Overtraining Syndrome and Its Effects on the Martial Artist

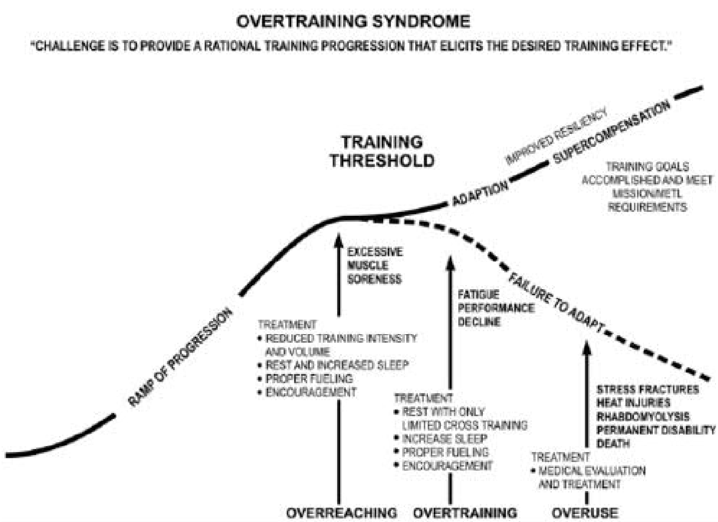
Evan Jackson

Introduction

Overtraining syndrome is known by many names: staleness, chronic fatigue, and prolonged underperformance to name a few. Its effect on athletes can be profound. Recovery from a stint of overtraining syndrome can require anywhere from days to months of rest and limited activity.[1] Awareness of the symptoms of overtraining are critical to actively training martial artists, as the recovery period can seriously detract from valuable training time. To understand overtraining, one must first understand the physiology and theory behind training for athletic events.

In the basic theory of athletic training, pushing the body beyond its normal limitations is required for improvement. Physical exertion that exceeds the body's capabilities is known as "over-reaching" and is often a "planned phase of most training programs".[2] In accordance with a theory known as the General Adaptation Syndrome, the body's ability to perform will then deteriorate in response to the stress and fatigue. If allowed adequate rest time, however, the body will heal and reach a point of improved performance known as supercompensation. Overreaching is a normal and useful physiological response to exercise. When recovery time is limited, and the athlete is forced to overreach time and time again, the result is known as overtraining syndrome, at which point the body will not recover to supercompensation and performance will remain impaired, despite rest or lowered training load (see Figure 1 below). The circumstances commonly leading to a sudden increase in over-reaching for a martial artist can involve returning to training after a hiatus or injury, or beginning a ramp up in preparation for a belt test. The consequences of overtraining syndrome are severe enough to merit a martial artist and/or mentor to draft a periodized training plan to control for necessary recovery time to maximize physical improvements.

Figure 1



Source: Baechle

Two distinct forms of overtraining syndrome have been proposed: sympathetic and parasympathetic. For reference, the sympathetic nervous system is often cited as the source of the “fight-or-flight” response, and stimulates an alert, aroused state in the body. When activated, the sympathetic nervous system will increase heart rate, dilate pupils, increase blood flow to muscles, and stimulate breakdown of glycogen to free up glucose for consumption by muscles and the brain. In contrast, the parasympathetic nervous system serves to put the body in a relaxed state. The parasympathetic nervous system will stimulate digestion, storage of glucose into glycogen, slow heart rate, and promote muscle recovery following exertion.

Sympathetic Model

In sympathetic overtraining, there is a chronic overactivation of the sympathetic nervous system, and it is often considered an early indication of overtraining syndrome. This type of overtraining is often associated with high intensity anaerobic training, namely speed or power drills (such as those practiced by Taekwondo or Judo practitioners preparing for competitive sparring).[3] It is characterized by an elevated resting heart rate, unintentional weight loss, excessive sweating, and disturbed sleep patterns.[4] It should be noted that in power-based events like sprinting, overtraining is not necessarily seen often, potentially due to the large volume of rest built into regular sprint training. This consideration should be used to better shape training and practice for martial arts practitioners who are looking for high intensity speed and/or power training. It has been found that athletes who periodize their training to include high intensity rounds, interspersed with appropriate rest periods show greater gains and improvements than athletes who persistently do moderate intensity training.[5] In martial arts, this translates to having athletes spar and drill at levels close to their maximal intensity level, then allowing longer rest periods than may seem or feel necessary in between rounds.

Parasympathetic Model

In the other form of overtraining syndrome, parasympathetic, can be more difficult to distinguish from the usual physiological responses to normal athletic training. Athletes suffering from this form of overtraining syndrome will often present a depressed resting heart rate, as well as a submaximal heart rate during exercise, both of which are typical adaptations to healthy training. However, in parasympathetic overtraining syndrome, these adaptations tend to correlate with early fatigue onset and “impaired maximal work capacity”, indicating that parasympathetic overtraining syndrome is a more advanced form than sympathetic overtraining.[6] It can be theorized that this lowering of athletes’ submaximal heart rates will then translate to a lower maximal heart rate during exertion. Physiologically, this would prevent the heart from pumping fast enough to adequately perfuse muscle tissues with fresh, oxygenated blood. In turn, muscles operating aerobically would then become oxygen-deprived, and forced into anaerobic activity. To understand the issues arising from an inability to function aerobically, one must understand the physiology of the three major muscle-energy systems.

