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REVIEW ARTICLE

Physiological Perspective of Endurance Overtraining – A Comprehensive Update

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Abstract: Overtraining is a condition in which adaptive mechanisms of athletes are stressed that diminishes the capacity to maintain a balance between exercise and recovery. Due to this chronic fatigue state the physical performance is hampered, leading to appearance of various pathophysiological and psychological symptoms. Excessive stress with insufficient recovery period is the main cause of overtraining. It usually happens due to sudden increase in training volume with shorter recovery times in between the successive training bouts. However, other stressors, apart from training, exist in an athlete's life, and these may also ameliorate the chances of getting overtrained. Academic and parental pressures exist particularly in case of young athletes. Exterminating or minimising these causes by proper counselling on training loads, recovery times, nutrition and use of suitable markers can aid to prevent overtraining syndrome in athletes. Present review was undertaken to thoroughly scrutinize the physiological perspectives of overtraining with special emphasis on the different angles of recent research observations related to causes, markers, signs and symptoms, types, mechanisms involved, recognition and possible remedial measures of overtraining. Checking the prevalence of overtraining in young athletes with gender variation (if any) was another major concern of the review work.
Key words: Overtraining markers, fatigue, stress, injuries, recovery.

Introduction:

Athletes often engage in very hard training persistently to achieve better performance without being aware of the fact that physiological improvements in sports only occurs during the rest period following hard training. If sufficient rest is not included in training program and optimal balance is not maintained between training and recovery then complete regeneration can't occur and performance plateaus [1] . This state of chronic fatigue is known as overtraining characterized by an imbalance between stress and recovery – one of the most etiological factors that lead to fatigue and injuries in athletes [2-6]. In some cases, using the term "overtraining" may not be appropriate, as other stressors (e.g. psychological, lifestyle, malnutrition, infection) are also responsible for under-performance [7]. Several researchers refer the overtraining syndrome differently as overfatigue, staleness, burnout, overuse and overwork [8-10]. Lack of standard terminology creates confusion during diagnosis [11].

Perhaps "Overtraining Syndrome" is the better terminology that can only be resolved by at least two weeks rest [12]. It is very difficult to recognize overtraining at the early stage and by the time it is detected, it is too late [13]. Various syndromes have been proposed to identify overtraining called "Overtraining Syndrome" that has received much attention of researchers and practitioners over the last two decades due to its serious threat for athletic performance and health [14]. However present review has been focused to look momentarily the various physiological aspects of overtraining syndrome in athletes including the types, symptoms, causes, early detection by different markers, prevention and its treatment as focused in different angles of research and studies.

Definition of Overtraining: Overtraining is the result of an imbalance between stress and recovery [3, 5, 15-17]. It is a physical, behavioural and emotional condition that occurs when the volume and intensity of an individual's exercise surpasses their recuperation capacity [6, 18]. The progress of athletic performance is ceased, and can even lead to a drop in strength and fitness. Overtraining is a common problem in weight training, but it can also be experienced by runners and other athletes [6, 18]. The term "overtraining syndrome" is commonly used to represent the emotional, behavioural, and physical symptoms which appear due to overtraining that persists for weeks to months. It is also defined as a neuroendocrine disorder characterized by poor performance in competition, inability to maintain training loads, persistent fatigue, reduced catecholamine excretion, frequent illness, disturbed sleep and alterations in mood state [8, 19].

Definition of Overreaching: Overreaching is a term used to describe the phase just prior to overtraining, which can require 2 days to 2 weeks of recovery time. This usually occurs slowly over the course of a month or two, but it can happen much quicker due to a dramatic increase in training volume and/or intensity [20]. Overreaching occurs when full recovery is not achieved for an extended time period and fatigue builds up. Symptoms associated with overreaching are increased resting heart rate, premature fatigue during training, decrease in work capacity, increased heart rate during submaximal loads and an increased thirst, especially at night [20].

Difference between the consequences of overtraining and overreaching: Overtraining is a syndrome that occurs on a fatigue continuum [1]. The consequences of overreaching and overtraining may be of the following three categories [21]:-

- Functional Overreaching: Short-term overtraining, mild and a normal part of athletic training. It can be recovered within few days to weeks [12, 21-22].
- Non-Functional Overreaching: Long-term and moderate kind of non-functional overreaching that may restore the performance capacity and may last from several weeks to months [21].
- Overtraining Syndrome: The most severe cases are referred to as Overtraining syndrome, where recovery period for normalization may take from several months to years [4, 21, 23]. It is characterised by premature fatigue, decline in performance, mood changes, emotional instability and decreased motivation.

