

Physiological and Biophysical Analysis of Overtraining and Overtraining Injuries

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Introductory Remarks

The common belief of 'the more training the better' has persisted since ancient times, largely as a result of the notion that increasing levels of success demand more work and pain. This unfortunate principle continues to be imposed on misguided athletes either by themselves or by uninformed coaches, since they maintain that the optimum training load is the maximum training load a person can endure.

The more enlightened coaches have modified this archaic system in a more sensible direction. They consider that 'the more training the better' principle is still sound provided that a person commences training at low intensity and continually increases intensity and duration within his limits of endurance and the time available. Their new package includes stretching exercises, as they believe that lack of suppleness is the major non-traumatic cause of injuries. They, together with several medical experts, assert that there is no clinical condition identifiable as overtraining and that the term 'overtraining injury' more precisely should be applied to damage caused by lack of suppleness, faulty technique, inappropriate footwear and so on.

The fact remains that the equivalent of overtraining and overtraining injuries is well known in physics and engineering. The frequent application of moderate forces or the occasional application of large, impulsive forces can cause metal fatigue, structural failure or general deterioration of some or many of the components of a system. This is the reason why all cars, machines and structures require regular inspection and maintenance. The human body, however, performs a great deal, but not all, of its own repair. Small injuries are accompanied by the usual internal bleeding and the formation of scar tissue, which eventually restores most or all of the original functioning of the damaged part. Larger injuries often require surgical intervention, but whatever the extent of the injury, it is clear that structural weakening or failure of an engineering system has its parallel in the human body, whether it be called 'overtraining injury', 'overuse injury' or something else.

It would then possibly appear as if overtraining is the sole cause of nonaccidental training injuries, whereas undertraining is safe and merely leads to lack of progress. This is only partly true. Consistent undertraining, which never familiarizes the sportsman with high stress levels or the so-called 'pain-barrier', may expose him to risk during the excitement of a competition. Moreover, undertraining accompanied by faulty technique, drug usage, inadequate sleep, poor nutrition or the use of unsuitable equipment can also lead to injury.

A Biophysical Framework

Overtraining injuries may be categorized more precisely if injuries in general are considered to be the result of part or all of the body being called on to control, absorb or generate over a specified period:

1. Too large a force component in a given direction or over a certain distance (where $\text{force} = \text{mass} \times \text{acceleration}$)
2. Too much work (or energy) (where $\text{work} = \text{force} \times \text{displacement}$)
3. Too much power (where $\text{power} = \text{work done per second}$)

Categories 1 and 3 generally concern the usual traumatic or impulsive injuries incurred over a short period, particularly in contact sports such as boxing and rugby. Circuit training, with light weights accelerated rapidly, can generate greater forces than those involved in world record attempts in powerlifting and is therefore particularly dangerous in contributing to this type of injury. These two categories also describe the micro-injuries or micro-ruptures which may be produced without any obvious pain signals, but which may gradually accumulate and lead to ultimate macro-injuries. This propagation of what may be considered as tissue 'dislocations' is well known in the field of solid-state physics.

Category 2 refers to what is more commonly considered to cause overtraining injuries, which are incurred when the total work 'volume' due to frequent application of a modest load or to moderately -frequent application of a large load is too great to permit effective physical adaptation over a prolonged period.

A Physiological Framework

Overtraining and exhaustion are both the consequence of imbalance between stress and adaptability of the organism. Any imbalance causes the body's homeostatic mechanisms to decrease stress or enforce short - or long-term rest to prevent further damage. Exhaustion is the systemic result of short-term imbalance, whereas overtraining is the result of imbalance accumulated over a prolonged period.

The insidious road to overtraining is signposted, not always clearly, by residual fatigue or soreness, persistent minor injuries, loss of motivation, or lack of progress. It is vital that all such symptoms be recognized by the sportsman and his coach, since the popular practice of forcing oneself through these negative phases can lead to acute or chronic injury.

Overtraining is a specific type of physical and psychological stress and an appreciation of the mechanisms underlying human stress is essential to understand overtraining. Some of the early pioneering work on stress was done by Hans Selye, who defined stress to be "...essentially the wear and tear in the body caused by life at any one time". He maintained that stress draws on the adaptation energy or vitality of the body, this energy being stored in two forms: the superficial kind, which is ready to use; and the deeper kind, which acts as a sort of frozen reserve. When superficial adaptation energy is exhausted through exertion, it can slowly be restored from a deeper store during rest. This gives certain plasticity to our resistance. It also protects us from wasting adaptation energy too lavishly in certain foolish moments, because acute fatigue automatically stops us" (1).