Physiology of the Muscle-Energy Systems

Muscles can gain energy from any of three main energy systems to produce the body's energy storage molecule, adenosine triphosphate (ATP). Hydrolysis of ATP is responsible for the "power stroke" phase of muscle contraction, which physically powers muscle proteins past one another to shorten the muscle into a contraction. Listed in order of operating duration, these three energy systems are designated the phosphagen, anaerobic, and aerobic energy systems. These three energy systems are all susceptible to fatigue, and consequences vary significantly when given inadequate recovery time.

The Phosphagen System

The first and shortest duration system is known as the phosphagen system. This system is driven by the interaction of creatine phosphate (CP) and adenosine diphosphate (ADP) to form ATP for use by working muscles. Because creatine phosphate is stored in highly limited amounts in the body, the phosphagen system is only able to fuel the body through roughly five to ten seconds of intense activity. This system does not produce lactic acid and functions regardless of the presence of oxygen, thus it is well suited for high intensity, short-burst activities (under 30 seconds duration) like sprinting or power lifting. Training this system requires long rest periods (at least 5–7 minutes between sets of reps, or 20–30 min for more complete regeneration of CP in muscle tissue). As replicated in Figure 2 below, Baechle recommends a rest period of 12–20 times the duration of maximum exertion to allow muscles to recover fully.

The Anaerobic System

The anaerobic or glycolytic energy system is the most commonly used system by martial artists. This energy system functions during activities requiring intense, but not maximal sustained effort, such as in a sparring round of 2–3 minutes duration. This system is fueled directly by the hydrolysis of glucose during glycolysis. It has a very low ATP yield and thus can only supply the body with enough energy for thirty to sixty seconds of exertion. This system recovers with much less rest than the phosphagen system thanks to the body's ability to shunt the waste product (lactic acid) through the liver and convert it back into pyruvic acid.

Figure 2: Work-to-rest ratios grouped by exercise time

Approx. % of maximum exertion	Primary energy system in use	Typical exercise duration	Optimal exercise-to-rest recovery ratios
90–100	Phosphagen	5–10 sec	1:12 to 1:20
75–90	Anaerobic	15–30 sec	1:3 to 1:5
30–75	Anaerobic & Aerobic	1–3 min	1:2 to 1:4
20–35	Aerobic	>3 min	1:1 to 1:3

Source: Adapted from Baechle & Earle.[7]

Note that Baechle recommends a rest period of 3–5 times the exercise duration for full recovery from high intensity anaerobic exertion, whereas the typical martial arts tournament specifies an inter-round rest period of 30 seconds to one minute—not nearly long enough for full recovery! This is where the aerobic capacity of the competitors comes into play: those competitors who are better prepared for sustained aerobic activity will show less drop-off in their performance during the later rounds of a match. Of the three energy systems, the anaerobic energy system tends to suffer the worst effects from overtraining syndrome; this fact will be discussed at greater length later in this paper.

The Aerobic System

Lastly, the aerobic or oxidative energy system is the longest lasting, and uses the widest number of compounds as fuel sources, including complex carbohydrates, fats, and proteins. The aerobic energy system can utilize oxygen to synthesize large numbers of ATP molecules through a process known as oxidative phosphorylation. This large ATP volume enables the body to sustain activities for extended time periods (hours in some cases). An initial symptom of overtraining syndrome is a developing imbalance between the aerobic and anaerobic energy systems, as monitored by comparing maximum functional capacity of these systems.

Possible Causes of Overtraining Syndrome

Currently, the exact cause and mechanism of overtraining syndrome is unknown. It has been confirmed that of the many forms of exercise training, interval training has been the most associated with bouts of overtraining syndrome. The application of high intensity exercise with little to no rest periods appears to cause maximal muscle trauma, and be the main predisposing factor. There are multiple hypotheses that address the physiological cause of overtraining syndrome, ranging from biochemical causes to endocrine/immune issues.

Glycogen Depletion Hypothesis

The first hypothesis focuses around depletion of glycogen, a critical carbohydrate storage molecule.[8] Upon absorption of carbohydrates from the diet, the liver uses individual glucose molecules as building blocks, storing them in a long molecular chain known as glycogen. Glycogen is then shunted to the muscles for storage for catabolic use during exercise. Following exercise, muscles take in dietary carbohydrates for storage, but this capacity is limited according to the degree of muscle damage sustained by the workout. Because of limited muscle capacity, glycogen's main storage location is in the liver, meaning it is not available as an immediate fuel supply in active muscles, but must be broken down and available byproducts then sent to working muscles. As muscles work and require energy, glycogen is metabolized into individual glucose molecules, which can then be further metabolized into ATP. When glycogen stores are depleted, the body begins to use other molecules as fuel sources.

During aerobic exercise, eventually glycogen stores are spared for survival and fat stores begin to be metabolized into free fatty acids (FFAs). This adaptation is typically considered a beneficial effect of athletic training, as fatty acids can be metabolized to produce a much greater number of ATP than glucose. Changing the body's fuel source spares blood glucose to maintain available energy for the brain, and the body will even go so far as to block glucose uptake by cells to force the body to use fat reserves for energy. However, when fatty acids begin to be metabolized due to a forcible absence of glycogen, the oxidative stress placed on working muscles alters the fatty acid metabolic pathway, leading to increased production of polyunsaturated fatty acids (PUFAs).[9] These molecules are associated with various immunosuppressive and inflammatory effects, which in turn, will inhibit the ability of muscles to heal and recover following exertion.