Overtraining syndrome among athletes: Gender related prevalence rate: Prevalence of overtraining in sports varies with event type. Sports involving greater work-loads such as (running [24], swimming [17, 25], cycling [26], and rowing [27-28]) show a higher rate of overtraining syndrome. In the Atlanta Olympic Games in 1996, Gould *et al.* [29] demonstrated that out of 296 athletes of 30 different sports, 84 athletes (28%) were in overtraining. In studies conducted in the Winter Olympics in Nagano, 1988, Gould *et al.* [30] observed that 8 of the 83 American Olympic athletes (almost 10%), participating at 13 different sports, were in overtraining condition. Those athletes also considered other contributing factors to overtraining, such as excessive trips, decrease of resting periods, decrease of the necessary time for recovery and a `not very healthy' lifestyle. According to other researchers, the incidence of overtraining may vary from 7 to 20% [17, 25]. Years later, research involving endurance athletes (predominantly aerobic sports), especially swimmers, observed similar results (7% to 21%), out of which, 10% presenting severe symptoms [31-33].

Most of the research works and case studies depicted that nonfunctional overreaching is much more prevalent than overtraining syndrome. It has been estimated that the prevalence rate of overtraining syndrome is approximately between 20% and 60% of athletes who experience the negative effects of overtraining at least once during their career [34]. Such prevalence rate of between 20% and 60% seem to be more relevant for nonfunctional overreaching than for overtraining syndrome [14, 35-38]. The highly motivated and dedicated athlete is the most susceptible, since they continue training despite extreme fatigue [6, 39]. It has also been suggested that females are more prone to overtraining symptoms since they follow instructions more than males [39]. Studies related to gender differences in overtraining is unavailable [39].

Overtraining in child and adolescent athletes: Although being more frequently found in elite athletes, overtraining is also a problem in other levels of participation. Raglin and Wilson [9] suggested that overtrained young athletes are succumbed to training load comparable to adult and elite athletes. An intercultural and well-controlled study [40] , using physical and psychological tests and training load registry, showed that in 231 young swimmers, with age range of 14–18 years, 35% presented physical fatigue, reaching the conclusion that the frequency of overtrained young athletes was similar to that of elite athletes. Overuse injuries, overtraining and burntout are growing problems among child and adolescent athletes in the United States [6, 41]. Approximately 50% of all injuries seen in paediatric sports medicine are related to overuse [42].

Although inactivity and obesity are on the rise, the number of children and adolescents participating in recreational athletics has grown considerably over the past two decades [41]. Single sport specialization often leads to overtraining in paediatric / adolescent athletes due to the fact that the growing bones of the young athlete cannot withstand stress as the mature bones of adults do [43-44]. Young athletes who participate in a variety of sports, involving different body parts, have fewer injuries and are less susceptible to overtraining [45].

Types: Overtraining syndrome is of two types – sympathetic and parasympathetic [2, 6, 21]. The sympathetic form is characterised by increased sympathetic tone in the resting state and is more common in sprint type sports [1, 6, 21], whereas the parasympathetic form is characterised by domination of parasympathetic tone in the resting state as well as during exercise causing early onset of fatigue and apathy, and is most commonly seen in endurance athletes [1]. The results of various exercise physiological measurements differ between the sympathetic and parasympathetic overtraining. In more severe and extensive cases, the sympathic kind, characterized as exciting, is rarely found or perceived [24]. The overtraining symptoms reported in the literature in endurance athletes, tend to reflect not only sympathic characteristics but also parasympathic ones (Table-1). However, little evidence supports the overtraining syndrome classification in these two presentations [5].

Table-1: Distinguishing Symptoms of Sympathetic and Parasympathetic overtraining [2]

Sympathetic overtraining	**Parasympathetic overtraining**
Fatigue	Fatigue
Irritability	Calmness
Sleeplessness	Normal sleep
Lack of appetite	Normal appetite
Weight loss	No change in weight
Easy sweating	Normal sweating
Nocturnal Sweating	-----
Frequent headaches	No headaches
Palpitation, heaviness and stabbing pain in chest	-----
Rapid resting pulse rate	Normal pulse rate
Increased basal metabolism	Normal basal metabolism
Slightly increased body temperature	Normal body temperature
Delayed recovery of pulse rate	Normal recovery pulse rate
Faster than normal increase in breathing rate during exercise	No breathing problems
Decreased tolerance to stress	-----
Poor coordination of movements	Climsy movements and poor coordination specially during hard exercise
Shortened reaction time	Normal reaction time
Shaky hands	-----
Restlessness and / or depressed mood	Normal mood

Signs and symptoms of overtraining: Numerous signs and symptoms of overtraining have been identified but all of them are not necessarily present in each overtrained athlete. Moreover, the presence of some of these symptoms does not automatically mean that the individual is overtrained. The ultimate determination of overtraining is whether performance is impaired or plateaued.

