Overreaching and Undereating

A Holistic Nutritional Approach to Overtraining in Endurance Sports

Denis Faye M.S.

THESIS STATEMENT

Whole food-based, holistic nutritional intervention can be useful in preventing and rehabilitating a diverse range of physiological issues associated with overtraining in endurance athletes.

ABSTRACT

The objective of this paper is to look at holistic nutritional interventions for overtraining, particularly pertaining to endurance athletes. By the very definition of endurance sport, these athletes push their bodies to the extremes that can cause nutritional and physical imbalances. The failure to properly counter these imbalances is generally referred to as overtraining. The goal of training is to push the body past its limits for short periods so that the body can adapt and therefore progress. When this pushing is taken too far, progress stalls and, eventually, performance can regress. Furthermore, a detrimental domino effect can affect every system in the body. Issues may include neuroendocrine changes, central nervous system fatigue, excessive oxidative stress, skeletal muscular issues, and reduced immunity. While proper physical recovery is crucial for both warding off overtraining and repairing the body once overtraining has occurred, a proper diet is also vital in addressing this all-encompassing issue. This paper will investigate the individual problems overtraining creates, along with nutritional suggestions to address these problems. It will then bring these suggestions together to illustrate the potential benefits of a comprehensive, holistic diet.

INTRODUCTION

Endurance athletes have overtrained since the beginning of recorded history—and probably well before that. As far back as ancient Greece, Aristotle warned that overtraining hampered intellectual development (Edel, 1982). And athletes will most likely continue to overtrain in the foreseeable future. The main point of serious cycling, running, swimming, paddling or any other endurance sport is competition, either against others or against your previous personal achievements. The only way to succeed in this pursuit is to push your limits. And when you push your limits, it's inevitable that you push too far on occasion.

It's tempting to pin this situation in amateur athlete communities on excessive enthusiasm, ignorance, and a misunderstanding of effective adaptive training. Yet, the truth is that overtraining impacts professional athletes as well. A British study showed that 15% of elite female athletes and 35% of elite male athletes experiences some form of overtraining during their competitive season (Koutedakis & Sharp, 1998). Case in point, 41-year-old professional cyclist Chris Horner, whose 2013 *Vuelta a Espana* victory has been credited to a three-month, injury-induced rest period. Several in the professional cycling community postulate that this apparent increase in ability suggests that overtraining had been hampering his performance previous to his injury (Dansie, 2013).

It is safe to assume that most amateur endurance athletes aren't terribly interested in taking a Horner-inspired three-month rest period from their chosen sport, even in the face of injury, inclement weather, or the demands of a knowledgeable coach. Fortunately, they may not need to, given there's another factor in maintaining balance that a sportsperson should and can utilize year around: proper nutrition.

On a personal note, my background in endurance athletics is as an amateur competitive cyclist. I use many of the recommendations in this paper to manage my own overtraining issues. I also advise a number of my fellow cyclists on these issues. I am mindful of my bias is towards cycling. However, both the research and recommendations in this paper apply to all endurance sports, given the overtraining mechanisms are the same.

Definition of overtraining

When an athlete pushes the body beyond limits for a specific period of time, it will adapt to the situation—and fitness improves. This is known as functional overreaching. Creating adaptation using a balance of overreaching and proper rest is known as periodization. When an athlete overreaches for too long without sufficient rest, adaptation can stall and damage can occur. At this point, the longer an athlete continues to push beyond limits, the worse the damage and the longer it will take to recover.

Beyond this, definitions of the various degrees of overtraining shift from study to study. Many experts consider overtraining a continuum while others question the link between overreaching and overtraining (Halson & Jeukendrup, 2004). In reviewing a wide range of literature, it appears the most widely accepted theory is best explained by the European College of Sports Medicine, who break the process down into two stages (Kreher & Schwartz, 2012).

- *Nonfunctional Overreaching (NFO)* is the first stage. This level of training overload that can be recovered from in weeks to months. Complete recovery is possible.
- *Overtraining Syndrome (OTS)* – if NFO is ignored, it can evolve into OTS, which entails worse symptoms and performance decrement in excess of 2 months. This can take months or years to recover from—if recovery is achieved at all.

The symptomologies for NFO and OTS—or any other definition you choose to embrace—are extremely similar. The observations and recommendations here apply to all of them. (In fact, they also apply to athletes in a healthy state who wish to maintain proper periodization, thus avoiding the issue.) In this paper, both NFO and OTS will be referred to as "overtraining."

Symptoms of overtraining

The most obvious symptom of overtraining is a decline in performance. However, that's where the simplicity ends. There is no agreed upon list of overtraining systems, nor definitive comparison of overtraining symptoms across disciplines (Smith, 2000). However, Fry, Morton, & Keast (1991, p.37) compiled a list based on their appearances in literature, as represented in Table 1.

Table 1 Comprehensive List of Overtraining Symptoms

Physiological performance

Decreased performance
Inability to meet previously attained performance standards or criteria
Recovery prolonged
Reduced toleration of loading
Decreased muscular strength
Decreased maximum work capacity
Loss of coordination
Decreased efficiency or decreased amplitude of movement
Reappearance of mistakes already corrected
Reduced capacity of differentiation and correcting technical faults
Increased difference between lying and standing heart rate
Abnormal T wave pattern in ECG
Heart discomfort on slight exertion
Changes in blood pressure
Changes in heart rate at rest, exercise, and recovery
Increased frequency of respiration
Perfuse respiration
Decreased body fat
Increased oxygen consumption at submaximal workloads
Increased ventilation and heart rate at submaximal workloads
Shift of the lactate curve towards the X-axis
Decreased evening postworkout weight
Elevated basal metabolic rate
Chronic fatigue
Insomnia with and with night sweats
Feels thirsty
Anorexia nervosa
Loss of appetite
Bulimia
Amenorrhea or oligomenorrhea
Headaches
Nausea
Increased aches and pains
Gastrointestinal disturbances
Muscle soreness or tenderness
Tendonostic complaints
Periosteal complaints

Muscle damage
Elevated C-reactive
Rhabdomyolysis

Psychological/information processing
Feelings of depression
General apathy
Decreased self-esteem or worsening feelings of self
Emotional instability
Difficulty in concentrating at work and training
Sensitive to environmental and emotional stress
Fear of competition
Changes in personality
Decreased ability to narrow concentration
Increased internal and external distractibility
Decreased capacity to deal with large amounts of information
Gives up when going gets tough

Immunological
Increased susceptibility to and severity of illnesses, colds, and allergies
Flu-like illness
Unconfirmed glandular fever
Minor scratches heal slowly
Swelling of the lymph glands
One-day colds
Decreased functional activity of neutrophils
Decreased total lymphocyte counts
Reduced response to mitogens
Increased blood eosinophil count
Decreased proportion of null (non-T, non-B) lymphocytes
Bacterial infection
Reactivation of herpes viral infection
Significant variations in CD4: CD8 lymphocytes

Biochemical
Negative nitrogen balance
Hypothalamic dysfunction
Flat glucose tolerance curves
Depressed muscle glycogen concentration
Decreased bone mineral content
Delayed menarche
Decreased hemoglobin
Decreased serum iron
Decreased serum ferritin
Lowered TIBC
Mineral depletion (Zn, Co, Al, Mn, Se, Cu, etc.)
Increased urea concentrations
Elevated cortisol levels
Elevated ketosteroids
Low free testosterone
Increased serum hormone binding globulin
Decreased ratio to free testosterone to cortisol of more than 30%
Increased uric acid production

Robson-Ansley and Costa have distilled this list down six symptoms, which might be more accessible to the layman athlete (2014, p. 406).

- Increased fatigue during exercise
- Underperformance with an inability to increase the pace at the end of a race
- Increased fatigue and sleepiness during actual day living
- Increased upper respiratory tract symptoms
- Reduced sleep quality—waking unrefreshed
- Slow wound healing and muscle soreness

How nutrition impacts overtraining

Some problems caused by overtraining, such as skeletal muscular and blood sugar issues, are specific to the issue. However many other problems, particularly those related to the endocrine system, can be triggered by any type of stress.