Beyond simply being an alternate fuel source, metabolism of fats also effects the body's hormones as well. The hormone leptin helps regulate feelings of satiety and hunger, but more importantly plays a role as an inflammatory marker. Typically, during fatty acid hydrolysis, levels of the hormone leptin increase in the plasma, indicating a response to an inflammatory signal, namely muscle damaged by intense exercise. As a cytokine molecule, leptin additionally plays an important role in immune function, and this decrease might correlate with the diminished immune function seen in overtrained athletes. The metabolism of fats during aerobic exercise is beneficial because it spares the body's glycogen stores. However, excessive intense aerobic exercise can lead to negative consequences from fatty acid oxidation such as release of PUFAs, as well as increased immune and inflammatory responses due to leptin release.

Another complication of glycogen depletion occurs when the body begins consuming molecules known as branched-chain amino acids (BCAAs) as fuel. These molecules include amino acids such as leucine, isoleucine, and valine, which the body cannot freely make on its own, and must come from the diet for use in protein synthesis. When used as fuel, plasma levels of these amino acids drop, triggering the hypothalamus to increase uptake of free tryptophan, an amino acid carried in the blood. BCAAs act as competitors to tryptophan for receptors at the blood brain barrier.[10] Thus, when plasma levels of BCAAs decrease, fewer competitors exist, allowing more tryptophan uptake. Normally, the majority of tryptophan is carried by the binding protein albumin in the blood, and then is deposited at the blood-brain barrier. However, increasing plasma levels of PUFAs from fatty acid metabolism leads to competition with tryptophan for albumin binding. This competition leads to increased free tryptophan availability for brain uptake, as less is held in a bound state by albumin, and thus is more readily available for transport to the brain. In the brain, tryptophan is converted to serotonin, a neurotransmitter correlated with central fatigue.

Central fatigue is associated with the central nervous system (brain and spinal cord) and has been strongly associated with both elevated levels of serotonin in the brain and altered activity of 5-HT serotonin receptors. Central fatigue manifests as an inability to sustain muscular power for an extended period. The problem does not necessarily lie in a lack of available energy to working muscles, but instead in the availability of signals from the brain telling muscles to work.

Serotonin modulation is associated with regulation of pain, eating habits, sleep, mood, and fatigue. While serotonin is not the only factor involved in central fatigue, elevated levels have been found consistently in cases of central fatigue. Additionally, it is theorized that in response to glycogen depletion, central fatigue develops as a means of protecting the body from over-exertion. This serotonin build-up in the brain is also being attributed to the fatigue and mental haze reported by some overtrained athletes, as these same symptoms are reported by individuals taking selective serotonin-reuptake inhibitor (SSRI) drugs.

Glutamine Deficiency Hypothesis

Systemic glutamine deficiency is also a proposed cause of overtraining syndrome and central fatigue. Glutamine is the most prominent amino acid found in muscle tissue and plasma. Glutamine plays a crucial regulatory role in pH regulation in the body, due to its ability to be converted from glutamine into a glutamate molecule and a free ammonia molecule.[11] This inter-conversion is used by the body to handle the state of metabolic acidosis typically occurring after strenuous exercise. Additionally, the brain has no functional means of disposing of ammonia taken up from the blood during exercise, and thus must instead rely on the inter-conversion of glutamate to glutamine. This reaction lowers glutamate levels in the brain, removing available amounts of an important neurotransmitter, thus possibly contributing to central fatigue.

During exercise, normal glutamine pathways are disrupted, and more glutamine than usual is recruited to the liver for gluconeogenesis (glucose production).

Glutamine is also used in the kidneys for pH regulation capabilities, as greater amounts of ammonia are produced as waste molecules during exercise.[12] The glutamine shunt to these organs can dramatically decrease plasma concentrations of glutamine, leaving significantly less glutamine available for its other crucial role: supporting the immune system. David Rowbottom, et al, found a linear relationship between glutamine concentrations and exercise intensity, with some athletes showing up to a fifty percent reduction in baseline glutamine concentrations after a ten-day exercise overload period.[13]

Glutamine is a crucial fuel for intestinal mucosal and immune cells such as lymphocytes, macrophages, and natural killer cells.[14] Additionally, it serves as a precursor for synthesis of purine nucleotides, which are used to build DNA in dividing cells, such as those of the immune system or in healing tissue. Diminishing the available fuel for the immune system combined with the natural increase in exposure to pathogens during exercise can make overtrained athletes even more susceptible to infection. Martial artists who operate in very close quarters with sparring partners and grappling opponents are exposed to a wide range of bacteria and other microorganisms during the average practice. During a bout of exercise, exposure to airborne pathogens is profoundly increased due to depth of breathing, and it is theorized that gut permeability increases during exercise, allowing increased entry of bacterial endotoxins.[15] This exposure combined with the immune “open window” created by decreased glutamine concentrations leaves overtrained athletes at risk of infection.

Immune System Effects

The immune system undergoes a great deal of change during a bout of exercise, and experiences sustained changes for some time following exercise. Athletes experiencing heavy training load may be found to have decreased plasma leukocyte concentrations as well as an increased frequency of upper respiratory infections (URIs). With fewer immune cells circulating through the blood, the body is much less likely to detect an invading pathogen, and even more importantly, unable to mount a sufficient immune response to kill the infection quickly. Overtrained athletes might experience chronic recurrence of URIs upon attempts to return to training following an inadequate rest period, due to their immune system not being fully regenerated to full strength.