Listed below are some frequently cited signs of overtraining [40]:

Physiological

- Altered resting heart rate (HR), blood pressure and respiration patterns
- Decreased body fat and post-exercise body weight
- Increased VO_2, VE, and HR during submaximal work
- Decreased lactate response
- Increased basal metabolic rate
- Chronic fatigue
- Sleep and eating disorders
- Menstrual disruptions
- Headaches, gastrointestinal distress
- Muscle soreness and damage
- Joint aches and pains

Performance

- Decreased muscle strength, power, endurance, cardiovascular endurance
- Decreased training tolerance
- Increased recovery requirements
- Decreased motor coordination

Increased technical faults

Immunological

- Increased occurrence of illness
- Swelling of lymph glands
- Decreased rate of healing
- Impaired immune function (neutrophils, lymphocytes, mitogen responses, eosinophils)

Biochemical

- Increased serum cortisol and SHBG
- Decreased serum testosterone,
- Decreased testosterone : cortisol
- Decreased muscle glycogen
- Decreased serum hemoglobin, iron, and ferritin
- Negative N_2 balance
- Rhabdomyolysis [86]
- elevated C-reactive protein

Psychological

- Depression and apathy
- Decreased self-esteem
- Decreased ability to concentrate
- Decreased self-efficacy
- Sensitive to stress
- Lack of coordination

Etiology of overtraining syndrome: Excessive training is rarely the only reason for overtraining [2]. Various factors including personal factors, such as general health and nutritional status, mood, personality type, age, and medical conditions [6] as well as external factors like intensity and amount of physical training, socio-economic and psychological stressors, training history, environmental conditions (altitude, temperature), sleep, drugs (medication, alcohol, tobacco) increases vulnerability to the overtraining state [6, 46].

Mechanisms of overtraining: High amounts of stress in life impact ones ability to adapt to a strength-training programme, with low-stress individuals showing significantly greater improvements in squat and bench press strength than those with high-stress levels. This study was conducted on 135-undergraduate students who trained twice a week (1.5-hour training sessions) for 12-weeks [85]. Several authors have suggested the possible underlying cause of overtraining syndrome and how the overtraining processes are initiated.

Some of the proposed mechanisms have been hypothesized as follows:

- Glycogen Hypothesis, which has looked at reduced levels of glycogen as markers of fatigue and overtraining.
- Central Fatigue Hypothesis, which looks at, reduced levels of circulating tryptophan (an amino acid), which cause it to be taken up in the brain to a greater extent. Tryptophan is a precursor to serotonin, a neurotransmitter which, when elevated has effects on the body such as increased need for sleep and reduction in appetite (both are tell-tale signs of overtraining).

In normal conditions, tryptophan can't enter the brain. But after vigorous exercise, the decrease in blood level of glycogen and long chain amino acid were noticed. As a result tryptophan gets a preference and enters into the brain. Tryptophan then leads to the formation of serotonin which causes central fatigue and thereby a change in mood generally occurs.

- Glutamine Hypothesis, which seeks to explain the decrease in immune function and increase in illness during periods of overtraining, as glutamine is an important amino acid used for fuel by lymphocytes in the immune system.
- Hypothalamus and Hypothamic-pituitary-adrenal axis implications, where the blood catecholamine, glucocorticoid and testosterone levels are altered.
- Lack of day-to-day variations in training, which expose the athletes to "burn-out" and potential overuse injuries.

Together, all of the above theories explain some aspect of overtraining syndrome, yet a definite underlying cause has not been concluded upon.

The mechanisms underlying overtraining syndrome have not been clearly identified, but a number of possible mechanisms for overtraining have been postulated [5,18-19]:

- Microtrauma to the muscles is created faster than the body can heal them.
- Amino acids are used up faster than they are supplied in the diet [47]. This is sometimes called "protein deficiency".
- The body becomes calorie-deficient and the rate of break down of muscle tissue increases. Muscles also become deficient of glycogen [48].
- Levels of cortisol (the "stress" hormone) are elevated for long periods of time [49].
- The body spends more time in a catabolic state than an anabolic state (perhaps as a result of elevated cortisol levels) [50].
- Excessive strain to the nervous system during training [2].