Not only does proper periodization improve physical capacity, but exercise-induced adaptation can also help with anxiety regulation in the brain, therefore improving the athlete's general stress response (Schoenfeld et al, 2013). However, during overtraining, exercise becomes a detrimental stressor like any other, causing hormones, particularly cortisol, to react accordingly (Urhausen, Gabriel, & Kindermann, 1995).

With this in mind, a whole food-based, holistic nutrition program combats overtraining in two ways. First, it has a direct physiological impact on the various issues. For example, proper use of carbohydrates is a primary asset in blood glucose regulation, which plays a key role in many overtraining issues. Furthermore, whole foods are potent healers. As Lui (2003) states in the *American Journal of Clinical Nutrition*, "Food provides not only essential nutrients needed for life but also other bioactive compounds for health promotion and disease prevention. Previous epidemiologic studies have consistently shown that diet plays a crucial role in the prevention of chronic diseases. Consumption of fruit and vegetables, as well as grains, has been strongly associated with reduced risk of cardiovascular disease, cancer, diabetes, Alzheimer disease, cataracts, and age-related functional decline" (p. 517S).

Second, a healthy diet helps to balance the "stress/rest" ratio. When overtraining is a stressor just like work, domestic issues, illness, or a master's thesis deadline, it becomes part of the total stress load. If this is the case, the athlete isn't overtraining as much as "overliving" (Cordain & Friel, 2012, p. 123). With this mindset, a holistic strategy, including diet among other healing modalities, is crucial to restore homeostasis.

It's important to note that this paper does not suggest that food can replace rest. Proper rest and recovery phases are vital to any healthy fitness program. However, proper nutrition can help increase the benefits of these phases and even reduce time needed to recover. Furthermore, when used prophylactically, proper nutrition can potentially mitigate the damage caused by overtraining with greater effect than commonly realized.

Pathophysiology

Despite extensive research, the physiological processes associated with overtraining are still a subject of speculation. There is no single, all-inclusive paradigm explaining why OTS, specifically, happens (Kreher & Schwartz, 2012).

However, regardless of the inciting cause, the symptoms of overtraining are universal and occur across many of the body's systems. The fact that these symptoms are wide-ranging and not completely understood creates another compelling reason why a similarly wide-ranging holistic approach to nutrition has a much better chance of benefiting the overtrained athletes than relying entirely on an allopathic, targeted approach.

This paper will discuss various overtraining etiology hypotheses in order to better understand the issues and how the sports medicine community has approached them. However, given the encompassing nature of the solutions discussed, a whole food-based, holistic nutritional intervention should be of benefit regardless of the accuracy of these individual hypotheses.

In other words, overtraining is a whole-body issue in that it involves the breakdown of a number of bodily systems. Therefore, instead of focusing on one, outstanding process, this paper will embrace a more overarching nutritional approach.

PHYSIOLOGICAL ISSUES

The issues related to overtraining can be overlapping and/or cascading in nature, making them difficult to separate. However, breaking them down makes it easier to offer direct nutrition considerations to the individual issues. Given these issues can overlap, a holistic solution is all the more compelling. Surprisingly, while nutrition-based solutions to the various issues exist with plenty of scientific backing, a review of literature found no single plan that gathered these solutions, allowing them to work synergistically.

Skeletal muscular issues

Muscular microtrauma

Overloading muscles is a key component in training. Continued muscle contraction and repetitive joint movement cause microtrauma, or small tears in the muscle fiber. This triggers the release of cytokines, hormone-like proteins causing a localized inflammation response that doesn't just heal the fibers, but strengthens them against further assault (Kreher & Schwartz, 2012).

On a local level, if a muscle is overtrained, this microtrauma isn't allowed to heal, causing a continuous inflammatory response that can, eventually, become chronic. Cytokines will activate white blood cells known as monocytes which create additional cytokines in such volume that they move beyond the localized area, resulting in systemic inflammation (Smith, 2000).

One study on Ironman triathletes found that low-grade, systemic inflammation remained for 5 days after an event for even non-overtrained athletes, with levels of C-reactive protein (an inflammation marker) remaining slightly but significantly higher 19 days post-event (Neubauer, König, & Wagner, 2008).

The "cytokine hypothesis" points to this issue as the primary driver for overtraining. It postulates that this inflammatory cascade eventually affects the liver and the central nervous system and in so doing causes NFO and OTS (Smith, 2000). This hypothesis has been further refined to the "interleukin-6 (IL-6) hypothesis," focusing on IL-6, a cytokine linked to fatigue sensation, immune system response regulation and glucose regulation during prolonged exercise. (Robson-Ansley & Costa, 2014).

Depleted glycogen

The "glycogen hypothesis" is another important overtraining theory. Muscles fibers gain the energy to contract using the chemical adenosine triphosphate (ATP). The body creates ATP by converting carbohydrates, fat, and to a much lesser degree, protein. Carbohydrate oxidization is the primary source of ATP via glucose. On average, humans store about 80 calories worth of glucose in their blood. They also have reserves in the form of glycogen, a polysaccharide that's easily converted back to glucose. On average, the liver contains approximately 400 calories worth of glycogen and muscles contain about 1,500 calories worth, enough for 90 to 120 minutes of vigorous activity (Eberle, 2014).

The body also relies on the oxidization of fat stored both in adipose tissue and the muscle itself for fuel, but fat takes longer than glucose to convert to energy. The glucose-to-fat-oxidizing ratio depends on the intensity and duration of effort, but even when fat oxidation is high, during 4-6 hours of moderate-intense effort, the body still pulls 30% of its energy from glycogen (Eberle, 2014).

The glycogen hypothesis stipulates that chronic low glycogen triggers increased oxidation of protein, specifically leucine, isoleucine, and valine—the branched chain amino acids (BCAAs) found in the blood supply. This decreased concentration of BCAAs in the blood causes a disruption in the production of neurotransmitters (see *Central nervous system fatigue* for a detailed explanation), therefore potentially causing overall fatigue (Kreher & Schwartz, 2012).

Snyder (1998) brought this theory into question by increasing the workload of swimmers while increasing their carbohydrate load as to maintain muscle glycogen stores. The swimmers still met the criteria for NFO, questioning how much glycogen plays a role in overtraining. However, it remains widely accepted that inadequate carbohydrates impact performance, and a more recent stance from Robson-Ansley and Costa (2014) claims that lack of carbohydrates can alter stress hormone responses, worsen mood state, cause general fatigue, and lead to NFO.

One possible reason for Snyder's findings is that muscle damage (including microtrauma) can impede glucose transportation to muscles, impairing muscle glycogen production and therefore hampering performance (Smith, 2000).

The cytokine hypothesis does not discount the importance of muscle glycogen. In fact, it proposed that the two are strongly interlinked in several ways. Studies show that ingesting carbohydrates during exercise reduces exercise-induced levels of IL-6, thus regulating inflammation (Kraakman, Whitman & Febraio, 2014). Also, IL-6 impacts the hunger centers in the hypothalamus, suppressing hunger, therefore potentially limiting carbohydrate intake (Smith, 2000).

Central nervous system fatigue

Sore muscles are easy to identify. A far more insidious aspect of overtraining is its effect on the central nervous system (CNS). Overtraining symptoms involving the CNS include mood and behavior issues as well as poor sleep (Kreher & Schwartz, 2012).

The neurotransmitter serotonin (5-HT) plays a number of roles, including regulating sleep, emotion, appetite, and the hypothalamic-pituitary axis (Roelands & Meeusen, 2014). The precursor to 5-HT is the amino acid tryptophan (TRP). In the blood, TRP binds to the protein albumin. However, when it is unbound, TRP passes across the blood brain barrier to synthesize 5-HT via the same receptors as other amino acids, including BCAAs. Exercise alters this process in two ways. First, prolonged exercise causes BCAAs in the blood to be oxidized to fuel muscle contraction. Second, fatty acid concentration goes up in the blood, and these fatty acids bind to albumin, displacing TRP. These two actions cause an increased flow of TRP across the blood brain barrier and therefore an increase in 5-HT (Davis, Alderson & Welsh, 2000).