The reason for decreased immune function in overtrained athletes is multifaceted. During exercise, the body undergoes a profound release of mature neutrophils from bone marrow. Michael Gleeson has theorized that over prolonged weeks and months of training, this regular burst of neutrophils depletes bone marrow stores of mature neutrophils, forcing the body to release a smaller number of neutrophils, or even immature cells.[16] A study by Hack & Strobel, et al, found that neutrophil phagocytic activity (i.e., ingestion of foreign particles and organisms) diminished significantly following intense exercise, but recovered partially with appropriate rest.[17] Laurel Smith theorized that this downregulation of neutrophil function is indicative of chronic inflammation occurring because of microtrauma sustained by tissues during intensive exercise.[18] This chronically inflamed state creates a negative cycle with the immune system becoming less effective at fighting off infection and allowing the body to heal, creating an athlete or martial artist who is unable to achieve maximal performance.

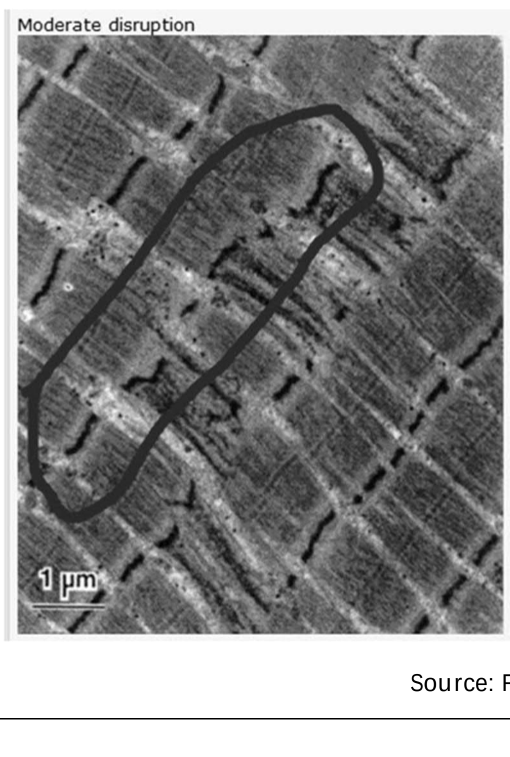
The body's main line of defense, production of antibodies in the form of immunoglobulins also markedly decreases following exercise. Most notably, Immunoglobulin A (IgA) found in mucous, tears, and saliva, shows a profound decrease in concentration, indicating a decreased ability of the body to fight off pathogen. In athletes across disciplines, salivary concentrations of IgA were markedly decreased after intensive training periods. Low levers of IgA have been correlated with increased rates of upper respiratory tract infections and serve as another potential marker of overtraining syndrome.[19] It is important, especially with upper respiratory tract infections, that athletes are allowed adequate recovery time to ensure they do not miss more training than is necessary due to repeat and recurrent infections. Comprehensive rest allowing immune system recovery will in turn allow for more productive training days than an athlete who is unable to fully participate due to fighting a chronic infection.

During a bout of exercise, blood concentrations of circulating leukocytes and neutrophils increase markedly. Additionally, plasma concentrations of immunomodulating compounds such as interferon-α, tumor necrosis factor-α, interleukins 1, 2, and 6, and C-reactive protein increase. However, Gleeson showed that during recovery from exercise, these numbers fall dramatically, and remain diminished beyond pre-exercise levels.[20] It has also been found that the ability of B-cells to secret immunoglobulins is impaired following acute exercise. These decreased responses, combined with diminished supporting plasma glutamine levels leads to a markedly weakened immune function. This recovery period of weakened immune response makes the athlete particularly vulnerable to infection. Over long periods of time with repeated cortisol release in response to exercise stress, athletes become immunocompromised and are simply unable to fight infection. Additionally, the non-specific immune responses of athletes become diminished with time, as evidenced by decreased complement protein levels in overtrained athletes.[21] Complement proteins act as a magnification cascade to amplify the body's specific immune response. If complement proteins are decreased, the body's innate immunity to provide broad-spectrum protection against antigens is diminished. The natural killer cells, the body's targeted immune response, also showed a steady decline in both number and cytotoxic activity in athletes undergoing ten days of rigorous training. Furthermore, while immune cell activity increases during a period of exercise, this activity diminishes during the recovery period, and if rest periods are inadequate, will lead to prolonged immunosuppression.

Microtrauma as a cause for impaired immunity

A proposed mechanism for the impaired immunity seen in overtraining syndrome lies with microtrauma. Exercise generates trauma on a microscopic level to muscles and connective tissues. Mechanical damage occurs to muscle fibers, most notably during eccentric (muscle lengthening) contractions.[22] For martial artists, this will be seen in motions such as the axe kick (hamstrings contract to pull the leg down while that same muscle is being stretched and extended) or resisting an armbar (bicep muscle contracts to attempt to bend the arm against resistive straightening). The Z-line, the anchoring point between individual sarcomeres (individual muscle units), has been shown to sustain damage following intense exercise (See Figure 3 below). Following this damage, individuals typically demonstrate decreased force production as well as muscle soreness. Additionally, damaged muscle shows an impaired ability to store glycogen, leaving it ill-equipped to have fuel through additional bouts of exercise.[23]

