce a state of overreaching. While this is an appropriate means of inducing such a state, an increase in training load does not guarantee that the athlete will become overreached. It is possible for athletes to respond positively to a period of intensified training and, therefore, it is critical that performance is measured. Additionally, if performance is measured and remains unchanged after the increased training load, by definition the athlete cannot be diagnosed as overreached.

Numerous studies have reported changes in a variety of physiological and biochemical responses to intensified training; however, it is necessary to discriminate between those that have induced a decline in performance,^[3,20-24] those that did not^[25-27] and those that have either failed to measure or did not report performance changes.^[16,28,29]

The importance of measuring performance is highlighted when examining many of the commonly suggested markers of overreaching and overtraining. Many of these markers, described throughout this article, are indicators of a positive adaptation to training (e.g. reduced submaximal heart rate and plasma lactate concentrations). Therefore, it is essential that possible indicators be considered in relation to changes in performance.

While a performance decline is necessary to indicate a state of overreaching, the magnitude of performance decline may vary widely depending on the specific performance assessment. Hooper et al.^[22] reported a 2.4% increase in performance times in swimmers who were overreached compared with a 1.1% decrease in well trained swimmers. While only percentage change data were presented and not absolute times, performance tests were completed over 100m for sprinters and 400m for distance swimmers. Both Jeukendrup et al.^[3] and Snyder et al.^[30] reported a decrease in maximal aerobic power achieved during a graded incremental cycle test to exhaustion of approximately 3–4% as a result of 2 weeks of intensified cycling training. Jeukendrup et al.^[3] reported a slightly larger decline in performance (5%) when the same subjects completed a time-trial test with an approximate duration of 15 minutes. When researchers incorporate time to fatigue assessments, a larger decline in endurance capacity is evident.^[20,24] Fry et al.^[20] and Urhausen et al.^[24] reported a 29% and 27% decline in performance, respectively, when using a time to fatigue protocol.

From this information, it appears that both the type of performance test employed and the duration of the performance test are important in determining the changes in performance associated with overreaching or overtraining. As a variety of performance assessments have been utilised in overreaching research, it is difficult to compare changes in associated variables.

Debate exists as to which performance test is the most appropriate when attempting to diagnose overreaching and overtraining. In general, time to fatigue tests will most likely show greater changes in exer-

cise capacity as a result of overreaching and overtraining. Additionally, they allow the assessment of substrate kinetics and submaximal measures can be made at a fixed intensity and duration. However, these tests are not an accurate performance indicator, as they do not sufficiently reflect the true demands of the athletic competition.

2.2 Mood State

An objective marker to indicate negative adaptation to training stress is clearly lacking in the research literature. However, there is general agreement that the overtraining syndrome is characterised by psychological disturbances and negative affective states.^[17]

In several studies in which subjects were identified as overreached, clear signs of psychological distress were observed.^[2,3,20,24] However, increases in global Profile of Mood States (POMS) scores have also been reported in periods of increased training that have not resulted in a state of overtraining.^[31,32] Increased global POMS scores were noted in swimmers after 3 days of increased training^[27] as well as after 10 days of increased training.^[32] In both of these studies, alterations in mood state occurred in the absence of changes in performance. Over a 4-year period, the POMS questionnaire was able to correctly identify 'stale' athletes on an average of 81.45% of occasions in collegiate swimmers.^[16,32] However, in one study, performance was not measured and the team coach completed the classification of stale athletes based on an inability to train at a previous level.^[16] These studies suggest that changes in mood state may be a useful indicator of overreaching; however, the need to combine mood disturbances with measures of performance is necessary.

2.3 Physiology

Other studies have measured physiological variables that are related to performance in an attempt to examine markers and mechanisms of overreaching. An 8% decrease in peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) [4.8 vs 4.4 L/min] was reported after 14 days of intensified training in competitive cyclists.^[3] A sim-

ilar decrease in $\dot{V}O_{2\text{peak}}$ was also reported by Snyder et al.^[30] after 15 days of increased high-intensity training (4.94 vs 4.65 L/min).

Jeukendrup et al.,^[3] Lehmann et al.^[33] and Urhausen et al.^[24] all reported reduced maximal heart rates (HR_{max}) after increased training. This may be the result of a reduced power output observed during maximal exercise due to an inability to attain a maximal effort. However, it is not clear whether the decreased HR_{max} and possibly a decreased cardiac output is the cause or the consequence of premature fatigue.