In moderation, this increase in 5-HT can have a positive influence on mood, possibly preventing depression (Young, 2007). However, 5-HT has a calming effect, functioning antagonistically against the stimulatory neurotransmitter dopamine. Some research suggests a high 5-HT-to-dopamine ratio can lead to decreased motivation, lethargy, tiredness, and loss of motor coordination (Davis, Alderson & Welsh, 2000).

The theory that this increased 5-HT is the primary driver of overtraining is known as the "central fatigue hypothesis." There is some debate as to whether overtraining is brought on by increased 5-HT or increased *sensitivity* to 5-HT. Evidence suggests well-trained athletes adapt so that they acquire a reduced sensitivity to 5-HT, while overtrained athletes appear to have lost this adaptation (Budgett et al, 2010).

Reduced immunity

The relationship between immunity and overtraining is not fully understood. Prolonged periods of exercise, specifically those lasting longer than 90 minutes at moderate to high intensity (55-75% of VO2 max), increase stress hormones and suppress a number of immune functions, including natural killer cell activity, T and B cell function, and salivary IgA concentration. However, these changes are acute, not chronic, typically lasting 3-24 hours (Nieman, 2014; Gleeson 2007).

The reasons of this immunodepression are wide ranging, including stress hormone changes, as well as sympathetic nervous system stimulation, body temperature shifts, dehydration, muscle damage (see *Skeletal muscular damage*), oxidative stress (see *Oxidative stress*), and nonsteroidal anti-inflammatory drug (NSAID) use (Nieman, 2014). Reduced blood concentration of glutamine has also been suggested as a cause, given this amino acid acts a substrate for many immune cells (Jeukendrup & Gleeson, 2010).

According to Nieman (2014), these shifts are transient and the "resting immunity of athletes varies little from that of nonathletes" (p. 479). However, other research indicates prolonged training can reduce efficacy of the mucosal immune system—thin, permeable barriers that cover areas of the body especially susceptible to infection including the gut-associated lymphoid tissue (GALT), urogenital tracts, lacrimal glands, lactating mammary glands and, in the respiratory tract, the bronchus-associated lymphoid tissue (BALT), salivary glands, and nasal-associated lymphoid tissue (NALT) (Gleeson & Pyne, 2000).

A 3-month study on competitive swimmers showed a chronic suppression in saliva immunoglobulin A (IgA) antibodies by the end of the season (Tharp & Barnes, 1990). Gleeson and Payne (2000) further state that, while IgA levels typically recovery within 24 hours, low IgA levels can become chronic as the result of years of intense exercise. Given secretory IgA in the gut can be the immune system's first line of defense against allergens and microbes, low levels may lead to infection and inflammation.

Epidemiologically, overtrained athletes report increased upper respiratory symptoms. However, this increased frequency of illness has not been linked directly to a suppressed immune system. External factors that may also play a part include localized non-infective inflammation in the airways due to breathing high volumes of air, inhalant allergies, and/or stress-induced asthma (Robson-Ansley & Costa, 2014).

The "glutamine hypothesis" links overtraining and lowered immune function by way of this immune cell substrate. Low plasma glutamine levels are common in overtrained athletes. Therefore, the theory is that overworked muscles are either overusing this amino acid or not enough of it is being produced (Kreher & Schwartz, 2012).

Hiscock and Pederson (2002) claim that plasma glutamine reductions most likely aren't large enough to play a role in post-exercise immunodepression. However, at least one study shows glutamine supplementation (.1 g/kg body weight) to reduce the occurrence of respiratory infection in marathon and ultra marathon runners following intense training (Castell, 2002; Castell & Newsholme, 1998).

Whether or not exercise-induced immunodepression is a symptom of overtraining, modifying nutrition to address the issue is worth considering (Robson-Ansley & Costa, 2014).

Oxidative stress

The relationship between exercise and free radicals—or reactive oxygen species (ROS) as they're known within physiologic contexts—has been known about since at least 1982, when Harvard researchers discovered that contracting muscle fibers to exhaustion increases ROS concentrations two- to three-fold (Davies et al., 1982).

The oxidation-reduction (redox) cycle is crucial to many biological processes, including those needed for exercise. When ROS (which drive oxidation) exceed antioxidants (which drive reduction) it's known as oxidative stress.

The "oxidative stress hypothesis" of overtraining suggests that oxidative stress can become pathologic, resulting in inflammation, fatigue, and muscle soreness (Kreher & Schwartz, 2012). Two separate studies show increased resting oxidative stress markers in overtrained athletes, although they don't establish causality (Margonis et al, 2007; Tanskanen, 2010).

ROS, in particular, play an important role in the inflammatory process, acting as a vasodilator and clearing away damaged muscle tissue (Tiidus, 1998). *Limited* oxidative stress is thought to play an important role in muscle adaption, given ROS may trigger the upregulation of endogenous antioxidants, therefore increasing muscle tolerance of further exercise-induced stress (Niess & Simon, 2007).

Excessive oxidative stress has a more negative impact, in that ROS can damage cellular lipids, proteins, and DNA; and has been linked to over 100 human diseases (Halliwell, 2001). In a small study done on German triathletes, training for and participating in a full Ironman triathlon did not appear to cause DNA damage (Reichhold, 2008). However, another study on Swiss mice found that, while intense training improved performance without damage, induced overtraining resulted in DNA damage (Pereira et al, 2013).

Peternelj & Coombes (2011) claim that the positive effects of ROS-mediated physiological processes should not be interfered with via antioxidant supplementation. Jeukendrup & Gleeson (2010) question whether these adaptations are significant enough to protect athletes who exercise extensively. (See *Antioxidants* for further analysis.)

Other hormonal imbalances

Adrenaline and noradrenaline

The hormones of the hypothalamic-pituitary-gonadal axis play key roles in energy metabolism during exercise. This section covers just a few. Initially during exercise, catecholamines (adrenaline and noradrenaline) are released from the adrenal medulla to stimulate heart rate and influence blood vessel diameters. Adrenaline plays the additional roles of promoting glycogenolysis and lipolysis (the breaking down of glycogen and fat for fuel). During prolonged, strenuous efforts, the adrenal cortex releases cortisol, a steroid that increases the effectiveness of the catecholamines and promotes amino acid release from muscle, among other things (Gleeson, 2014).

In an overtrained state, the levels of catecholamines and cortisol increase (Budgett, 1998). A number of theories explain the impact of this. One theory postulates that the increase in catecholamines causes a downregulation of receptors, resulting in decreased sensitivity in target tissues (muscles, liver, heart) to catecholamines. Because catecholamines play a role in glucose metabolism, this causes a decrease in the conversion of glucose to energy, followed by a reduction in lactate levels, which inhibits the body's ability to exert itself. (Jeukendrup & Gleeson, 2010).

This reduced sensitivity to receptors is potentially evidenced by a study on long distance runners during which overtraining was induced. As performance decreased, so did nocturnal urinary catecholamine excretion, even though exercise-related plasma catecholamine responses increased. Simply put, adrenaline and noradrenaline were generated in an increasing volume, but not utilized properly (Lehmann et al, 1992).

This juxtaposition possibly explains the "autonomic nervous system hypothesis" of overtraining. In this theory, the body's inability to properly use adrenaline and noradrenaline inhibits sympathetic activation—the "fight or flight" reaction—an important factor in athletic performance (Kreher & Schwartz, 2012).

Cortisol and testosterone

Some research suggests that proinflammatory cytokines, along with other mediators, promote cortisol and suppress testosterone in overtrained athletes, causing a high cortisol-to-testosterone ratio (Kreher & Schwartz, 2012). Given cortisol is associated with catabolism but testosterone is anabolic, this suggests that overtraining can be tied to catabolism, the degradative metabolic state associate with the breakdown of proteins (Budgett, 1998).

Reduced testosterone can potentially inhibit muscle repair since this steroid hormone stimulates protein synthesis in skeletal muscle (Brodsky, Balagopal & Nair, 1996).

Although strong support exists for the cortisol-testosterone ratio theory, particular regarding the elevation of cortisol, research from Lehman et al (1992) shows cortisol levels to actually *decrease* with overtraining. The researchers claim "The clear decrease in basal catecholamine excretion and the behavior of cortisol and testosterone in the present study do not confirm specifically the hypothesis of increased catabolism in overtrained athletes such as is assumed on the basis of the cortisol-testosterone ratio" (p. 241).

