Fatigue: Enemy or Saviour?

Even the most determined of athletes cannot beat the force of fatigue. When an athlete is pushed out of their comfort zone their physical and mental ability to maintain peak performance decreases. Despite best efforts, fatigue sets in and lifting the same weight to finish a set or maintaining the pace to stay with the pack becomes impossible. It is the moment the body's performance and especially power output plummets and sensations of tiredness take over. Is fatigue the enemy of a high-performance athlete or is it the body's protective mechanism to prevent irreversible damage?

So why does fatigue happen? There is no single answer to this question and that's why fatigue is a complex puzzle for exercise physiologists, strength and conditioning coaches, and sports psychologists. What we do know is a fatigued athlete has an increased risk of injury. Therefore, when we work with elite athletes, we should endeavour to find out at what duration and intensity of performance the athlete typically starts to show signs of physical and mental fatigue. We can help high-performance athletes to become more attuned to their bodily sensations, recognising the early warning signs. Elite performance with longevity is more than just 'push harder'. Understanding fatigue allows for effective training programme design to delay its onset and the management of its symptoms and impacts on a strategic performance.

Types of fatigue

As exercise-induced fatigue is so complex there have been many dedicate their time to trying to decode and define it. This has led to fatigue being considered in multiple ways:

Physiological and Psychological

- Physiological fatigue: a decreased or impaired response from cells to organ systems in response to exercise stress. For example, neuromuscular fatigue causes a reduction in muscular force production or power
- Psychological (cognitive or mental) fatigue: characterised by increased feelings of tiredness or exhaustion. It is associated with a reduction in cognitive performance and reduced desire to continue performance or training

Central and Peripheral

- Central fatigue: fatigue of the central nervous system (brain and spinal cord) and the signals it sends. For example, a decreased activation of motor neurons
- Peripheral fatigue: fatigue of the muscular system, where muscle fibres lose their ability to sustain contraction speed and/or strength

Contributory factors to fatigue

Central fatigue: during prolonged bouts of physical activity biochemical changes occur in the central nervous system. Serotonin accumulates which increases sensations of tiredness and the rate of perceived exertion. This prevents the beneficial increase in dopamine leading to an earlier onset of fatigue. The conduction of axonal action potentials may become blocked causing a decrease in the firing rate of motor neurons.

Researchers have tried to delay central fatigue by using the nutritional supplement BCAA (branched-chain amino acids) to prevent the accumulation of serotonin, however the jury is still out on whether this affects time to fatigue or overall performance. Animal studies provide evidence that exercise training over time decreases the serotonin system and increases the dopamine system leading to less central fatigue for the same activity.

Peripheral fatigue: an anaerobic bout of physical activity will lead to changes in the internal environment (the blood and space around the cells) and the muscle fibres themselves.

In the internal environment, the onset of blood lactate accumulation (OBLA) is passed causing the hydrogen ions (H^+) which dissociate from lactate to build up lowering the pH and making the environment more acidic. There is also an increase in heat which triggers the sweat response and fluid loss can lead to dehydration states.

In the muscle fibres, the sarcoplasm sees a decrease in glycogen stores limiting fuel availability. An accompanying accumulation of inorganic phosphates (P_i) and H^+ inhibit cross-bridge action and lead to a decrease in contractile force. The release and reuptake of calcium ions (Ca^{2+}) also decrease, due to magnesium ion (Mg^{2+}) and H^+ accumulation respectively. This may lead to an increased time requirement for muscle relaxation after a powerful contraction. The biochemical changes also include the flight of potassium ions (K+) away from the muscle fibre, negatively affecting action potential conduction velocity and conversion of electrical signals to mechanical responses (**excitation-contraction coupling**).

Fatigue and Muscle Fibre Type

The effect of peripheral fatigue differs by muscle fibre type. All muscles include a variety of muscle fibres and motor units which differ in contraction speed, force production and resistance to fatigue. The accumulation of inorganic phosphates (P_i) affects type I (slow twitch) and type II (fast twitch) fibres differently. Under these fatigue-related conditions type 1 fibres suffer contraction speed whereas type II fibres suffer force production.

Type I muscle fibres are fatigue resistance and less vulnerable to disruptions in excitation-contraction coupling. ATPase turnover, the enzyme involved in the breakdown of ATP for energy release, is lower and cross-bridge action is slower leading to decreased contractile speed and force production but over a longer duration than type II muscle fibres. In comparison type II fibres are sensitive to fatigue with a higher turnover of ATPase and force production can suffer up to 30 times more under fatigue-related conditions.