Lehmann et al.^[33] reported a tendency towards increased resting stroke volume after an increase in training volume in middle- and long-distance runners. This was in conjunction with a decreased HR_{max} . A recent study by Hedelin et al.^[34] reported increased plasma volume and reduced HR_{max} following a 50% increase in training volume in elite canoeists. However, performance was not assessed following recovery and, therefore, it could not be determined if the athletes were fatigued or overreached.

Reductions in maximal physiological measures such as oxygen uptake and heart rate during incremental tests to exhaustion after intensified training may be a consequence of a reduction in exercise time and not related to abnormalities in physiological function *per se*. Future studies should examine such measures during exercise at identical time-points and identical intensities to determine if changes do indeed occur with overreaching independent of changes in intensity and duration.

2.4 Biochemistry

In the search for a reliable and valid indicator of a state of overreaching and overtraining, a variety of biochemical responses to an increased training load have been explored. Lowered submaximal and maximal blood lactate concentrations have been observed in a number of investigations.^[3,20,24,30,35] Jeukendrup et al.^[3] noted a shift to the right in lactate curves in cyclists who underwent 2 weeks of intensified training. Lehmann et al.^[35] reported a decrease in submaximal lactate values (2.9 vs 2.4 mmol/L) as

well as maximal values (11.3 vs 9.5 mmol/L). A number of other studies have identified lower blood lactate concentrations after significant increases in training load; however, changes were not significant.^[20,24,33,36]

When discussing changes in blood lactate concentrations as a result of intensified training, it is important to consider glycogen status and possible decreases in muscle and liver stores due to increased training. Future research should ensure that dietary intake is reported and standardised on the day before all performance assessments.

Other biochemical markers such as concentrations of creatine kinase, urea and iron levels have all been considered as possible indicators of overtraining. However, inconsistent findings and the inability to distinguish acute fatigue resulting from intensified training from overreaching or overtraining does not support the use of the majority of biochemical markers as diagnostic tools. Importantly, if decreases in maximal and submaximal lactate are to be used as indicators of overreaching, this must be in conjunction with a decline in performance. This ascertains whether or not the athlete demonstrates a positive or negative training adaptation.

2.5 Glycogen Depletion

As overreaching is thought to be brought about by high-intensity training with limited recovery, it is perceivable that the fatigue and underperformance associated with overtraining is at least partly attributable to a decrease in muscle glycogen levels. Therefore, two studies have been performed in an attempt to elucidate the role of carbohydrate and dietary intake on performance after intensified training.^[25,30]

Costill et al.^[25] investigated this possibility by examining the effects of 10 days of increased training volume on performance and muscle glycogen levels. Of the 12 swimmers participating in the investigation, four were unable to tolerate the increase from 4000 to 9000 m/day and were consequently classified as non-responders. The group of non-responders consumed approximately 1000 kcal/day less than their estimated energy requirement and

consumed less carbohydrate than the responders (5.3 vs 8.2 g/kg/day). However, importantly, muscular power, sprint and endurance swimming ability were not affected in either the responders or the non-responders. Costill et al.^[25] concluded that the glycogen levels of the non-responders were sufficient to maintain performance, but inadequate for the energy required during training and, therefore, fatigue resulted. As overreaching and overtraining are primarily defined by a reduction in performance, the ability to ascertain whether the non-responders were indeed overreached is limited.

These findings directed Snyder et al.^[30] to examine performance responses to intensified training with the addition of sufficient dietary carbohydrate, in an attempt to determine whether overreaching could still occur in the presence of normal muscle glycogen levels. To ensure sufficient carbohydrate intake, subjects consumed 160g of a liquid carbohydrate in the 2 hours following exercise. Subjects completed 7 days of normal training, 15 days of intensified training and 6 days of minimal training. Resting muscle glycogen was not significantly different when compared with normal training (530.9 μ mol/g dry weight) and intensified training (571.2 μ mol/g dry weight) as determined by needle biopsy of the vastus lateralis muscle. Subjects were reported to be overreached; however, maximal power output during an incremental cycle test was not statistically different after intensified training. Only four of the eight subjects demonstrated both a decline in maximal power output and an increase in responses to questionnaires. From the two studies cited above, the role of carbohydrate intake and glycogen depletion in overreaching is unclear.^[25,30] Again, this is partly due to inappropriate analysis of performance.