Lehman's research, pointing to an overall decrease in hormones, suggests the possibility of an Addison's disease-type overtraining situation in which adrenal glands are overly fatigued (Brooks & Carter, 2013). This makes adrenal exhaustion another possible cause or result of overtraining.

Insulin

Insulin issues have not yet been shown to be a factor in overtraining (Smith, 2000) despite overtraining-related increases in adrenalin and cortisol, both which raise blood sugar; and despite the fact that insulin resistance can be a metabolic response to muscle trauma (Stoner, 1987). This may be explained by the unusually high dietary carbohydrate requirements of endurance athletes (Robson-Ansley & Costa, 2014). Also, exercise has a strong impact on insulin. During exercise, muscles uptake glucose independent of insulin-stimulated clearance. This uptake persists for several hours afterwards, at the same time enhancing insulin function (Braun & Miller, 2014). Finally, IL-6, which increases in overtrained athletes, has been shown to enhance glucose uptake in working muscle, possibly managing insulin (Kraakman, Whitman & Febraio, 2014).

Thyroid hormones

The impact of overtraining on the thyroid has not been as widely studied as other factors. However, a study from Hackney et al (2012) did show heavy exercise to suppress the conversion of the thyroid hormone thyroxine (T4) to its active form, triiodothyronine (T3). Intense interval training showed to have a stronger impact than endurance training, requiring at least 12 hours for proper recovery.

Microcytic anemia

Iron deficiency is a common issue in the athletic community for a number of reasons including sweat loss and nutritional insufficiency. In addition, inflammatory cytokines increase the hormone hepcidin, the master iron regulator (Robson-Ansley & Costa, 2014). Hepcidin inhibits dietary iron absorption via macrophage sequestering, meaning it induces these white blood cells not to release iron stores. Therefore, chronic inflammation can result in chronic iron sequestering and, eventually, anemia (Rossi, 2005).

NUTRIENTS TO BE CONSIDERED

Given the wide range of issues associated with overtraining, it stands to reason that a wide-ranging nutritional strategy would be effective. While this may be true, there are a few key strategies and nutrients that may be of particular benefit to the overtrained athlete, as well as the athlete seeking to avoid overtraining.

Calories

The caloric needs of endurance athletes are considerable. U.S. Olympic Committee senior sport dietitian Nanna Meyer estimates that Olympic cycling, swimming, marathon, and rowing athletes require 3,000-8,000 calories a day (Barclay, 2012). According to Jeukendrup & Gleeson (2010), a survey in the *International Journal of Sports Medicine* found that the average 159-pound, male, amateur elite cyclist consumes 4,370 calories a day. A 145-pound, female amateur elite cyclist consumes 2,586 calories daily.

Keeping a food log is an important aspect of endurance training for several reasons, including tracking calories, considering suppressed appetite is a common symptom of overtraining. Clinical research links increased proinflammatory cytokine levels with alterations in hypothalamic and sensory appetite regulation, causing the appetite reduction (Robson-Ansley & Costa, 2014).

The Harris Benedict formula is a valuable tool for making an athlete aware of their approximate caloric needs (Mueller & Hingst, 2013, p. 248).

Once a resting metabolic rate (RMR) has been determined, activity level should be factored in, using Table 2.

Males: 88.362 + (4.799 x height in centimeters) + (13.397 x weight in kilograms) – (5.677 x age) = RMR

Females: 447.593 + (3.098 x height in centimeters) + (9.247 x weight in kilograms) – (4.330 x age) = RMR

Table 2 Activity factors for caloric intake determination

Very Light	Largely bed rest	RMR x 1.2-1.3
Light	No planned activities	RMR x 1.5-1.6
Moderate	Walking daily	RMR x 1.6-1.7
Heavy	Planned, vigorous activity	RMR x 1.9-2.1

Keep in mind that additional calories may be required if the athlete is recovering from injury or from intense exercise. If an athlete consumes insufficient calories, the body will break down muscle—and in severe cases also break down skin collagen, bone, and visceral protein—in order to heal (Demling, 2009; Molnar & Stuart, 2009).

In these situations, Demling recommends the following modification (2009, p. 10).

RMR x 1.2 (injury-induced stress factor) x Activity Factor = Recommended caloric intake

Carbohydrates

As the body's primary fuel source, carbohydrates play a central role in the endurance athlete's diet (Burke, 2014; Jeukendrup & Gleeson, 2010). As previously stated, insufficient carbohydrates can alter stress hormone responses, worsen mood state, cause general fatigue, and lead to overtraining (Robson-Ansley & Costa 2014).

The International Olympic Committee's recommendation for carbohydrate intake for an endurance athlete participating in moderate to high intensity exercise 1-3 hours per day is 6-10 g/kg body weight daily (Maughan & Burke, 2012).

Timed carbohydrate intake

Nutrient timing in endurance sport is a vast topic, worthy of its own paper, if not several hundred papers. The findings below offer a broad overview as it relates to overtraining.

Carbohydrates have several tasks for endurance athletes. Timed use before, during, and after longer training sessions and competition has an ergogenic effect, increases fatigue resistance, improves motor skills, and maintains glycogen stores (Jeukendrup, 2014). During prolonged exercise, they attenuate levels of plasma cortisol, adrenaline, and cytokines (Jeukendrup & Gleeson, 2010). They also enhance recovery, thus staving off overtraining. Given the rapid depletion of energy in this timeframe and the fact that muscle absorbs glucose independent of insulin during and after exercise, high-GI carbohydrates are a better option due to their fast-absorbing nature (Braun & Miller, 2014; Jeukendrup & Gleeson, 2010).

Carbohydrate consumption during exercise may also ward of central nervous system fatigue by reducing the exercise-induced rise of TRP, thus helping maintain the balance of BCAAs and TRP, which can prevent excess 5-HT (Roelands & Meeusen, 2014).

Carbohydrate consumption after prolonged, strenuous exercise has also been shown to prevent a decrease in the function of white blood cell neutrophils, boosting immunity (Costa et al, 2011).

Carbohydrates also allow faster absorption of other nutrients shown to be effective against many of the issues associated with overtraining. These nutrients include BCAAs and other proteins (Ivy & Portman, 2004). The benefits of a carbohydrate/protein combination post-exercise will be discussed under *Protein*.

Recommended amounts vary, but a general guideline is a mouth rinse for the first 60 minutes of training, 30 g/h for the next hour, 60 g/h for the next 30 minutes, and 90 g/h beyond that (Jeukendrup, 2014).

Dietary recommendations for timed carbohydrates

Although many athletes look to pre-packaged sports supplements for nutritional needs during training, it is possible to fuel using whole foods. For example, bananas and coconut water both supply carbohydrates and electrolytes, with coconut water matching the nutritional profile of popular sports drinks without the potentially carcinogenic dyes (Kelinson, 2009; Kobylewski & Jacobson, 2010).

Other benefits of carbohydrates

Adequate carbohydrates are necessary for healthy immune function in that glucose is used as a fuel for several immune cells, including lymphocytes, neutrophils, and macrophages (Jeukendrup & Gleeson, 2010).

Finally, high-quality carbohydrates such as fresh produce and whole grains function as a source of other nutrients. As previously discussed, overtraining has a wide-ranging impact on the body, including oxidative stress, skeletal muscular breakdown, potential illness and infection, and hormone imbalances. Various nutrients play various roles in restoring homeostasis in these situations (as to be discussed below) and quality carbohydrate foods supply many of these nutrients. Robson-Ansley and Costa (2014) suggest that consuming a varied diet and sufficient energy can meet vitamin and mineral needs in athletes.

Protein

Athletes have increased protein needs over the general population. While the Institute of Medicine recommends 0.8-0.9 g protein/kg/day for most people, the general scientific consensus for athletes is between 1.2 and 1.7 g protein/kg/day (Phillips, 2014).