At a muscular level Selye's theory seems to be substantiated by the finding that different types of muscle fibre are recruited by different types of exercise. Sustained low-intensity exercise such as marathon running utilizes slow-twitch (ST) muscle fibres whereas brief, intense exercise such as weightlifting or sprinting recruits fast-twitch (FTb) white fibres. Exercise of intermediate intensity and duration of between 1-5 minutes involves the fast-twitch (FTa) red fibres (Fig 1).

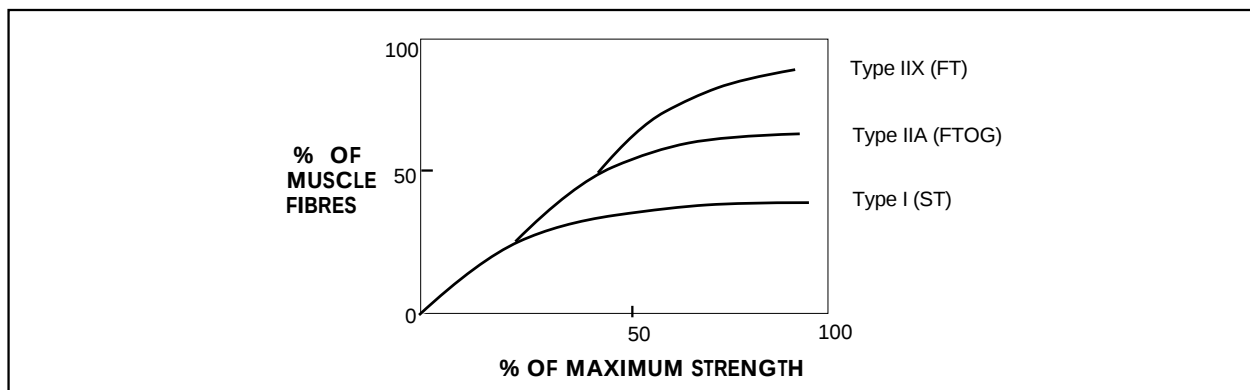


Figure 1 Normal recruitment order of muscle fibre types (2)

There are two types of overtraining: general and local. General overtraining affects the whole body and results in stagnation of a decrease in performance, whereas local overtraining affects a specific body part.

Adaptation to physical, psychological or environmental stress depends on the inextricable links between the central nervous system (the fast control system of the body) and the endocrine system (the slow control system) (Fig 2).

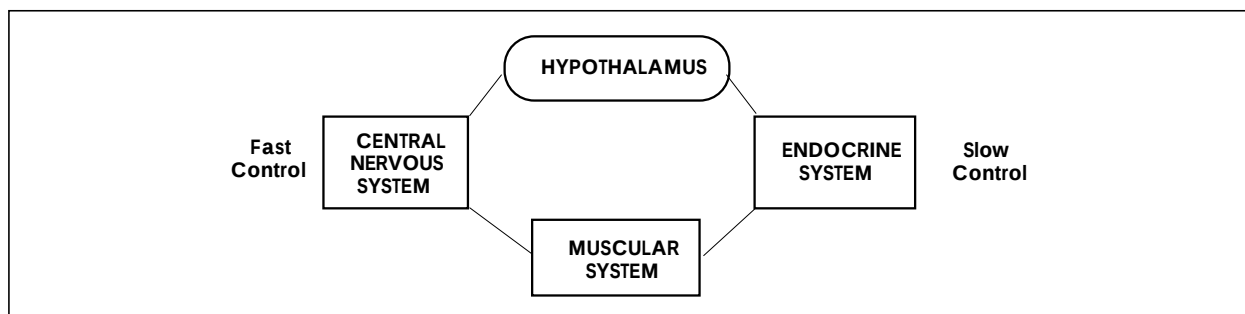


Figure 2 Some of the physiological control systems involved with motor processes.

Any changes in the central nervous and endocrine systems can affect performance in the muscular system. The endocrine system in particular controls an intricate group of glands whose hormones are vital to all aspects of human life.