Figure 3: Annotation of Z-line damage



Source: Roth, et al

In response to this muscle damage, a mild inflammatory response begins. Macrophages arrive at the site of the muscle injury, and begin releasing compounds known as cytokines, which include interleukins and interferons. These molecules regulate the inflammatory cascade in an attempt to heal the injured tissue. The primary molecules involved in muscle inflammation include interleukin-1β, interleukin-6, and tumor necrosis factor-α.[24] Immediately following exercise, the body's response is that of acute inflammation, and is helpful in healing muscle damage, and in turn making stronger tissues. However, in circumstances of overtraining, with inadequate healing time, acute inflammation becomes a chronic, whole-body inflammatory response, with inadequate immune resources to regulate the inflammatory state.[25] In the general theory of adaptation to stress, this response indicates an attempt to recover from and survive stress, rather than adapt and get stronger because of it. This stressed recovery state can often include behaviors such as depression, reduced appetite, and sleep disturbances, all of which can be seen in overtrained athletes.

The activity of these cytokines affects both the inflammatory response as well as the central nervous system, by activating the sympathetic nervous system. This might contribute to the sympathetic overactivation seen in some forms of overtraining syndrome. Inflammatory cytokines have also been shown to influence the hypothalamic-pituitary-adrenal axis, which in turn controls the body's hormone levels, and thus might be responsible for the neuroendocrine responses seen in overtrained athletes. The cytokine stimulation of the hypothalamic-pituitary-adrenal axis leads to the release of cortisol, an anti-inflammatory immune-suppressing hormone, which has the potential to keep an athlete in a prolonged weakened, fatigued state.[26] Additionally, in response to magnified pro-inflammatory cytokine release, the body will in turn release a large volume of anti-inflammatory cytokines as well, to balance and regulate the inflammatory response. However, the presence of these anti-inflammatory compounds over a long period of time produces a net effect of immunosuppression.[27] This inflammatory paradox seems to explain the drawn-out experience of overtraining syndrome. By the time an athlete notices the developing symptoms of overtraining syndrome, he or she has been exposed for a prolonged period of time to a barrage of anti-inflammatory compounds produced by the body in an attempt to manage and regulate the intense inflammatory response generated by damaged muscle tissue.

Physiological Effects of Overtraining Syndrome

The physiological effects of overtraining syndrome affect multiple body systems, including the central nervous system, endocrine, immune, reproductive, musculoskeletal, and cardiovascular systems.

Hormonal Effects

The central nervous system plays a profound role in managing overtraining syndrome and is in turn profoundly affected by overtraining syndrome. The hypothalamus regulates a great deal of body functions that are affected from by athletic training. As the seat of hormone regulation, the hypothalamus regulates a major proportion of hormones via the hypothalamic-pituitary axis, which can in tern act on the gonads, thyroid, or adrenal glands. The central nervous system is profoundly affected by the presence of cytokines such as the interleukins IL-1 and IL-6, which both have specific receptors in the hypothalamus.[28] These cytokines may modulate both the hypothalamic-pituitary-adrenal axis and the hypothalamic-pituitary-gonadal axis, which in turn influence stress and reproductive hormones. The feedback loops affected by overtraining syndrome are complex and are very sensitive to outside stressors.

The first hormonal imbalance noticed in overtrained athletes is centered on the hormone cortisol. Cortisol is the body's main stress-related hormone, produced by the adrenal gland. It functions to increase available blood glucose, suppress the immune system, and increase catabolism of fat, protein, and carbohydrates. This hormone is thus valuable during high intensity exercise to mobilize the body's resources to fuel workouts and increases significantly during intense exercise. However, when cortisol levels are constantly elevated, the athlete's ability to heal and repair muscles becomes impaired. Muscle growth and recovery is an anabolic process, requiring molecules to be constructed for repair, rather than molecules broken down for energy usage (catabolic process). Additionally, cortisol increases plasma insulin levels, leaving the athlete in a potentially chronically hypoglycemic state, having less available blood glucose to fuel working muscles. This state likely contributes to the sluggish and constantly fatigued feeling reported by overtrained athletes. Overtrained athletes typically show significantly diminished nocturnal catecholamine excretion, showing an impaired metabolic ability to clear the stress hormone, and possibly a decreased sensitivity to it as well.[29] Cortisol serves as a stimulus to the central nervous system, activating the sympathetic branch, and elevated levels indicate an athlete in the sympathetic branch of overtraining syndrome. As cortisol levels remain elevated, the sympathetic nervous system cannot sustain an adequate response to it, reaching an equivalent point to central fatigue.

Overtraining also desensitizes the body to other catecholamine molecules such as epinephrine, which are released during intense exercise. Epinephrine increases heart rate, which has a net effect of increasing the volume of oxygenated blood pumped to working muscles and stimulates glycogenolysis and glycolysis in active muscle cells. The β2-adrenergic receptor is embedded in the sarcolemma (the cell membrane of muscle cells), and binds epinephrine, triggering a signal cascade within a muscle cell. These receptors, in response to high levels of catecholamines, diminish in both responsiveness as well as density in tissue.[30] Thus, in overtrained athletes, individual muscle cells are less responsive to signals to break down glycogen to produce more available glucose, making them less productive overall. Physiologically, at a certain concentration of epinephrine particles, the number of available receptors drops to zero, as all receptors are saturated, and the system collectively becomes less sensitive to the presence of the catecholamine.