Thinking in a different angle, overtraining can be considered as a protection against overload-dependent irreversible cellular damage and in part as ultimate negative feedback regulation of the organism [51]. This includes:

i. Decrease in neuromuscular excitability [3, 24, 51-52].
ii. Decrease in sensitivity to adrenals to ACTH, i.e., decreased cortisol release and depressed metabolic competence [3, 24, 49, 51].

iii. Decrease in β-adrenoreceptor density causing depressed metabolic and chronotropic competence [3, 24, 51, 53].
iv. Decrease in sympathetic intrinsic activity, i.e., depressed motivation [3, 24, 34, 51, 54-55].
v. Decreased turnover in contractile proteins [56].
vi. Increased synthesis of heatshock proteins – HSP70 [57].
vii. Inhibitory effects on first [58] and second α-motoneurons [52, 59].
viii. Depressed hypothalamic-pituitary activity can be observed [34, 49, 55].

Researcher Lucille Lakier Smith [87] has proposed the idea that overtraining may begin with (and be caused by) tissue trauma.

First, it is important to note that some level of tissue trauma is reasonable. In fact, a little bit of trauma is needed in order to force an adaptation (hence the name Adaptive Microtrauma). If we don't impose some level of stress on our bodies, then we have nothing to adapt to, and no improvements are made. The pattern then looks like this:

Train (impose a stress on the body) –> Recover from that stress (heal)–> Train again (breakdown a little more) –> Rinse and repeat

Training leads to trauma, which leads to a local inflammatory process and the release of cytokines. Cytokines are basically like messengers which, transfer information from cell to cell and, when they are found in increased concentrations in the blood, they can transfer information around the whole body, having a more systemic effect. There are various types of cytokines with some having pro-inflammatory properties and others having anti-inflammatory properties. Three important pro-inflammatory cytokines are interlukin-1ß, interlukin-6, and tumor necrosis factor.

Alteration of muscle Calcium Homeostasis can leads to overtraining: During endurance training the maximum calcium uptake and Ca2+ affinity in sarcoplasmic reticulum (SR) is reduced after training in rat model [60]. SR regulates the release of Ca2+ into cytosol via ryanodine receptors (RyR) and SR Ca2+ ATPase (SERCA) governs the transport from cytosol to the lumen of SR [61]. It is well known that SR characteristic differs between muscle fiber types [62]. Among two main isoforms of SERCA , SERCA1 is present in fast-twitch skeletal muscle fibers and SERCA2 is present in cardiomyocytes and slow-twitch fibres [61,63]. Experimental evidences suggest that the training induced changes in SERCA pumps are specific to the nature of training [64-66]. In endurance trained subjects, Ca2+ release, SERCA and Ca2+ uptake rate are lower than untrained subjects [66]. It may be because of the fact that type II muscle fibers are less in number than untrained ones [67]. SERCA are highly energy consuming pumps which require 25-40% of ATP during muscle contraction [68-69]. It was shown that ATP utilization by SERCA is higher in Fast twitch fibers than that in slow twitch fibers [70]. It is well known that short endurance training can reduce O_2 cost of cycling [71]. Since overtraining is a state of chronic fatigue, less calcium is released and limits the number of attached actin-myosin bridges connections of actin-myosin.

The slowing down of the muscular response represents a deterioration of the function of actin-myosin bridges. Thus the delicate balance between beneficial effect of endurance training and deleterious effects of overtraining is maintained by the modest change in muscle Ca2+ homeostasis in overtrained athletes.

Recognition of overtraining: Recognizing overtraining syndrome is vital for its prevention [72]. Several problems are encountered in detecting overtraining due to the lack of objective parameters suitable for its diagnosis [73].

Several physiological, biochemical and immunological markers have been proposed to identify overtraining. Taken alone, none of them have an absolute significance [12]. These potential markers of overtraining include underperformance, chronic fatigue, increased perceived exertion during exercise, reduced motivation, sleep disturbance, increased early morning or sleeping heart rate, altered mood states, loss of appetite, GI disturbance, recurrent infection, psychomotor speed, leukocyte responses to antigens, salivary IgA, neutrophil / Lymphocyte Ratio, T-cell CD4+ / CD8+ Ratio, T-cell CD4+ CD45RO+ expression, plasma cortisol or cortisol / testosterone ratio, urinary steroids or catecholamines, plasma glutamine, plasma cytokines, blood lactate response to incremental or high intensity exercise, plasma or salivary cortisol response to high intensity exercise, increased gut permeability that leads to GI tract infections [12].