For instance, the adrenal glands selectively prepare the skeletal muscle for physical activity in the face of stress. The hormone thyroxine, secreted by the thyroid gland, not only increases the rate at which cells burn their fuel (glucose) but it is involved in various anti-stress responses, including demands for extra energy. Human growth hormone (HGH), secreted by the pituitary gland in the brain, plays an essential role in general growth and in the elevation of blood glucose. Insulin, secreted by the pancreas, is concerned with the metabolism of glucose, and the sex hormones such as testosterone influence sexual behaviour and muscle growth, in the male (3).

This central role played by certain hormones in the occurrence and management of stress implies that it is logical to associate general overtraining, a stress-related phenomenon, with some disturbance of the endocrine system.

Researchers have identified at least two types of general overtraining on this basis (4):

- (a) A-overtraining (Addisonic overtraining) named after Addison's disease, which is associated with diminished activity of the adrenal glands. This category of overtraining affects predominantly the parasympathetic pathways of the autonomic nervous system and is difficult to detect early, due to the absence of any dramatic symptoms. Suspicion that something is amiss may be aroused by the appearance of stagnation or deterioration of the sportsman's performance.
- (b) B-overtraining (Basedowic overtraining), named after Basedow's disease, which is associated with thyroid hyperactivity. This category of overtraining affects predominantly the sympathetic pathways of the autonomic nervous system and, as the classical type of overtraining with its abundance of symptoms, is easy to diagnose.

These two types of general overtraining are compared in Table 1.

Overtraining has also been shown to be associated with electrocardiographic changes, in particular a smaller T wave (5), so that Table 1 could no doubt be extended to include such features.

The presence of local overtraining is relatively simple to recognize, since it is often accompanied by stiffness or soreness of a particular muscle group which does not subside with alternate days of rest. Moreover, the performance of that muscle group might be static or diminished and some of the symptoms of general overtraining, such as impaired coordination, might be present. In weight training, this situation may be revealed by outstanding performance in one supplementary exercise such as the squat, but diminished performance in another exercise such as the bench press.

In the case of strength training, overtraining injuries may be the result of too many repetitions or sets, regular training with near maximum loads, training the same muscle groups too frequently, inadequate recovery periods, insufficient rest or faulty execution of any movement.

Table 1 Symptomatic comparison of A and B types of overtraining

Variables	A-Overtraining	B-Overtraining
1. Blood pressure	diastolic increase to over 100mm Hg, during and after physical stress	slight increase
2. Coordination	impaired	impaired, with increased reaction time
3. Bodymass	normal	decrease
4. Endurance	slight increase in tiredness	tendency to tire easily
5. Sleep requirements	no increase	increase
6. Resting pulse	low	elevated
7. Body temperature	normal	slightly increased
8. Appetite	normal	reduced
9. Metabolism	normal	altered, with increased tendency to sweat; abnormally increased breathing rate under stress
10. General muscle soreness	little or none	mild to pronounced, with tendency to muscle stiffness and pain
11. General resistance	normal	tendency to headaches, colds, fever blisters; prolonged recuperation
12. Recovery time	normal or slightly increased	increased
13. Psychological changes	none, other than slight loss in motivation	nervousness, poor motivation, inner unease, eventual depression

"Inappropriate use of the different types Of muscle contraction ('concentric' , eccentric' or isometric) may also lead to overtraining injuries. Concentric (miometric) contraction refers to the case of a muscle developing tension while shortening, whereas eccentric (pliometric) contraction refers to tension produced by a lengthening muscle (e.g. in the lowering phase of a squat or biceps curl). Muscles are stronger in the pliometric mode than in the miometric mode, therefore one should be especially careful not to overtrain with pliometric exercises (6).

Similar care should be taken not to overtrain with special machines or manoeuvres, isokinetic, pliometric or otherwise, which vary the load intensity throughout the range of movement and constrain the lifter to produce unusual patterns in tension, space, time and leverage.

A Biophysical Model of the Overtraining Process

The different proneness to injury by individuals is not always appreciated by sportsmen and their coaches, largely because genetic or structural susceptibility to damage is not easy to measure. Injury proneness depends on a variety of factors including inherent muscle, tendon and ligament strength and mechanical stiffness; the ratio of strength between flexor and extensor muscles; body leverages; and previous injury.

The role of tissue stiffness in overtraining injuries may be appreciated by examining the behaviour of two springs of different stiffness stretching as a result of absorbing the same amount of energy (Fig 3).