The timing of protein ingestion is important for aiding in muscle recovery, which could play a role in avoiding overtraining. Post prolonged exercise, glycogen stores are depleted and cortisol and adrenaline are elevated, putting the body in a catabolic state. Studies have shown that a combination of carbohydrates and protein taken within an hour of exercise is optimal for restoring an anabolic state, replenishing glycogen and increasing insulin response, which increases protein synthesis in muscles (Ivy & Portman, 2004).

Again, several pre-packaged supplements supply the approximate 4-1 protein-carbohydrate recommended ratio. However, a cup of plain, low-fat yogurt with a spoonful of honey added offers a similar ratio. (While full-fat yogurt is technically more of a whole food, low-fat allows for faster absorbency.) One study on young, male weightlifters shows that milk protein is especially beneficial for gaining muscle mass when consumed for recovery. It is worth noting that the study was funded by the US Dairy Council (Hartman, 2007).

Dietary recommendations for protein

Phillips (2014) recommends high-quality proteins such as dairy, eggs, and lean meat in general, given "protein quality also appears to be important in maximizing the accretion of muscle proteins" (p. 145).

Branched-Chain Amino Acids (BCAAs)

The BCAAs, leucine, isoleucine, and valine, are essential amino acids. Unlike other amino acids, they can be oxidized by skeletal muscle for fuel. Other amino acids need to be broken down in the liver (Shimomura et al, 2004).

Endurance athletes supplement BCAAs for a number of reasons, many of which can apply to overtraining. Much of the research regarding the benefits of BCAAs is mixed.

Glycogen sparing/As a fuel source. Research is mixed. Current studies show carbohydrate and fat oxidation in muscles is considerably higher than that of BCAAs. Possibly for this reason, supplementation of BCAAs has not been shown to improve immediate performance in studies (Jeukendrup & Gleeson, 2010; Mueller & Hingst, 2013; Roelands & Meeusen, 2014).

Prevention of protein breakdown. Given 35% of the essential amino acids in muscle protein are BCAAs, and given endurance exercise oxidizes BCAAs, it stands to reason that supplementation would benefit muscles (Shimomura et al, 2004). Mueller & Hingst (2013) and Shimomura et al (2004) point to many studies supporting this theory. Jeukendrup & Gleeson (2010), on the other hand, claim that the studies on the prevention of protein breakdown are primarily in vitro, stating that only "limited scientific evidence supports the commercial claims that orally ingested BCAAs have an anticatabolic effect" (p. 186).

Combating central nervous system fatigue. A Swedish study on athletes before and after a 30-km competitive cross country run showed an improvement in the ability to do complex tasks post-run for subjects supplementing a BCAA and carbohydrate mix, suggesting a possible TRP/BCAAs uptake balancing (Hassmen et al, 1994). Another study on endurance-trained cyclists showed BCAA supplementation caused lower perceived exertion and mental fatigue. However, there was no difference in performance (Blomstrand et al, 1997).

Enhancing immunity. BCAA supplementation has been shown to limit reduction of serum glutamine, an amino acid important to many immune cells (Mueller & Hingst, 2013).

BCAA toxicity in relation to exercise has not been reported (Shimomura et al, 2004). Typical dosage ranges from 6 to 14 g per day with a leucine:valine:isoleucine ratio of 2 or 3:1:1 (Mueller & Hingst, 2013).

Dietary recommendations for BCAAs

Whole food sources of BCAAs include red meat, dairy, chicken, fish, and eggs. Soy also contains BCAAs, although not in as high a volume. Some research also shows that soy supplementation may decrease exercise stress-induced lipid peroxides, which are markers of oxidative stress (Kelly & Bongiorno, 2006).

Glutamine

Glutamine, which is produced from another amino acid, glutamic acid, is a conditionally essential substrate for many immune cells. (See *Reduced immunity.*) Given the lack of studies proving its effectiveness and the research indicating its reduction during exercise in healthy athletes isn't substantial, many experts do not recommend it as a post-exercise, immune-boosting supplement (Jeukendrup & Gleeson, 2010; Nieman, 2014).

However, glutamine reduction occurs during other periods of metabolic stress as well (Kelly & Bongiorno, 2006). During extreme metabolic stress such as injury, levels in muscles can decrease 50%, making glutamine supplement an important factor in healing (Askanazi, 1980).

Therefore, it is worth considering for overtrained athletes.

Dosage can be 1.5 g-4.5 g for general usage and up to 30 g for acute situations (Mueller & Hingst, 2013).

Dietary recommendations for glutamine

Dietary sources of glutamine include animal products, cabbage, beans, beets, and spinach (Mateljan, 2007).

Tyrosine

Tyrosine is a nonessential amino acid and a precursor to dopamine, the antagonist to 5-HT, thought to be a prime driver of central nervous system fatigue. It is also a precursor to thyroid hormones T3 and T4. Oral doses have shown to increase circulating concentrations of dopamine, adrenaline and noradrenaline (Jeukendrup & Gleeson, 2010).

According to Roelands & Meeusen (2014), in animal studies, tyrosine "reduces many of the adverse effects of acute stress on cognitive performance in a wide variety of stressful environments" (p. 209). In a study by Banderet at al (1989), supplementing 100 mg/kg body weight of tyrosine was shown to decrease adverse moods and performance impairments in humans after 4.5 hours of exposure to cold and hypoxia. A 2011 study on cyclists showed that 150 mg/kg body weight of tyrosine improved endurance capacity in heat (Tumility et al, 2011).

Dietary recommendations for tyrosine

Food sources include soy, fowl, fish, peanuts, almonds, and dairy (Mueller & Hingst, 2013).

Fat

Alongside carbohydrates, fat is an important fuel source for athletes. Muscles, in fact, have their own fat stores known as intramuscular triacylglycerol. Some athletes experiment with high-fat/low-carbohydrate diets as a means of forcing adaptation. However, these diets decrease glycogen levels and impair fatigue resistance (Jeukendrup & Gleeson, 2010), therefore they aren't ideal in an overtraining situation.

On the other hand, steroid hormones, including testosterone, are derived from cholesterol. One study showed that low-fat diets decrease the levels of this sex hormone in healthy men, while high-fat diets increase it (Dorgan et al, 1990).

There is no formal guideline for fat intake for athletes, but experts often recommend 20%-30% of total dietary intake (Mueller & Hingst, 2013).

Omega 3 Fatty Acids

While the anti-inflammatory properties of omega-3 fatty acids, specifically alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are well established, research on their influence on athletes is mixed. Small studies on untrained athletes have been positive (Mueller & Hingst, 2013). Another study on exercise-trained men performing a treadmill climb found that 5,000 mg of combined EPA/DHA supplementation decreased resting levels of inflammatory markers including C-reactive protein (Bloomer et al, 2009). However, yet another study on trained cyclists showed EPA and DHA supplementation to have no influence on inflammation or immunity (Kraakman, Whitman & Febraio, 2014).

Several animal studies show the impact of omega-3 fatty acids on neurotransmitters (Logan, 2003). Delion et al (1994) demonstrated that ALA deprivation can lead to an increase in serotonin receptors and a decrease in dopamine receptors, along with a decrease of endogenous dopamine, in the brains of rats. This suggests the importance of adequate omega-3 levels in a central nervous system fatigue situation.

40-170 mg/kg of body weight is the recommended dosage (Mueller & Hingst, 2013).

Dietary recommendations for omega-3 fatty acids

Sources of EPA and DHA include fatty fish such as salmon (2.1 g per 4 oz) and sardines (1.4 g per 4 oz). Flaxseed (3.5 g per 2 TBS) and walnuts (2.3 g per .25 cup) are good sources of ALA (Mateljan, 2007).

Monounsaturated Fats (MUFAs)

Robson-Ansley and Costa (2014) point out that MUFA-rich foods such avocados, almonds, walnuts (and other raw nuts and seeds), and olives should play a dietary role in an overtraining situation. They, like omega-3 fatty acid-rich foods, have anti-inflammatory properties.

Water

Little research appears to exist linking dehydration and overtraining. However, dehydration has been linked to increased catecholamine (adrenaline and noradrenaline) response, which leads to increased glycogen breakdown. This may contribute to fatigue during prolonged exercise (Jeukendrup & Gleeson, 2010). Given the link that excess catecholamine release and depleted glycogen stores possibly play in overtraining, more research is warranted.