Prevention of Overtraining: Overtraining is a cumulative process that requires extensive recovery and therefore prevention of overtraining is encouraged rather than treating the trouble [74]. In order to prevent overtraining, coaches often provide combinations of training intensity, volume and frequency for individual athletes but they must be continually aware of the possibility of occurrence of overtraining and consider all the stresses in the athlete's life and not just those associated with training.

Overtraining monitoring programme including measurement of early morning heart rate, periodic recording of heart rate during and after submaximal exercise, a time trial on a selected event, some measure of power output, a scale for perceived fatigue taken over the whole season and lactate testing should be incorporated into the training programme [6].

Some important guidelines recommended to prevent overtraining in athletes include:

- Care should be taken for individual differences of athlete [75].
- Progressive increase in training load with periodized training programmes and sufficient recovery time should be provided [76].
- Training volume and training intensity are inversely related [40].
- Performing every set of every exercise of every session to absolute failure, with no variation should be avoided [40].
- Incorrect exercises that overuse certain muscles or joints and excessive competitions should be avoided [40, 77].
- Mental and relaxing sessions might be integrated in the daily training [6].

- Development of psychological, physiological and social abilities, through the maintenance of good health and physical conditioning should be encouraged [78].
- A balanced diet rich in carbohydrates, proteins, nutrients and electrolytes should be taken [12, 79].

Treatment of overtraining: Athletes with overtraining syndrome generally have seriously disrupted competitive season [80]. According to current evidences, physiological recovery with proper nutrition is an important aspect to treat the overtraining syndrome. Low-level exercise has been shown to speed the recovery process rather than complete rest [81]. The emphasis should be given at gradual increase in volume rather than intensity. The longer the period of overtraining, the more rest will be required. The length of rest range from few days to several weeks depends on severity of overtraining [82].

Overtrained athletes and those leading towards overtraining may be "treated" according to the following guidelines [18]:

- Determination and elimination of factors leading to overtraining :
  - Allowing more time for the body to recover
  - Taking a break from training to allow time for recovery
  - Reducing the volume and/or the intensity of the training
  - Suitable periodization of training
  - Splitting the training program so that different sets of muscles are worked on different days.
  - Increase sleep time.
- Spa treatments :
  - Deep-tissue or sports massage or self-massage of the affected muscles.
  - Cryotherapy and thermotherapy.
  - Temperature contrast therapy
  - Hydro therapy
- Alteration of dietary pattern :
  - Ensuring that calorie intake at least matches expenditure.
  - Ensuring total calories are from a suitable macronutrient ratio.
  - Addressing vitamin deficiencies with nutritional supplements.

A general guideline of nutritional modifications of overtrained athletes has been prescribed by Downey and Hopkins [83] which shows the average requirement of total calories (44-52g/kg/day) including carbohydrate (6-8g/kg/day), protein (1-1.2g/kg/day), lipids (0.8-2.1g/kg/day). Simultaneously carbohydrate and water ingestion during the endurance training at the rate of 0.4 g / kg / h and 5 ml / kg / h, respectively has also been recommended [83]. Overtraining can deplete essential micronutrients, e.g., zinc, magnesium, calcium, vitamin B and C, which must be supplemented additionally. Anti-oxidants should be used for combating the free radicals that form as a result of overtraining. DHEA, Glutamine, arginine and ornithine supplementation are also suggested [84].

Conclusion

Present review reveals that overtraining is considered as a state of fatigue where performance fails to improve or even deteriorates, despite of continuous training. It is due to physical and mental overloading which disturb the physiological and psychological states of the athletes who fail to excel their best performance. Excessive training with insufficient recovery is the main aetiology of overtraining syndrome that leads to a debilitation of performance and well being for unlimited period. Eliminating or minimising these problems by providing advice and guidelines on training loads, recovery times, nutrition or pharmacological intervention and regular monitoring of athletes using an appropriate battery of markers can help to prevent overtraining in athletes.

Heart rate, plasma cortisol and blood lactate response to a standardized bout of high intensity exercise are objective and prime markers of impending overtraining. By increasing our knowledge and understanding of overtraining, coaches, parents, and athletes can become more aware of even the slightest sign of this complex condition and take the appropriate actions.

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