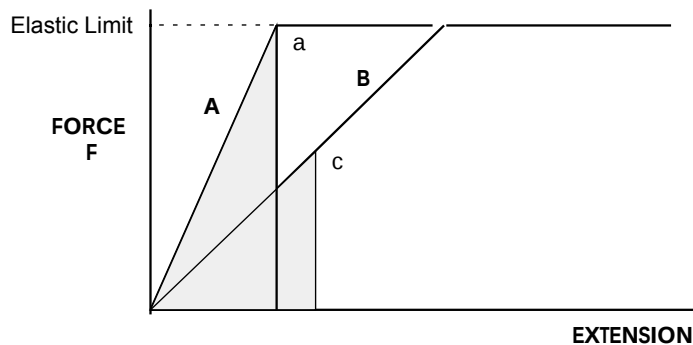


Figure 3 Force-extension behaviour of two springs of different stiffness absorbing the same amount of energy E . The elastic limit is the same for both springs. The shaded area up to a is the same as the shaded area up to c and represents the energy absorbed, E .

The stiffer spring A, in absorbing the energy E , is forced to its elastic limit at a , whereas the less stiff spring B extends further to C , but reaches nowhere near its elastic limit at b . It is possible, too, that certain individuals may have similar tissue stiffness but higher elastic limits. Again, the result will be a superior ability to absorb energy as imposed for instance on the soft tissues of the knee by running, jumping or squatting. This analysis is particularly relevant to an understanding of tendon injuries, since much of the muscle activity in running is associated with tensioning of the tendons to store energy, a process which involves little length change in the muscle fibres themselves (7).

Instead of referring solely to "overtraining injuries" it would probably be more valuable to talk of "exercise imbalance injuries". Such a term would embrace any form of unbalanced training, be it excessive, drug assisted or technically faulty.

The occurrence of "exercise imbalance injuries" may then be described scientifically on the basis of a qualitative topological model, called Catastrophe Theory by its inventor, Prof R Thom (8). Theories which consider overtraining to be a gradual, continuous change from health to injury do not adequately describe the abrupt appearance of some overtraining injuries.

Catastrophe theory uses abstract multi-dimensional surfaces to describe such changes of state. It provides a behaviour surface, something like a buckled carpet, whose characteristics (such as its shape) are determined by one or more control dimensions. In the case of joint or general body stability the behaviour surface describes the state of health of the joint or body. The nature of this behaviour surface may be regarded as depending on the following four control factors:

Structural Predisposition to Injury: This depends on heredity, structural changes caused by previous exercise, earlier injuries, ageing and so on.

Technique Stress: This is stress caused by faulty technique, posture and equipment, including footwear.

Physical Stress: This concerns the exercise load and frequency, current illness, adequacy of sleep, and environmental conditions (such as temperature and altitude).

Psychological Stress: There are several different types of catastrophe structure, depending on the number of behaviour and control dimensions. In the case under discussion there is one dimension of behaviour (state of health) and the four control dimensions given above, so that the appropriate system must be a "butterfly catastrophe". To depict this requires a 5 - dimensional drawing, which is impossible. However, if the four control dimensions are reduced to two by keeping two of them constant (e.g. psychological stress and technique stress), a useful version of the "butterfly" surface may be sketched (Fig 4).