2.6 Immune System

Given the many anecdotal reports of increased illness rates and upper respiratory tract infections (URTI) in overreached and overtrained athletes,^[37] the role of exercise-induced immunosuppression has been explored. It seems plausible that the prolonged and/or intense exercise usually required to induce

overtraining, may increase both the duration of the 'open window' and the degree of the resultant immunosuppression. While this alteration in immune function is indeed possible and there are numerous anecdotal reports of increased susceptibility to illness in athletes who are overtrained, there is little scientific information to substantiate this inference.

Mackinnon and Hooper^[38] increased the intensity of training of a group of 24 swimmers. Of those swimmers that were identified as overreached, one in eight (12.5%) reported symptoms of URTI. Surprisingly, in the group of 16 athletes who responded positively to the intensified training, nine (56%) exhibited self-reported symptoms of URTI. Therefore, increased URTI incidence is likely to reflect the increase in training, regardless of the response of the athlete to the increased physical stress.

Whilst a plethora of literature exists on the effects of single exercise bouts and periods of increased training on URTI incidence, the above-mentioned study is the only investigation that has examined increased URTI incidence in conjunction with a decline in performance indicative of a state of overreaching or overtraining. Similarly, a limited number of investigations have been performed that explore the relationship between immune suppression and the overtrained athlete.^[23,39-42]

As leucocytosis is typically the immediate response to intensive exercise,^[43] resting peripheral blood leucocyte numbers have been determined during both periods of training that has resulted in overreaching and in athletes diagnosed as overtrained.^[23,40-42] With the exception of Lehmann et al.^[23] all previous studies have not demonstrated changes in leucocyte number in overreached subjects. Interestingly, Lehmann et al.^[23] reported a significant decline in leucocyte number when the training volume was increased. No changes were observed following an increase in training intensity and during this condition a state of overreaching did not develop. The clinical consequence of a reduction in leucocyte number is presently unclear and changes may simply reflect cell redistribution or increased cell turnover.^[44]

Similarly, resting peripheral blood lymphocyte numbers also appear not to be influenced by overtraining.^[39-42] However, while cell numbers may remain constant, activation of lymphocytes may be increased. Fry et al.^[39] reported a significant increase in the activation level of peripheral blood lymphocytes (CD25+, HLA-DR+, CD3+ : CD25+ ratio). Following intensified training that resulted in overreaching, Gabriel and Kindermann^[45] also reported increased HLA-DR+ T cells.

Neutrophil numbers have been reported to be unchanged^[39,41,46] and increased^[42] in response to intensified training that resulted in a state of overreaching. Importantly, neutrophil function has not been assessed in overreached athletes and, therefore, the relative contribution of neutrophil cells to possible immune dysfunction in overreached athletes is unknown.

Natural killer cell numbers appear to be unaltered in athletes showing symptoms of overreaching.^[39,46] Currently, there are no reports in the literature that document natural killer cell function in overreached or overtrained athletes.

The mucosal immune system response has been examined in athletes who were reported to be overtrained using salivary IgA as a marker.^[47] IgA is an important factor in host defence and has been observed in relation to increased URTI incidence in endurance-trained athletes.^[44] To date, there are limited data on changes in mucosal IgA as a result of overreaching. Mackinnon and Hooper^[48] reported 18–32% lower salivary IgA concentrations in three athletes showing symptoms of overtraining compared with those who were well trained. It is difficult to determine if these athletes were overreached or overtrained based on the data presented. A recent investigation also reported lower IgA levels after intensified training; however, this was not statistically significant.^[49]

In summary, the current information regarding the immune system and overreaching seems to only confirm the role of intensified training in immune suppression. Whilst many cell numbers do not appear to change during overreaching, those cells that do alter, appear to simply reflect the nature of the

training performed. Therefore, immune parameters may change in response to intensified training, independent of whether the training results in overreaching or overtraining.

A further methodological concern in this area is the lack of functional cell measurements. It is generally accepted that exercise-induced leucocytosis is transient and cell number changes have little clinical significance.^[50] Immunocompetence is best assessed by examining cell function as opposed to cell number and future research investigating the immune system and overreaching should address this concern.

Overtrained athletes often anecdotally report an alteration in immune system function and the use of markers of immune function as a diagnostic test for overtraining has been suggested. However, while some studies claim the athletes investigated are overtrained, it is more likely that the athletes were overreached. Whether immune function is seriously impaired in overtrained athletes is unknown as the scientific data are not available.

