HUMAN MUSCLE FATIGUE

White Paper

MYOCENE
SPORT TECHNOLOGY

Introduction

Activities of all kinds in humans produce more or less marked fatigue. We generally distinguish between nervous fatigue secondary to wake duration and intellectual or psychic activity and physical fatigue secondary to physical or muscular activity.
All physical activities, physical exertion or muscular work, whether in the context of sports, work or activities of daily life, lead to more or less fatigue depending on the intensity of the physical effort and its duration. This fatigue reduces the subject's physical performance, especially when the degree of fatigue is important.
Due to this physical fatigue, the subject will no longer be able to develop his maximum strength or power. At a more advanced stage of physical fatigue (exhaustion), the subject will not be able to maintain or repeat a sub-maximal physical effort for longer or at the same level of intensity.
This reduction in the potential for physical effort, due to fatigue, is then observed through multiple means of evaluating muscular and athletic performance by measuring speed, power, displacement, strength, duration, etc. of a gesture, a series of gestures or a defined type of exercise.

Definition

As mentioned in the here above introduction, physical fatigue is secondary to muscular exertion and is thus generally so-called muscle fatigue.
This muscle fatigue can be reflected in a decrease in physical performance and it is this decrease in performance that is indeed used by most researchers as the definition (1, 2). Actually, any reduction in maximal muscle force or power output due to exercise is defined as fatigue (3, 4). More precisely, investigators are measuring maximal force of a muscle to investigate the physiology of muscle fatigue and thus define muscle fatigue as a loss of maximal force generating capacity (5, 6, 7).

Fatigue sites

The generation of voluntary muscle contractions starts at the central nervous system which excites motoneurones. This excitation (action potential) is transmitted to the muscle fibres then to the reticulum sarcoplasmic which releases calcium ions (Ca^{2+}). These Ca^{2+} ions bind to troponin and trigger actine-myosin cross-bridges mechanical response i.e., muscle contraction and force.
Each possible fatigue sites have been deeply investigated and most focus on three possible areas: central fatigue, failure at the neuromuscular junction, and deficits in the muscle fibre. For healthy subjects,

neuromuscular junction is not concerned in voluntary contractions and thus two sites are actually concerned: central and muscle fibre (7, 8, 9, 10, 11, 12). Therefore, physiologists describe nowadays two kinds of fatigue (Figure 1): the central or nervous fatigue and the peripheral or muscle fibre fatigue (13, 14, 15).

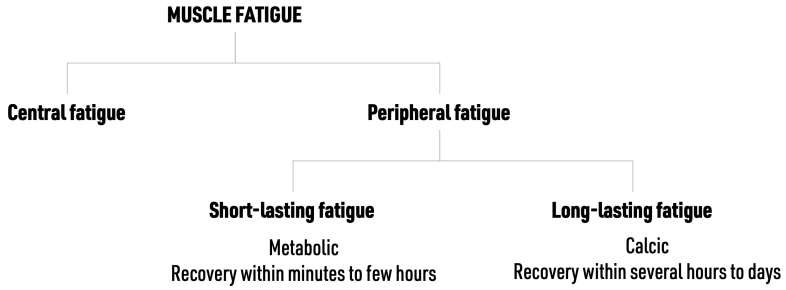

Figure 1: The different types of muscle fatigue

Central and Peripheral Fatigues

The central fatigue is a diminution in the nerve impulses firing on motor-units and thus less motor-units are recruited and/or at a lower frequency and consequently less muscle force is generated. This reduction of the central nervous system firing on motoneurons is largely described in the muscle physiology literature and can be demonstrated and measured by the twitch interpolation technic (16, 17, 18, 19, 20, 21, 22).

The peripheral fatigue is a diminution of force of the muscle fibres in response of nerve impulses i.e., for a same nervous system impulses firing, the muscle is producing less force output. The peripheral fatigue or muscle fibre fatigue has two components: a short-lasting component (short-lasting fatigue) and a long-lasting component (long-lasting fatigue) (7, 10, 23, 24).