Therefore, overtrained athletes with less receptors embedded in the sarcolemma overall will hit a desensitized point to epinephrine much faster than athletes not suffering from overtraining syndrome. The desensitization of the β2 adrenergic receptor system is likely partly responsible for the "decrease in contractile performance due to high intensity resistance exercise overtraining".[31] Regardless of the exercise stimulus, desensitization of β2 adrenergic receptors leads to impairment in muscle performance.

Testosterone is a critical hormone to help athletes maintain and gain muscle mass following strenuous workouts. After a typical workout, testosterone levels rise, helping the body repair and develop musculature. However, following a series of intense workouts, resting testosterone levels begin to fall. It is theorized that testosterone functions in a pre-determined ratio with cortisol to manage the balance between the body's catabolic and anabolic states.[32] When cortisol increases, and testosterone decreases in response to prolonged intense exercise, this ratio becomes skewed, and the body is unable to successfully adapt to exercise. Under these conditions, the muscles of overtrained athletes are being broken down faster than they are being built up and will be unable to withstand the rigors of intense athletic training. Low testosterone levels are detrimental not just to the ability of the athlete to put on and maintain muscle mass, but bone mass as well. In high impact activities such as martial arts, the ability to heal both muscle and bone tissue not just from overuse, but from impact traumas as well is critical, and any circumstances impairing this ability are severely problematic for athletes. Control of testosterone levels is centered in the hypothalamus, as part of the hypothalamic-pituitary axis, which is regulated in turn by Luteinizing Hormone Releasing Hormone (LHRH), which in turn is affected by plasma levels of inflammatory cytokines. Thus, the inflammatory stress excess exercise puts on the body can be inferred to influence the body's testosterone levels.

Reproductive System Effects

In female athletes, gonadal hormones are also profoundly affected. After crossing a certain threshold of workout intensity, women may experience amenorrhea, a cessation of the menstrual period. The interruption of the menstrual cycle has been correlated with a loss in body fat composition, but also is associated with notably diminished leptin hormone levels. Amenorrhea is typically associated with low estrogen levels, a hormonal state seen in overtrained athletes. While many women view the absence of a monthly period as an enjoyable side-effect of hard athletic training, the consequences can be steep, due to estrogen's involvement in both bone density and mood. Chronically low estrogen levels put female athletes at risk of osteoporosis and diminished bone density, which, in high contact activities like martial arts, can be highly detrimental and put female martial artists at significantly higher risks for fractures, particularly as they age. Additionally, low estrogen levels have been shown to have a strong association with poor mood quality; given that mood is already negatively affected by altered brain chemistry in overtrained athletes, estrogen depletion will most certainly not be beneficial to the mental state of female athletes.

Musculoskeletal System Effects

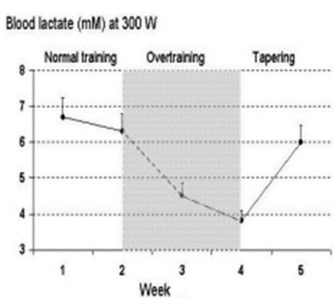
The toll of overtraining on the musculoskeletal system is profound. Serum creatine kinase levels (a known marker of muscle tissue damage) remain elevated in overtrained athletes, implying a state of muscle catabolism, meaning the bodies of overtrained athletes are actively metabolizing muscle proteins as an energy source, leading to underperformance. The ability of damaged muscle to absorb blood glucose and re-synthesize glycogen is limited, further contributing to fatigue. Beyond enzymatic muscle damage, overuse and structural injuries are common results of overtraining, including tendonitis and stress fractures. However, it is important to note that it is uncertain whether these injuries occur because of high training volume, the body's impaired healing abilities, or some combination thereof. Damaged muscle attempts to repair itself by recruiting nearby "satellite" cells (underdeveloped muscle cells), which then fuse with existing muscle cells. In healthy, rested athletes, this process results in muscle growth and hypertrophy. However, in the overtrained athlete, this process further potentially contributes to the problem of inflammation as satellite cells may release IL-6 during their activation.[33] This muscle damage typically occurs due to eccentric contractions, as mentioned previously. It is therefore important for martial artists to be aware and structure workouts that avoid excessive repetition of high resistance eccentric actions (i.e., axe kicks, armbar escapes), to minimize the damage done to muscle tissues.

Cardiac muscle also sustains wear and tear from excessive exercise. A cardiac protein, troponin, can be measured in the blood, and is often used as an indicator of heart attack risk. High troponin levels typically indicate damage to cardiac muscle tissue, but due to their disappearance after a rest day, researchers theorize that it is cardiac muscle fatigue, rather than damage that raised troponin levels in these instances. Strangely, athletes measured after a standard marathon presented raised troponin levels higher than those presented by athletes following an ultra-marathon style race, presumably because of the higher average exertion level during a marathon vs. an ultra-marathon event.[34] It is likely that during strenuous exercise, there is a slow leak of troponin proteins, rather than a sudden traumatic bout of damage to the heart. While healing from these minor bouts of damage likely makes the heart even stronger with adequate rest, inadequate rest puts the heart tissue at risk for a significant cardiac event or abnormal heart rhythm such as an atrial fibrillation.