Additional factors affecting fatigue:

- **Gender**: Research shows females have a lower anaerobic pathway efficiency and higher perceptions of exercise effort, stress and fatigue.
- **Type and duration of sporting activity**: Ultra-endurance sports show higher central fatigue than short duration sports.
- **Mental wellbeing:** Stress or anxiety can reduce arousal and lead to physical symptoms which increase central fatigue

Fatigue is the body's built-in defense mechanism, powerful signals telling the athlete when to lower the pace in the face of overexertion. After all exercise is a stress for the body. A natural safeguard, the fatigue process prevents to potential of irreversible damage. However, it is far from simple. Fatigue is multifactorial, it is complex and contextual and the understanding of how to manage and reduce it is very much still developing. It is important to treat athletes holistically and as individuals. Sports and exercise scientists work to enhance the athlete's physiological systems to delay fatigue, tolerate its effects and manage its symptoms. Ultimately, elite performance is not just about pushing harder, it's about training athletes to tune into their bodies and manage their effort under intense pressure.

Examples of Fatigue Markers for Assessment

Neuromuscular	Biochemical	Psychological	Performance
Electromyography (EMG) can record the action potentials of the active muscle fibres and measure peripheral fatigue rates. Prolonged intense activity shows the amplitude and conduction velocity of action potentials decreases in the sarcolemma.	Circulating biochemical markers can be assessed with a simple blood sample. Creatine kinase (CK) is a well-used indicator in high-intensity and strength training as a rise in CK levels is associated with eccentric muscle fibre damage. Blood lactate concentration is the most commonly used indicator to suggest a threshold above which an athlete will start to fatigue (the onset of blood lactate accumulation, OBLA).	A popular psychological marker of fatigue is the rating of perceived exertion (RPE), a scale from 6 to 20 which asks the athlete to rate their perception of how hard the activity is to complete.	A performance test of neuromuscular fatigue is the countermovement jump test (CMJ) where biochemical or mechanical fatigue would lead to a reduction in power output or force production, i.e. a lower jump height recorded in a fatigue state.

Fatigue and Injury

Fatigue leads to a greater risk of injury. The reduced ability of the neuromuscular system to recruit motor units leads to a lack of strength, coordination, postural control and affects joint stability and proprioception.

- In a research study of the top European professional men's football clubs (including Arsenal, Manchester United, Chelsea, Liverpool, Milan, Real Madrid etc.), researchers Ekstrand and colleagues suggest fatigue may be the root cause of an increase in injuries over time on the pitch during a single match.
- Footballers were significantly more likely to suffer a traumatic injury the longer they were on the pitch in both the first and second halves. The rate of contusions, ligament sprains and muscular strains increased over time in both the first and second half of a match. This aligns to research that shows the distance covered, high-intensity movement and technicality all decrease towards the end of a game.
- If you want to know more about the lead researcher for this study, check out their profile at Linköping University, Sweden (Jan Ekstrand - Linköping University). Professor Jan Ekstrand is the lead researcher on sports safety for elite-football players in Europe.

Research Insight: Revolutionising Surgeon Wellbeing

Surgeons are among the highest takers of sick leave in the country. Long hours performing intricate surgeries often in static positions take a toll on their bodies. They experience high levels of muscular and cognitive demand during their work which, over time, can lead to musculoskeletal decline.

Enter robotic surgery, an innovation argued to improve surgeon wellbeing and career longevity while increasing patient care. Surgeon Shugaba and colleagues (2023) set out to explore how robotic (seated) surgery compares to more traditional laparoscopic (standing keyhole) on both muscular and cognitive demand.

Advanced technologies were used: electromyography (EMG) to compare muscular demand and fatigue in the trapezius, deltoid, biceps brachii and latissimus dorsi muscle groups and electroencephalography (EEG) using a head cap of electrodes to assess cognitive fatigue.

After 28 robotic and 26 laparoscopic surgeries they found overall, robotic surgery produced a lower physical strain, but a higher cognitive demand than laparoscopic surgery. The research doesn’t stop there, now investigating the forearm and neck muscles the researchers aim to create a comprehensive understanding of the toll on surgeons.

To find out more explore the publication in Annals of Surgery Open and to learn about how a sports and exercise scientist is pioneering research in this area check out integrative physiologist Dr Chris Gaffney Christopher Gaffney - Lancaster University.