2.6.1 Glutamine

As glutamine is an important substrate for cells of the immune system, especially lymphocytes, macrophages and possibly natural killer cells,^[51] during periods of immunological challenge glutamine production is increased. Therefore, it may be expected that low plasma glutamine levels commonly observed after prolonged exercise may result in reductions in immune function. In turn, this could lead to an increased risk of infection and may partially explain the increased URTI incidence in endurance-trained athletes.

Given the changes in plasma glutamine levels that are commonly observed after prolonged exercise and the function of glutamine in immune cells, the role of this amino acid in overtraining has recently gained attention. Parry-Billings et al.^[52] reported lower plasma glutamine concentrations (503 $\mu\text{mol/L}$) in 40 athletes diagnosed as overtrained when compared with controls (550 $\mu\text{mol/L}$). While Mackinnon and Hooper^[38] found no relationship between incidence of URTI and glutamine, they observed 23% lower glutamine concentrations in swimmers

considered overtrained than in well trained swimmers.

At present, the role of glutamine in overreaching is not clear. While plasma glutamine concentration may or may not decrease following periods of intensified training, there is still no evidence to link low glutamine levels with impaired immune function and increased susceptibility to illness or infection.

2.7 Hormones

2.7.1 Cortisol and Testosterone

In a study examining the pituitary hormonal response in overtrained endurance athletes, Urhausen et al.^[53] reported no significant changes in resting cortisol (254 \pm 19 vs 264 \pm 28 nmol/L, normal vs overtrained, respectively) when subjects were examined prior to and during a state of 'short-term overtraining'. Similarly, no changes in resting serum cortisol concentration were observed by Flynn et al.,^[21] Mackinnon et al.^[41] or Hooper et al.^[42]

Maximal cortisol responses, however, appear to be reduced during overreaching. Snyder et al.^[30] reported a decrease in plasma cortisol concentration from 514.8 \pm 56.8 to 381.8 \pm 52 nmol/L following a period of intensified training that resulted in a state of overreaching. Urhausen et al.^[53] also reported similar reductions in maximal cortisol levels in overreached athletes.

The documented response of both total and free testosterone concentrations in overreached athletes is contradictory. Flynn et al.^[21] observed decreased serum total and free testosterone levels coincident with a decrease in performance following intensive training. Vervoorn et al.^[54] also reported lower testosterone levels in rowers following an increase in intensive training; however, there were no significant changes in performance and, therefore, the presence of a state of overreaching or overtraining cannot be confirmed. There were no significant differences in resting testosterone levels during normal training and during a state of overreaching in endurance athletes identified as overreached by a significant reduction in performance.^[53]

The ratio of testosterone : cortisol is suggested to indicate the balance between androgenic-anabolic

activity (testosterone) and catabolic (cortisol) activity.^[55] Cortisol (a steroid and primary stress hormone) and testosterone (a primary androgenic-anabolic hormone) are both released in response to high intensity (>60% maximal oxygen uptake [$\dot{V}O_{2max}$]) aerobic and anaerobic exercise.^[56] The testosterone : cortisol ratio is believed to be an indicator of the positive and negative effects of training due to the opposing effects that the hormones have on growth, protein synthesis and muscle metabolism.^[41]

A decrease in the testosterone : cortisol ratio of approximately 30% or a fall below 0.35×10^{-3} has been suggested as an indicator of a state of overtraining.^[55] The usefulness of this ratio as a diagnostic tool has not been supported in the literature. The ratio has been shown to remain unchanged in overreached athletes,^[53] yet a decreased ratio has been reported in athletes who show no performance decrements after intensive training.^[54] Therefore, the ratio of testosterone : cortisol has not been proven to have the ability to discriminate overreached athletes from well trained athletes.

2.7.2 Other Hormones

Urhausen et al.^[53] reported lower resting adrenocorticotrophic hormone (ACTH) levels and lower exercise-induced ACTH release in overreached athletes. In addition, a reduced maximal plasma growth hormone (GH) concentration was also reported.^[53]

Decreases in exercise-induced plasma hormone concentration, especially cortisol, appear to be evident in overreached athletes. Reports of resting hormone concentrations are highly variable, with some researchers showing increases, decreases and no change. It remains difficult to draw conclusions about possible changes in hormone concentrations due to different performance assessments and changes in duration and intensity of exercise as a consequence of intensified training. Additionally, plasma hormone concentrations may be different in overtrained and overreached athletes.