Beyond direct exercise-induced trauma to muscle and cardiac tissues, the body's ability to efficiently shuttle fuel is likely impaired in overtrained athletes. It has been traditionally understood that lactic acid, a byproduct of anaerobic respiration, is a useless waste product that contributes to muscle fatigue. It has recently been discovered, however, that lactic acid is recycled by the body in the form of lactate that is transported via a shunt to the liver to be reused as helpful fuel. The residual lactate accumulated in blood following a bout of vigorous exercise is then oxidized in the liver using the tricyclic acid cycle to form more ATP. Lactic acid buildup occurs during a period in which the body in is "oxygen debt", meaning the body is utilizing more oxygen than it can take in during normal ventilation, and must begin producing ATP by anaerobic respiration. During the recovery period following intense exercise, the body will then begin to transport the excess lactate to the liver to "pay back" the oxygen debt by forming additional fuel and ATP while oxygen is readily accessible. This lactate is either converted back to glucose or stored as glycogen, depending on the energy needs of the body at the time. There is a threshold point reached during exercise, known as the lactate threshold in which the volume of lactate produced matches the rate at which lactate is cleared and reused by the body. Beyond this point, lactate begins to accumulate, and begins resonating between its naturally produced form, lactic acid, and lactate plus a hydrogen proton. This buildup of hydrogen protons decreases the pH in the muscle tissue, generating an acidotic state. This pH drop and proton buildup is thought to be a major contributor to muscle fatigue.

Figures 4 and 5

Fig. 4: Reduction in the blood lactate concentration during a 2-week overtraining period with normal training and a recovery taper period in a group of elite cyclists.



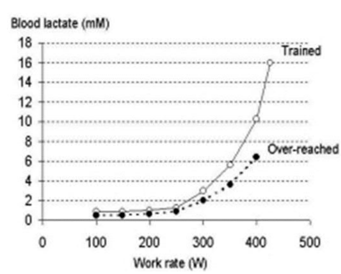


Fig. 5: Example of the lower blood lactate response to incremental cycle ergometer exercise following a period of over-reaching in elite cyclists.

Source: Jeukendrup, via Gleeson

Overtrained athletes demonstrate a significantly lower lactate threshold, indicated a diminished ability to clear excess lactate and a more rapid onset of fatigue (See Figures 4 and 5 below).[35] For an athlete unable to clear lactate quickly, the acidotic fatigue state will continually be rapid in onset, which will be limiting both physically and mentally, and hamper training progress.

Symptoms

Overtraining syndrome has several manifestations on athletes, both in physical performance and in psychology. The detriment to performance can be enough to drive martial artists to take a temporary or permanent hiatus from training, motivated by either physical or mental fatigue. It is therefore in the interest of both martial artists and mentors to be aware of the complications of overtraining syndrome and take every effort to notice and prevent its effects.

Psychological symptoms

Psychological symptoms of overtraining are often the first symptoms to become apparent. Healthy athletes demonstrate what is known as an “iceberg” structure of mentality. They typically score “lower than the normal population on scales of tension, anxiety, anger, confusion and fatigue, and score above the normal population in vigor”. This attitude typically leads to successful, highly motivated athletes. However, overtrained athletes show an inversion of this iceberg structure. Scores for vigor tend to drop, while scores for “negative moods such as depression, tension, anger, and fatigue” rise. For martial artists, where training even more vocally emphasizes control over anger, fatigue, and other negative emotions, and positively rewards work ethic and energy, overtraining syndrome can make a positive training attitude nearly impossible to achieve.

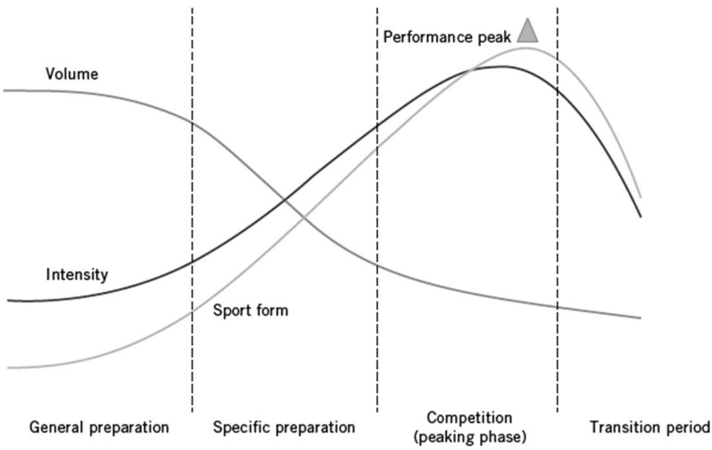
For the active martial artist, training is both a physical learning experience and also a profound psychological one. Each workout not only requires focus and coordination of body, but also a mental presence and focus of mind. In martial arts, the mental effort exerted during training, particularly during intensive dan training, can be exhausting and is constant. The toll overtraining can take on the psyche of the martial artist is heavy. Beyond sleep disturbances and chronic fatigue, athletes will find themselves suffering from profound apathy, depression, anxiety, and a loss of self-confidence. The inability to make the body perform at an accustomed skill level can be extremely mentally jarring, and in the already depressive state of an overtrained athlete, can have serious consequences on training mentality. Mentors and training partners of active martial artists should be vigilant for signs of overtraining, such as decreased enthusiasm and diminished work ethic. Given that the physical effects of overtraining syndrome are difficult to gauge without various lab tests, it is recommended that coaches and mentors shape training programs according to the mood and affect of their students. Additionally, martial artists should take steps to monitor their own mental states, being wary of prolonged states of agitation or noticeably diminished training motivation. Taking rest days as needed, even solely for the sake of mental rest can be very important, and open communication between martial artists and mentors can help facilitate an appropriate training schedule. It can be appropriate in cases of suspected overtraining syndrome to radically reduce training volume and intensity for several weeks, or even take several weeks off from training in order to rest and recover appropriately.