Dietary recommendations for hydration

Exercise hydration needs vary depending on length, type, and difficult of task, as well as ambient temperature and the athlete's physiology. Sweat loss during strenuous exercise in high heat can be as much as 2 to 3 liters/hour. Even at temperatures of 59-68 degrees Fahrenheit, a marathon runner can sweat up to 1,200 milliliters/hour (Jeukendrup & Gleeson, 2010). Therefore, hydration with an electrolyte mix beyond standard daily water intake is key. Coconut water provides this combination in addition to carbohydrates (Kelinson, 2009).

One common method to determine hydration needs is for the athlete to weigh in before and after training. If more than 2 pounds of water weight is lost, this is an indication that hydration was inadequate. A pound equals 16 ounces of fluid. This method assumes no fluid lost via urine (Eberle, 2014).

Micronutrients/Phytonutrients

Given the all-encompassing nature of overtraining, almost every vitamin and mineral can be associated with the condition. However, here are micronutrients with particularly strong links and/or sizable research on the correlation.

B-complex vitamins

The B vitamins play roles in energy production, immune function, muscle development, and neurotransmitter metabolism—all functions involved with overtraining issues (Volpe & Nguyen, 2014; Yarlagadda & Clayton, 2007). Given their role in energy production, exercise, like any stressor, will deplete them. Although research was not able to link overtraining and B deficiency, maintaining adequate levels is still crucial.

- *Thiamin (B1)* aids various enzymes in the metabolism of carbohydrates, fats, and BCAAs (Volpe & Nguyen, 2014). Sato et al (2011) studied swimmers and found that high-intensity training impacts thiamin levels in blood (but not riboflavin). Recommended dosage is 1.1 to 1.2 mg/d (Mueller & Hingst, 2013).

- *Riboflavin (B2)* is a constituent of coenzymes involved in redox reactions, electron transference (crucial for the production of ATP), amino acid metabolism, and hormone production. Studies have not found a pattern of deficiency in athletes. Typical supplemental dosage ranges from 1.7 to 10 mg/d (Mueller & Hingst, 2013).

- *Pyridoxine (B6)* plays a role in amino acid metabolism, as well as over 100 enzyme reactions. It is an important cofactor in the creation of neurotransmitters, including GABA, dopamine, and serotonin (Yarlagadda & Clayton, 2007). Recommended dosage for stress-related issues ranges from 100 to 500 mg/d (Lieberman & Bruning, 2007).

- *Folate (B9) and cobalamin (B12)* are important to the creation of red blood cells and therefore oxygen transportation. Low levels can result in anemia. Research appears limited as to whether additional B12 intake is warranted for athletes. Recommended dosage of B9 to improve vascular function is 10 mg/d. Limited research exists linking exercise and increased need for B12, however supplementation for "at risk" populations ranges from 25 to 100 mcg/d (Mueller & Hingst, 2013).

Dietary recommendations for B vitamins

Sources for thiamin include asparagus (.2 mg per cup), crimini mushrooms (.1 mg per 5 oz), spinach (.2 mg per cup), sunflower seeds (.8 mg per .25 cup), romaine (.1 mg per 2 cups), and tuna (.6 mg per 4 oz) (Mateljan, 2007).

Sources of riboflavin include crimini mushrooms (.7 mg per 5 oz), calf's liver (2.2 mg per 4 oz), leafy greens (varies), asparagus (.2 mg per cup), dairy (varies), and eggs (.2 mg per egg) (Mateljan, 2007).

Sources of pyridoxine include leafy greens (varies), bell peppers (.2 mg per cup), garlic (.4 mg per oz), tuna (1.2 mg per 4 oz), and crimini mushrooms (.2 mg per 5 oz) (Mateljan, 2007).

Sources of folate include leafy greens (varies), asparagus (262.8 mcg per cup), calf's liver (860.7 mcg per 4 oz), broccoli (93.9 mcg per cup), and lentils (358 mcg per cup) (Mateljan, 2007).

Cobalamin is found in animal products, especially calf's liver (41.4 mcg per 4 oz) (Mateljan, 2007).

Antioxidants

Antioxidants include vitamins A, C, E, selenium, zinc, copper, manganese, as well as phytonutrients including flavonoids, isoflavonoids, and lignans, and carotenoids (Mateljan, 2007).

Purely from an athletic performance perspective—without considering overtraining—antioxidant supplementation has come into question as of late. Oxidative stress is an aspect of functional overreaching and adaptation. The free-radical reactive oxygen species (ROS) are thought to play a number of important roles. Their release has been shown to strengthen the body's endogenous antioxidant system, especially by strengthen the enzymes superoxide dismutase and catalase in muscle. ROS has also been shown to increase force production in muscle (Jeukendrup & Gleeson, 2010).

In some cases, antioxidant supplementation has been shown to inhibit athletic performance, specifically endurance capacity (Braun & Miller, 2014). A review of 23 studies showed, in some situations, heavy antioxidant supplementation can compromise the positive effects of exercise, as well as inhibit ROS-mediated physiological processes (Peternelj & Coombes, 2011).

One study showed that vitamin C (1,000 mg/d) and E (300 mg/d) supplementation for 6 weeks did not alleviate muscle damage after an ultramarathon (Mastaloudis et al, 2006).

However, overtraining brings additional considerations. While Jeukendrup & Gleeson (2010) point out the positive aspects of ROS, they also point out the damaging influence they can have on the immune system, including the inhibition of locomotory and antibacterial activity of neutrophil, the reduction of T- and B-cells, and the inhibition of natural killer cell activity. Therefore, they recommend that athletes training extensively "should consider increasing their intakes of nutritional antioxidants such as vitamins C, E, and beta-carotene to reduce free-radical damage" (p. 381).

Studies backing this statement up are somewhat mixed. Nieman et al (2002) tested 1,500 mg/d of vitamin C supplementation on ultramarathoners before, during, and immediately after a race, finding it did not serve as a countermeasure to oxidative or immune changes. However, Peters et al (1993) followed ultramarathon runners for 14 days after a race and found that 600 mg/d of vitamin C supplementation reduced upper respiratory tract infection symptoms.

Studies on flavonoids, specifically quercetin, have been promising in reducing post-exercise illness. One studied showed quercetin, when mixed with green tea extract, isoquercetin, and fish oil, to also reduce inflammation and oxidative stress (Nieman, 2014).

This sum benefit suggests the benefits of a strategy of seeking antioxidant through whole foods, where the antioxidant cocktail is pre-mixed, so to speak. This is a concept widely favored in the sports science community. As Nieman (2014) puts it, "The health-protective effects of plant foods are not produced by a single component but rather complex mixtures of interacting molecules. The polyphenols and natural components provide a multifaceted defensive strategy for both plants and humans" (p. 486).

Exogenous antioxidants may or may not be beneficial. However, endogenous antioxidants, created by the body, are crucial to balancing the redox cycle. Braun & Miller (2014) suggest that when researching nutrients that can fortify endogenous antioxidants, isolated components are less important than active compounds, given active compounds "have their effect in the context of the other compounds around them" (p. 459). In other words, they believe that there is strong evidence indicating that the antioxidant properties of foods, along with the endogenous antioxidant boosting properties of foods, are more effective than any single antioxidant.

Lui (2003) explains how this theory relates to current supplement research. "It is now believed that dietary supplements do not have the same health benefits as a diet rich in fruit and vegetables because, taken alone, the individual antioxidants studied in clinical trials do not appear to have consistent preventive effects. The isolated pure compound either loses its bioactivity or may not behave the same way as the compound in whole foods" (p. 518S).

Ristow et al (2009), in a paper titled "Antioxidants prevent health-promoting effects of physical exercise in humans," even defends produce, stating when discussing the relationship between antioxidants and type 2 diabetes, "…previously published findings tentatively suggest that fruits and vegetables may exert health-promoting effects *despite* their antioxidant content and possibly due to other bio-active compounds" (p. 8676).

On a final note, in a situation where an overtrained athlete has stopped training or is minimally training in an attempt to recover, the performance and/or adaption-inhibiting effects of antioxidants do not apply. Exercise is no longer the focus; healing is.