2.8 Autonomic Nervous System

Israel^[8] proposed that two types of overtraining might exist: (i) a parasympathetic or vagal form of

overtraining; and (ii) a sympathetic form. The parasympathetic form is suggested to be characterised by increased fatigue, apathy and altered mood state, immune and reproductive function.^[8] Lehmann et al.^[9] suggest that this form of overtraining is more frequently observed and may be referred to as the modern form of overtraining. This form of overtraining is said to be the consequence of an imbalance between extended duration, high-intensity endurance training and little regeneration, possibly in combination with other non-training stress factors.^[9] Catecholamine levels in urine and plasma can reflect the activity of the sympathetic nervous system and can, therefore, examine the possibility of a parasympathetic-sympathetic imbalance or autonomic imbalance.

2.8.1 Catecholamines

Basal urinary catecholamine excretion has been reported to be significantly reduced in overtrained athletes.^[9] Catecholamine excretion was negatively correlated to fatigue ratings and following a period of recovery, catecholamine excretion returned to baseline levels.^[9] Increased resting plasma noradrenaline levels were observed by Hooper et al.^[22] in athletes who were suggested to be overtrained. Lehmann et al.^[57] also observed increased resting noradrenaline levels following a period of increased training volume that resulted in performance incompetence. However, Urhausen et al.^[53] could not replicate the above findings and reported no significant differences in submaximal and maximal plasma catecholamine concentrations in overtrained athletes. The differences in the above findings may be related to methodological differences and high inter-individual differences in catecholamine responses to exercise. Some studies have used urinary 24-hour catecholamine excretion as a measure of the autonomic nervous system activity and others have used plasma or serum measures and, as such, comparison between measures are not directly possible. While 24-hour catecholamine excretion is often considered a more valid measure, catecholamine responses to an exercise challenge can give additional information on autonomic nervous system responses to exercise.

In the context of overreaching, the role of changes in dopamine has not been thoroughly investigated. At present, there is only one study that has examined changes in dopamine as a result of overreaching.^[57] In this experiment, dopamine remained unchanged as a result of intensified training; however, this was attributed to high inter- and intra-assay variability (up to 30%), reflecting both high methodological variation and high inter-individual variation.^[57]

2.8.2 Heart Rate Variability

Heart rate variability (HRV) is the term used to describe the oscillation in the interval between consecutive heart beats.^[58] HRV is commonly assessed by examining the intervals between successive R waves, which is determined from the detection of each QRS complex.^[58]

To date, few studies have investigated HRV in overreached athletes, with studies showing either no change^[34,59] or inconsistent changes.^[60] The lack of uniformity in findings is most likely related to different techniques and methods of presenting HRV analysis, differing methods of identifying overreaching and individual variation in both HRV and responses to training.

Hedelin et al.^[34] increased the training load of nine canoeists by 50% over a 6-day training camp. Running time to fatigue, $\dot{V}O_{2max}$, submaximal and maximal heart rates and maximal blood lactate production decreased (all previously reported responses to overreaching) in response to the intensified training; however, all indices of HRV remained unchanged. On average, there were no significant changes in low- or high-frequency power, total power or the ratio of low- to high-frequency power, both in the supine position and after head-up tilt. However, mood state was not measured and performance was not assessed after a period of recovery. Similarly, Uusitalo et al.^[59] reported no change in intrinsic heart rate and autonomic balance, assessed through pharmacological vagal blockade, in female athletes following 6–9 weeks of intensified training. In addition, both the time domain and power spectral analysis in the frequency domain were calculated during supine rest and in response to head-up tilt.^[60] Results

suggest that HRV in the standing position had a tendency to decrease in response to intensified training in the subjects who were identified as overreached.^[60] However, intra-individual variability was high in this investigation and again performance was not measured.

From these studies, it is not possible to comment confidently on possible changes in HRV. If performance is not assessed, we are unable to determine whether the subjects had a positive or negative adaptation to training and, therefore, it cannot be determined if the athletes were overreached. This may partly explain some of the lack of changes in measures of HRV.

In summary, there are very few well controlled studies that examine changes in possible indicators and mechanisms of overreaching. Most studies use overreaching as a model for overtraining for practical and ethical reasons; however, it cannot be certain that changes observed during overreaching are reflected in overtrained athletes.