Avoiding Overtraining Syndrome

Approaching training in a controlled, planned fashion is the best method for avoiding overtraining syndrome. The first guideline advised for both athletes and coached is to avoid increases in training volume greater than five percent in a given week. This will give the body time to adapt and hopefully be adequately prepared for further training. Training intensity is a particularly difficult variable to manage in martial arts. Typical competitions involve rounds set for anywhere from ninety seconds to five minutes of varying intensity activity. High intensity interval training, functionally necessary to train the body’s energy systems for this type of competition also makes athletes more susceptible to developing overtraining syndrome. Active rest is a critical component of any training calendar for an active athlete and can be particularly useful for martial artists. Rest days can be spent doing yoga, swimming, or other mobile but low impact activities at a low intensity, just to keep mobility in the joints and promote blood flow to fatigued muscles to help speed recovery.

In order to prepare adequately for a serious period of intense martial arts training, first and foremost the goals of the training period in question must be identified. Training for competition involved different requirements than training for a belt test or simply for general improvement. Martial arts tests are significantly longer in duration and have much more variable intensity than a competition fight. These landmark events should be decided upon as early as possible to avoid attempts to “cram” training time in and risk injury or overtraining. Upon developing concrete goals, it is important to develop training cycles using a system known as periodization (see Figure 6).

Figure 6



Source: Loturco

Athletic training can be categorized by time period, into microcycles, mesocycles, and macrocycles. Microcycles involve the day-to-day, at most week-long training calendars, adjusted according to their proximity in the greater macrocycle. In martial arts, this might involve determining the individual time break down of conditioning, skill work, sparring, and other practice.

Mesocycles represent two-to-six-week training phases, to slowly progress the athlete towards the end goal. For a martial artist, this might include setting technical themes to help guide each microcycle, each of which will develop the martial artist further towards his or her end goal. The macrocycle typically refers to an annual or other long-term preparation phase. The preparatory phase should occupy two-thirds to three-fourths of the macrocycle. This includes skill work, aerobic conditioning, as well as learning any rules or regulations involved in the type of competition being prepared for. Following the preparatory phase, the athlete enters the competitive phase, leading up to the main event. In the competitive phase, high intensity workouts taper off, while the emphasis on skill work and pre-event psychology become more important. Following the main event, athletes enter the transition phase, involving anywhere from a two-week to three-month rest and recovery period, for both mind and body to heal from the rigors of preparation.

Nutrition is also an important component of avoiding overtraining syndrome. Glycogen depletion is a strong contributor to certain aspects of overtraining syndrome, as is depletion of branched-chain amino acids (BCAAs). Replenishing carbohydrates immediately after each workout will help muscles store up more glycogen and recover more quickly for the next workout. Additionally, supplementing the diet with foods that contain BCAAs or simply adding a nutritional supplement of BCAAs can help stave off the body breaking down its own proteins to find fuel sources, and encourage muscle growth and development.

Conclusion

Overtraining syndrome is a result of multiple different variables coming together to seriously deter and hamper the training of an active athlete. It develops in response to a sudden increase in training volume or intensity, combined with inadequate rest periods. The body becomes unable to adequately adapt to the stressors placed upon it and becomes significantly more at risk of infection and/or injury. What distinguishes this syndrome from beneficial over-reaching is the lack of resolution of symptoms after more than two weeks of rest. For the martial artist, being unable to train to the maximum potential and work ethic can be both physically and mentally detrimental. The rapid onset of fatigue can create safety concerns for both the athlete and training partners, and the mental burden can affect the fundamental enjoyment and satisfaction derived from the practice of martial arts. Ongoing monitoring must be done by both mentors and martial artists to ensure overtraining does not occur, and to allow martial artists to achieve maximum benefit from training time. Adequate rest, nutrition, and pacing are the best ways to avoid overtraining syndrome, and the willingness to take both mental and physical days away from training will benefit the martial artist in the long term.

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Endnotes

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[2] Baechle, p. 114

[3] Hackney, p. 38

[4] Hackney, p. 39

[5] Budgett, 1998, p. 108

[6] Lehmann, p. 239

[7] Baechle, p. 88

[8] Howard, slide 28

[9] Petibois, p. 90

[10] Budgett, 1998, p. 109

[11] Howard, slide 30

[12] Rowbottom, p. 507

[13] Rowbottom, p. 507

[14] Ohtani, p. 162

[15] Gleeson, p. 34

[16] Gleeson, p. 37

[17] MacKinnon, p. 506, citing Hack, V., with G. Strobel, et al. "PMN cell counts and phagocytic activity of highly trained athletes depend on training period." Journal of Applied Physiology, v. 77, no. 4, Oct 1994, pp. 1731–1735.

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[20] Gleeson, p. 34

[21] Gleeson, p. 35

[22] Budgett, p. 105

[23] Gleeson, p. 36

[24] Smith, p. 321

[25] MacKinnon, p. 507

[26] Smith, p. 323

[27] MacKinnon, p. 507

[28] Smith, p. 323

[29] Gleeson, p. 36

[30] Fry, p. 1671

[31] Fry, p. 1670

[32] Smith, p. 327

[33] Smith, p. 321

[34] Shave, p. 171

[35] Jeukendrup, p. S91