Dietary recommendations for antioxidants

A wide spectrum of antioxidants can be consumed via a colorful variety of organic fruits and vegetables (Braun & Miller, 2014; Mateljan, 2007). Sources of vitamin C include bell peppers (174.8 mg per cup), parsley (10 mg per 2 TBS), broccoli (123.4 mg per cup), strawberries (81.7 mg per cup), and cauliflower (54.9 mg per cup). Strong sources of flavonoids include berries, onions, apples, lemons, and parsley (amounts vary per flavonoid) (Mateljan, 2007).

Zinc

The antioxidant zinc warrants special focus for overtrained athletes. Among other functions, this mineral plays an important role in the immune system, including the development of T-cells (Jeukendrup & Gleeson, 2010). It converts the thyroid hormone T4 to its active form T3 (Volpe & Nguyen, 2014). Some research indicates it may play a role in modulating serum testosterone (Kelly & Bongiorno, 2006).

Plasma zinc concentrations are thought to decrease during acute stress. Zinc deficiency can also occur in athletes seeking weight loss when lower body mass can be a performance advantage—a common situation in endurance sports (Jeukendrup & Gleeson, 2010).

Zinc supplementation, however, has the same issues as other antioxidant supplementation. One study on runners found that zinc supplementation (25 mg with 1.5 mg of copper, twice daily) actually inhibited T-cell function post-exercise (Jeukendrup & Gleeson, 2010).

Another study showed that zinc injections can acutely and temporarily reduce adrenal cortisol secretion (Brandão-Neto et al, 1990), which can be problematic given the positive role cortisol plays in endurance sports.

A study on Brazilian male football players showed 22 mg/d of zinc supplementation increased antioxidant capacity, but reduced plasma copper and iron (Volpe & Nguyen, 2014). Recalling that anemia is an occasional symptom of overtraining, this may be problematic.

Dietary recommendations for zinc

Sources include calf's liver (10.8 mg per 4 oz), crimini mushrooms (1.6 mg per 5 oz), spinach (1.4 mg per cup), as well as pumpkin seeds (2.6 mg per .25 cup) and sesame seeds (2.8 mg per .25 cup) (Mateljan, 2007).

Iron

Iron supplementation has not been shown to improve performance in non-iron deficient athletes. However, iron supplementation has been shown to improve muscle fatigue and VO2 max when used to treat deficient athletes. Therefore, supplementation is only necessary after anemia has been established by laboratory analysis, or perhaps in the case of low serum ferritin—an iron-storing protein. First however, dietary modifications are recommended (Lombardi, Lippi & Banfi, 2014).

Dietary recommendations for iron

There are two forms of iron. Heme iron, found in meat, is the superior form for bioavailability. Meats especially rich in iron include shrimp (3.5 mg per 4 oz) and venison (5.1 mg per 4 oz) (Mateljan, 2007).

Vegetable contain non-heme iron, which is less than 10% absorbed in humans—although non-heme iron is better absorbed when taken with meat protein or ascorbic acid (vitamin C) (Lombardi, Lippi & Banfi, 2014). Sources of non-heme iron include leafy greens (varies), cinnamon (1.7 mg per 2 tsp); soybeans (8.8 mg per cup); turmeric (1.9 per 2 tsp); lentils (6.6 mg per cup); pumpkin seeds (5.2 mg per .25 cup) and sesame seeds (5.2 mg per .25 cup) (Mateljan, 2007). (For vitamin C sources, see *Antioxidants*.)

Magnesium

Low serum concentration levels of this electrolyte are common in athletes, most likely brought on by loss due to sweat. Symptoms of magnesium deficiency include muscle weakness, cramping, and damage to muscle fibers—all issues associated with overtraining. Deficiency is thought to increase susceptibility to free radical damage and therefore exercise-induced muscle damage and stress response (Jeukendrup & Gleeson, 2010).

Dietary recommendations for magnesium

Sources of magnesium include leafy greens (varies), pumpkin seeds (184.6 mg per .25 cup), sunflower seeds (127.4 mg per .25 cup), cucumbers (11.4 mg per cup), ginger (12.2 mg per oz), summer squash (43.2 mg per cup), and green beans (140.3 mg per cup) (Mateljan, 2007).

Other nutrients

Beta glucans

Beta glucans are polysaccharides found in oat and barley bran, baker's yeast, and some mushrooms. They have shown promise in boosting immunity for athletes post-exercise. This is possibly because many immune cells, including macrophages, natural killer cells, and neutrophils, contain beta glucan receptors, causing them to be activated by this nutrient. Earlier studies show using oat beta glucan supplementation on cyclists had no impact on immunity (Nieman, 2014). However, McFarlin et al (2013) found that baker's yeast beta glucan supplementation (250 mg/d) was associated with a 32% increase in the antibody salivary IgA. Another study on cyclists showed beta glucan supplementation (also 250 mg/d) to increase monocytes and cytokines, but not IL-6 (Carpenter et al, 2013).

If supplementing, 100 to 500 mg daily is recommended during heavy training (Mueller & Hingst, 2013).

Dietary recommendations for beta glucans

Dietary sources include oatmeal and other whole grains, baker's yeast, as well as shiitake and maitake mushrooms ("Beta-Glucan", 2014).

Probiotics
A few studies have shown the immunity-boosting effects probiotics have on athletes. One reason for this could be how they reduce stress-related changes in the gut and positively impact gut associated lymphoid tissue (GALT) (Jeukendrup & Gleeson, 2010). Gleeson et al (2011) observed that endurance athletes supplementing *Lactobacillus casai Shirota* during winter training had a reduced risk of upper respiratory tract infection. Cox et al (2010) found that *Lactobacillis fermentum* supplementation reduced respiratory illness symptoms in elite distance runners. Another study on marathon runners using *Lactobacillis rhamnosus* found symptoms weren't reduced, but their duration was shortened (Jeukendrup & Gleeson, 2010).

Dietary recommendations for probiotics
Dietary sources of probiotics include yogurt, kefir, fermented vegetables, and kombucha (Katz, 2012).

Herbs
Research is limited regarding herbs and overtraining. Two herbs, however, may be of particular interest.

Ginseng
Limited research has been done investigating *Panax ginseng*'s effect on central nervous system fatigue. Two studies have shown ginseng to improve cognitive performance in healthy young people during sustained mental activity (Davis et al, 2014). It has also been shown to enhance natural antioxidant capacity and improved endurance in swimming tests in mice (Kelly & Bongiorno, 2006).

Other studies have shown no ergogenic benefits to ginseng supplementation, including one double-blind study on young adults that did not see increased performance after 21 days of supplementation (Allen et al, 1998). However, positive results for ginseng are sometimes reported after 6 weeks of supplementation, warranting a longer study (Kelly & Bongiorno, 2006).

Suggested supplementation dosage varies, but a recommended starting dose is 100 mg standard extract or 1-2 g powdered form taking twice daily (Mueller & Hingst, 2013).

Curcumin
While study of this metabolite, derived from the spice turmeric, is relatively new to the world of sports medicine, it's been used as an anti-inflammatory agent in Asia for centuries. Studies have shown it to attenuate exercise-induced oxidative stress in both mice and humans (Prasad, Tyagi, & Aggarwal, 2014). While this may raise issues similar to those of antioxidant supplementation, circumin has also been shown to reduce the expression of several inflammatory mediators associated with impaired performance and has been shown to block IL-6 responses in mice, suggesting its benefit in skeletal muscle fatigue (Davis et al, 2014).

Recommended dosage ranges from 500 mg to 3 g daily (Mueller & Hingst, 2013).

OTHER MODALITIES TO CONSIDER

As stated in the introduction of this paper, rest is the key component in recovery from overtraining. However, beyond recovery time and nutrition, there are other modalities to consider.

Massage therapy and self-myofascial release ("foam rolling") are two popular modalities that can improve circulation and ease muscle soreness, therefore promoting skeletal muscular healing (Dallas, 2014).

Acupuncture may have benefits, particular with chronic inflammation. One study showed that electroacupuncture of the "fenglong" (ST 40) acupuncture point lowered inflammatory IL-6 levels in rats (Xiao, 2013). Another study on rheumatoid arthritis patients showed reduction in a number of cytokines, including IL-6 (Ouyang, 2010.)