3. Overtraining Research

As mentioned in the introductory section, scientific data on overtrained athletes are extremely scarce. One of the most commonly cited papers on the mechanisms of overtraining is that of Barron et al.^[29] In this experiment, an insulin-induced hypoglycaemic challenge was administered to assess hypothalamic-pituitary function in overtrained athletes. This challenge stimulates the release of ACTH, GH and prolactin. Athletes were also intravenously administered luteinising hormone-releasing hormone (LHRH) and thyrotropin-releasing hormone (TRH), which act at the level of the pituitary. Overtrained athletes had significant decreases in GH, ACTH and consequently cortisol responses in response to insulin administration, which returned to levels similar to that of asymptomatic runners following 4 weeks of rest. This suggests that there was impairment at the hypothalamic level. Responses of hormones released as a result of LHRH and TRH (i.e. thyroid-stimulating hormone, prolactin, luteinising hormone and follicle-stimulating hormone) were unchanged. This demonstrated that there was

no evidence of pituitary dysfunction and hence the impairment was at the level of the hypothalamus.

This study^[29] was one of the first and only studies investigating possible mechanisms of overtraining; hormonal imbalance has since been cited by numerous authors as a mechanism of overtraining. While this research provided new and interesting information, subject numbers were very small and individual variation was high. Four overtrained athletes were investigated in total, with only two subjects given at rapid insulin alone. The prolactin responses of the subjects to this challenge ranged from <1 to 98 ng/min/mL. Additionally, subjects were reported to be recovered after a 4-week rest period. This suggests that the athletes were, indeed, overtrained; however, performance was not measured in this study at any timepoint. Although this study provides information on changes that may be associated with overtraining, the results are not entirely conclusive.

Rowbottom et al.^[40] examined a combination of parameters in ten athletes from different sports who were diagnosed as overtrained. Athletes self-reported difficulty maintaining their training programme and debilitating fatigue, which was not alleviated by rest or bed-rest; however, performance could not be measured at baseline. Resting haematological, biochemical and immunological measures were made and compared with established normal ranges. The only measured parameter that was significantly different to normal ranges was glutamine, indicating that in most haematological, biochemical and immunological aspects, these athletes were not different from normal controls. A recent study by Smith and Norris^[61] reported similar plasma glutamine levels in five athletes who were diagnosed as overtrained and athletes who responded normally to training and competition. While time taken to recover was not reported, it was stated that athletes took longer than 4 weeks to return to baseline training volume and intensity levels.

Hedelin et al.^[62] reported increased HRV and decreased resting heart rate in an athlete who was suggested to be overtrained. The athlete reported accumulated fatigue and reduced performance; however, the change in performance was not report-

ed and the type of exercise test employed was unclear. Compared with normally responding subjects examined during the same period, the overtrained subject exhibited an increase in high-frequency and total power in the lying 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.^[62]

From the above-mentioned studies, it is not possible to conclusively comment on the similarities or differences between overreaching and overtraining. This is primarily due to: (i) the lack of research in the overtraining area; (ii) a lack of baseline measures as symptoms are often evident before a performance assessment can be made; and (iii) the variation in methodologies and outcomes in experiments investigating overreaching. From the study by Rowbottom et al.,^[40] it appears there are few abnormalities in the variables that commonly indicate a state of fatigue due to increased exercise. This is similar to the research in the area of overreaching. Comparisons cannot be made between the maximal exercise responses in overreached athletes and those of overtrained athletes, as the information does not exist in overtrained athletes. There does appear to be some similarities in hormonal abnormalities; however, once again this is based on very little scientific overtraining information.

4. Conclusions and Directions for Future Research

Numerous scientific papers as well as popular literature suggest a number of markers that can be used to identify overreaching and overtraining. Additionally, some reports discuss possible mechanisms and causes of overtraining based on similar information. It is essential that research in this area is examined critically and it is evident that some of the previous research in this area should be interpreted with caution.

The majority of knowledge on markers of overtraining is based on the results of studies that have deliberately induced a state of overreaching in athletes. At present there is insufficient evidence to

draw accurate conclusions on the similarities or differences between the two states. More importantly, if there is very limited scientific research investigating overtraining, and overreaching can be thought of as a normal training process in which recovery occurs relatively quickly, and there is limited data to indicate differences between the two states, can it be conclusively said that the state of overtraining exists?

At present, the scientific research necessary to answer this question is deficient. While many athletes, coaches and scientists have anecdotal evidence that suggests that overtraining does exist, it is clear that further research to elucidate the nature and symptoms of overtraining is needed. It is crucial that future research incorporates and reports appropriate measures of performance and mood state. It is also important that the quality and quantity of training should be detailed and a recovery period should be included to determine the length of time necessary to recover from the training. While the difficulties in performing such research are appreciated, well controlled and monitored studies are vital in developing an understanding of overreaching and overtraining.

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