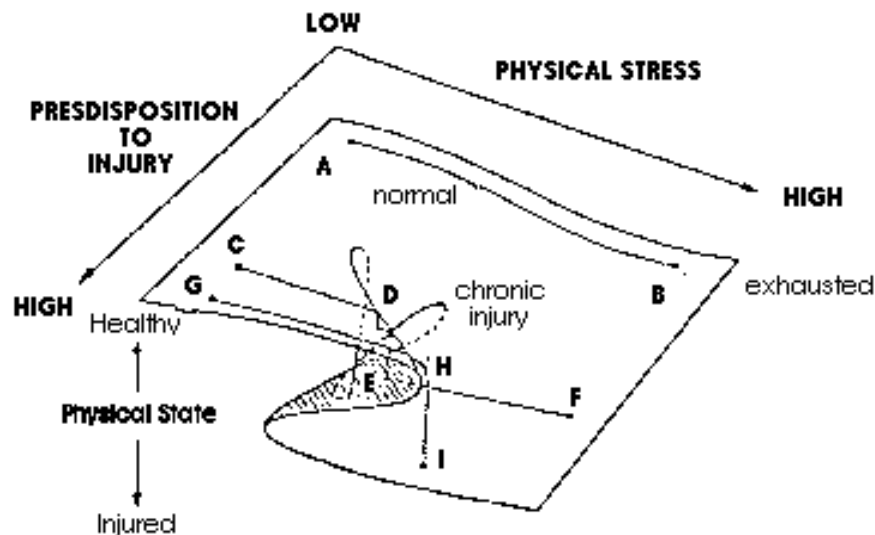


Figure 4 Butterfly Catastrophe Model of the Injury Process

Consider a subject with a predisposition to injury. His state before commencing exercise will be represented by point A. As his level of physical stress increases, so will he progress towards a state of exhaustion at B. His natural tendency will be to relax slightly to a more comfortable level back along AB, then to re-exert himself and repeat the process back and forth within the limits of his endurance.

A person with a very high predisposition to injury may begin exercising in a state G and without suffering undue stress may reach the threshold H. Any small increase in training load, however, may precipitate him without significant physical warning into the injured state at I. This is vital to remember, since damage may be occurring constantly without producing pain signals. Often pain occurs when it is too late to take evasive action. This is especially true of the insidious damage caused by years of executing inadvisable exercises such as conventional sit-ups, leg-raises or "bunny-hops" on the haunches.

The extent and location of the butterfly fold depends on the individual and may be influenced, for example, by appropriate supplementary training, medical treatment or ergogenic aids (drugs or supplements).

Consider now the individual who may begin his sporting career in a state C. Under moderate stress he may find himself trapped in a region of the fold in a state of chronic injury, which rest or medical attention may rectify, but only as long as he discontinues the stressful activity which caused his injury.

The person with very low predisposition to injury is not necessarily immune to overtraining or exercise imbalance injury. For instance, he may ignore the usual symptoms of exhaustion while approaching state B and progress towards an injured state such as F. This type of individual, characterized by intense motivation, may even shift his initial state from A towards C or increase the extent of the fold by training in a state of residual stress caused by inadequate rest.

Different combinations of any two control dimensions may be selected as the variables instead of "predisposition to injury" and "physical stress". In this way the sportsman and his coach can appreciate the importance of the four control dimensions (given earlier) in planning a training routine to minimize the occurrence of exercise imbalance or overtraining injuries. The sportsman should identify his characteristic paths of operation on the behaviour surface and prevent himself from exercising or competing too close to the catastrophe fold.

Avoidance of Overtraining

The sportsman will take significant steps towards avoiding overtraining and minimizing the incidence of overtraining injuries if he:

1. plans his training carefully and records the exact intensity, volume duration and frequency of his training load. In the case of strength training, he should register the exercise, load used, number of sets and repetitions. There should be an alternation of light, medium and heavy days and an avoidance of too frequent maximum attempts or too many repetitions. He should not train with heavy weights just to impress spectators in the gym. In addition he should have adequate recuperation periods between sets and between workouts.
2. keeps a check on the possible occurrence of any of the warning signs of general overtraining given in Table 1 and modifies his training schedule accordingly
3. takes note of lingering muscle or other soft tissue soreness or stiffness. Persistent disregard of these symptoms and inadequate periods of rest for individual muscle groups may lead to injury
4. provides sufficient variety and interest in his training programme
5. maintains a flexible mental attitude. Stubborn dedication to a strict training routine or unwillingness to heed advice readily predisposes one to overtrain. No training schedule can be designed to anticipate every variable one may encounter
6. ensures that imperfect technique is not placing excessive stress on any particular part of the body
7. has adequate rest and sleep, and an occasional change of environment
8. eats a balanced diet which includes all essential nutrients
9. avoids over-reaction to stressful situations in daily life and in training. Relaxation, massage and meditation techniques can be useful in minimizing the harmful effects of stress
10. takes an occasional complete break from his competitive sport
11. has regular sports-medical supervision
12. maintains an harmonious, productive relationship between himself, his coach and his training partners

It is appropriate to conclude with another Selye quotation: "The goal is certainly not to avoid stress - stress is a part of life. It is a natural byproduct of all our activities But in order to express yourself fully, you must first find your Optimum stress level and then use your adaptation energy at a rate and in a direction adjusted to the innate structure of your mind and body. It is not easy ... It takes much practice and almost constant self-analysis" (1).

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