Mindfulness meditation has also been shown to moderate stress levels. A study on older people saw improvements in respiratory signals (Ahani et al, 2013).

ASSEMBLING THE NUTRIENTS

Supplementation can be done with most of the nutrients above in hopes of positively impacting the symptoms of overtraining. However, it is generally agreed in the sports nutrition scientific community that athletes tend to over-rely on supplements while ignoring diet when whole foods should, in fact, be their nutritional foundation (Volpe & Nguyen, 2014; Jeukendrup & Gleeson, 2010).

Table 3 Overtraining issues and potential healing nutrients

Skeletal muscular issues	Carbohydrates, protein, BCAAs, glutamine, omega-3 fatty acids, MUFAs, water, thiamin, riboflavin, pyridoxine,folate, cobalamin, magnesium, curcumin
Central nervous system fatigue	Carbohydrates, BCAAs, tyrosine, omega-3 fatty acids, thiamin, pyridoxine, ginseng
Reduced immunity	Carbohydrates, BCAAs, glutamine, omega-3 fatty acids, thiamin, pyridoxine, antioxidants, ascorbic acid, zinc, beta glucans, probiotics
Oxidative stress	Carbohydrates, BCAAs, thiamin, riboflavin, pyridoxine, antioxidants, zinc, curcumin
Other hormonal imbalances	Carbohydrates, protein, tyrosine, water, thiamin, riboflavin, pyridoxine
Microcytic anemia	Folate, cobalamin, ascorbic acid, iron

Note: nutrients may have additional benefits. This table is based on the review of literature.

A sample day of eating

One benefit of the endurance athlete's diet is that the high calorie level allows for a correspondingly high level of macronutrients, micronutrients, phytonutrients, amino acids, fatty acids, and other nutrients—provided an athletes eats a variety of healthy, whole foods. To illustrate this, here is a sample menu for an average endurance athlete.

Note in Table 5 that all micronutrients falls well above the USDA's Dietary Reference Intakes (DRIs), allowing for any exercise-induced depletion, including B vitamins and antioxidants (USDA, 2014). Also note in Table 5 that therapeutic levels of the three BCAAs— at roughly the correct ratios—and glutamic acid have been achieved, as well as half the recommended dose of tyrosine.

This athlete is male cyclist, 44-years-old, 5'11" (180 cm), and 160 pounds (72.5 kg), so his Harris Benedict calculations would be as follows:

$$88.362 + (4.799 \times 180) + (13.397 \times 72.5) - (5.677 \times 44) = 1673.68$$

His resting metabolic rate is approximately 1674 calories. He is not in an overtrained state. His nutrition plan is prophylactic and he continues to train 1-3 hours per day, therefore his Harris Benedict activity factor will be 1.9.

$$1674 \times 1.9 = 3181 \text{ calories}$$

His totally daily calories should be approximately 3200 calories. The menu in Table 3 covers those calories while accommodating a 3-hour morning training block.

Table 4 A 3200-calorie, endurance athlete's menu

Upon rising	1 cup water
Breakfast	**Yogurt with fruit and nuts** 8 ounces plain, low-fat yogurt 1 banana, sliced 1 cup blueberries ¼ cup chopped walnuts ½ cup raw oats 1 cup fresh-squeezed orange juice
During ride (3 hours)	12 ounces coconut water 24 ounces water **Sunflower seed butter-and-honey sandwich** 1 slice whole grain bread 1 tablespoon sunflower seed butter 1 tablespoon raw honey
Recovery snack	12 ounces water 8 ounces plain, low-fat yogurt 3 large strawberries 2 Medjool dates
Lunch	**Quinoa tabouli** 1 cup cooked quinoa 2 cups parsley 2 Roma tomatoes, chopped ½ cup chopped raw red onion Juice of 1 lemon 1 tablespoon extra virgin olive oil 1 tablespoon cider vinegar 12 ounces of water
Afternoon Snack	1 large ruby red grapefruit 1 ½ ak-mak crackers 12 ounces of water
Dinner	**Large salad** 4 cups spinach 3 asparagus spears, chopped ½ cup kidney beans 1 handful raisins Sprinkle of raw sesame seeds 2 tablespoons extra virgin olive oil 2 tablespoons balsamic vinegar 2 teaspoons Dijon mustard 6 ounces wild Alaskan salmon, grilled 12 ounces of water, carbonated
Evening snack	3 cups air-popped popcorn 2 dashes turmeric 2 dashes sea salt 6 ounces of water

Table 5 Distribution of calories for Table 4 menu

Carbohydrates	447.2 g	53.2 %
Protein	139 g	16.5 %
Fat	112.9 g	30.2 %

Table 6 Nutritional totals with comparisons to DRIs

Nutrient	Unit	Total	DRI	% DRI
Kilocalories	Kcal	3230		
Protein	g	139		
Carbohydrate	g	447.2		
Dietary Fiber	g	65.8	38	173%
Total Sugars	g	217		
Total Fat	g	112.9		
Saturated Fat	g	18.7		
Monounsaturated Fat	g	50.3		
Polyunsaturated Fat	g	29.6		
Total Omega-3 Fatty Acids	g	5.55		
Total Omega-6 Fatty Acids	g	1.572		
Micronutrients and phytonutrients				
Calcium	mg	1706	1000	171%
Copper	mg	3.837	.9	426%
Iron	mg	32.9	8	411%
Magnesium	mg	1082	420	258%
Manganese	mg	9.224	2.3	401%
Phosphorus	mg	3052	700	436%
Potassium	mg	8183		
Selenium	mcg	140.4	55	255%
Sodium	mg	1831		
Zinc	mg	20.1	11	182%
Vitamin A	IU	23683	5000	474%
Vitamin C	mg	501.8	90	558%
Vitamin D	mcg	22.3	15	148%
Vitamin E	mg	20.4	15	136%
Vitamin K	mcg	2642	120	2201%
Thiamin (B1)	mg	2.841	1.2	237%
Riboflavin (B2)	mg	2.942	1.3	226%
Niacin (B3)	mg	32.5	16	203%
Pantothenic Acid (B5)	mg	8.814	5	176%
Pyridoxine (B6)	mg	3.915	1.3	301%
Folate (B9)	mcg	1005	400	251%
Cobalamin (B12)	mcg	12.4	2.4	516%
Beta-carotene	mcg	15637		
Applicable amino acids				
Glutamic Acid	g	20.1		
Isoleucine (BCAA)	g	5.484		
Leucine (BCAA)	g	9.899		
Tyrosine	g	4.675		
Valine (BCAA)	g	7.074		

CONCLUSION

Pushing limits is a core aspect of endurance sports. Because of this, cyclists, runners, rowers, triathletes, and other athletes will continue to wrestle with working beyond their capacity. The symptoms and issues involved in overtraining are complex, intertwined, and not completely understood. However, based on research, experience, and common sense, the sports nutrition community seems to agree that two factors potentially play a huge role in the solution: rest and proper nutrition.

Researching the benefits of a holistic nutritional intervention in regards to overtraining poses many challenges. From a preventative standpoint, overtraining's physiological triggers aren't clear, making it difficult knowing which issue to target and knowing when an issue has been successfully avoided.

Experimenting on holistic nutritional interventions for the already overtrained athlete is equally challenging. While individual nutrients/ solutions can be tested on isolated issues, testing a "good diet" against a "bad diet" on the overarching concept of overtraining would generate an overwhelming array of confounding factors. That said, many nutrients known to benefit athletes, particularly water and B vitamins, deserve much more critical analysis regarding their role in preventing overtraining.

"Eating clean" isn't as simple as popping a pill or scooping powder into a shaker. This can be challenging for an athlete whose chosen sport already consumes hours of his or her day, every day. Furthermore, a varied diet isn't a specific solution. For athletes whose success is based on very specific, rigid training schedules, heart rate monitors, and VO2 maxes, this can also be a challenge. But as this paper demonstrates, overtraining is not rigid or easy to define. It's truly a holistic issue—and it requires a holistic solution.

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