Short lasting fatigue is related to metabolic factors and is thus named as well metabolic fatigue. The metabolic changes during muscle exertion are indeed important: depletion of adenosine triphosphate, phosphocreatine, or glucose/glycogen and accumulation of metabolic products in the fibres cytoplasm can affect the function of the contractile elements. Whatever the metabolic changes responsible for muscle fatigue, the recovery is pretty fast. As describe in the literature, the muscles recover from metabolic fatigue within minutes or few hours depending on the type of the muscle exercises (25, 26, 27).

Long lasting fatigue

Long-lasting peripheral muscle fatigue has long been described in the literature (1, 2, 5, 10, 11, 13, 14, 23, 24, 26).

To understand this essential muscle fatigue, we need to consider the force-frequency relationship, that is, the force generated by a muscle in terms of the frequency of nerve impulses. The muscle force-frequency relationship draws a sigmoid curve. At very low frequency (roughly less than 10 impulses per second) the strength developed by a muscle does not increase. Then, at low frequency (above 10 Hz) there is a tetanus and the strength rises sharply with the frequency to reach its maximum force and a fused tetanus at high frequency (roughly above 80 Hz).

The long-lasting fatigue affects the muscle force-frequency relationship (Figure 2). The sigmoid curve moves to the right and the slope at the low frequency (roughly between 10 and 50 Hz) is significantly less sharp while at high frequencies (above 80 Hz) the force is just a little affected (4, 23, 28, 29).

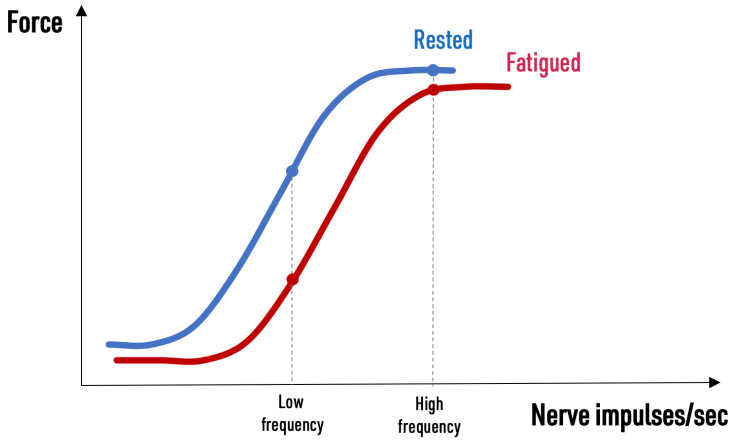

Figure 2 : The long-lasting fatigue is more pronounced at low frequency than at high frequency

Therefore, the long-lasting fatigue is markedly measurable at low frequency and less at high frequency firing of nerve impulses. Consequently, long-lasting fatigue is as well so-called "low frequency fatigue" as the force loss is well measurable for low frequency compare to high frequencies (30, 31, 32, 33).

The origin of the long-lasting fatigue or low frequency fatigue has been investigated in details. It is now well established that it is due to a reduction of Ca^{2+} ions released by the reticulum sarcoplasmic (RS) (34, 35, 36, 37). When an action potential is transmitted from motoneuron to muscle fibres, it propagates along the fibres membrane and the t-tubule, inducing the release from the RS of Ca^{2+} ions that trigger the actine-myosin cross-bridges mechanical response. As the amount of Ca^{2+} released from the SR into the cytosol decreases, this attenuates the binding of Ca^{2+} to troponin C. Fewer cross-bridges are formed between actin and myosin and consequently less force is produced by the contraction. Due to the relationship of long-lasting fatigue with Ca^{2+}, some now refer it as the "calcic fatigue".

As a matter of fact, the long-lasting fatigue or calcic fatigue is of primary importance for sport exercises. Firstly, because it lasts for several hours or days after the muscle exertion contrary to the "metabolic fatigue" which is rapidly restored. But as well because it moves the steep part of the force-frequency curve to the right causing a significant reduction in the force of contraction and needing the central nervous system to compensate partly by increasing the firing frequency of the motoneurones.

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