Chapter 10
Endurance Time Prediction using Electromyography

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ABSTRACT
The purpose of endurance time (Tlim) prediction is to determine the exertion time of a fatiguing muscle contraction before it occurs. Tlim prediction would then allow the evaluation of muscle capacities while limiting fatigue and deleterious effects associated with exhaustive exercises. Fatigue is a progressive phenomenon which manifestations can be observed since the beginning of the exercise using electromyography (EMG). Studies have reported significant relationships between Tlim and changes in EMG signal suggesting that Tlim could be predicted from early EMG changes recorded during the first half of the fatiguing contraction. However some methodological factors can influence the reliability of the relationships between Tlim and EMG changes. The aim of this chapter is to present the methodology used to predict Tlim from early changes in EMG signal and the factors that may influence its feasibility and reliability. It will also present the possible uses and benefits of the Tlim prediction.

INTRODUCTION
Neuromuscular fatigue is a very complex phenomenon (Boyas & Guevel, 2011b). This phenomenon is progressive (Bigland-Ritchie, 1981) and induces changes in the electromyographic (EMG) signal (De Luca, 1984). Moreover, it has been illustrated that changes in the EMG signal occur before any mechanical manifestations of muscle fatigue (Lindstrom, Kafedors, & Petersen, 1977). This suggests that EMG changes could provide useful information about the early manifestations of neuromuscular fatigue. The endurance time (Tlim) can be defined as the maximal duration during which an individual can sustain the required level of force. Several studies have reported significant relationships between Tlim and indicators characterizing the changes in the EMG signal (e.g. Dolan, Mannion, & Adams, 1995; Hagberg, 1981; Hagberg & Kvarnstrom, 1984; Mannion & Dolan,
1994, 1996; van Dieen, Oude Vrielink, Housheer, Lotters, & Toussaint, 1993). However, few studies have investigated the possibility of predicting the Tlim using the early changes in the EMG signal (Bouillard, Frere, Hug, & Guevel, 2012; Boyas & Guevel, 2011a; Boyas, Maisetti, & Guevel, 2009; Dolan et al., 1995; Maisetti, Guevel, Legros, & Hogrel, 2002a; Mannion & Dolan, 1994; Merletti & Roy, 1996; van Dieen, Heijblom, & Bunkens, 1998). This may be due to the fact that some factors influence the feasibility and reliability of the Tlim prediction such as the experimental conditions (contraction intensity (Boyas & Guevel, 2011a) and/or number of muscles involved (Boyas et al., 2009)) and physiological phenomena (putative compensations between muscles (Kouzaki, Shinohara, Masani, Kanehisa, & Fukunaga, 2002) and/or non-homogenous distribution of EMG activity within a muscle (Zijdewind, Kernell, & Kukulka, 1995)). However, this domain of research is relevant due to the multiple uses and benefits it can provide to clinical and sport fields.

The objectives of this chapter are i) to describe the methodology used to predict the endurance time of a muscle contraction using EMG; ii) to present the studies that have investigated endurance prediction during isometric and dynamic conditions and discuss the factors that may influence the feasibility and reliability of the endurance time prediction; iii) to depict the possible benefits of the endurance time prediction. The main studies in the field of endurance time prediction are presented in table 1.

**BACKGROUND**

**Tlim Prediction Methodology**

The study of relationships between the changes in the EMG signal and the Tlim of a muscle contraction requires the continuous recording of the EMG signal emanating from the muscles involved in the fatiguing contraction, from the beginning to the end of the contraction (Tlim). Then, EMG parameters classically used to characterize the changes in neuromuscular function, such as the Root Mean Square (RMS), the Mean Power Frequency (MPF), the Median Frequency (MF) and the frequency bands (i.e. power of the signal in a given energy band - FB) are calculated. These EMG parameters are calculated as follow:

$$RMS = \sqrt{\frac{1}{T} \int_0^T x^2(t) \, dt}$$

In this equation, $x$ is the EMG signal and $T$ the duration of the calculation window.

$$MPF = \frac{\sum_{i=1}^{M} f_i P_i}{\sum_{i=1}^{M} f_i}$$

In this equation, $P$ is the Power Spectral Density (PSD), $M$ the number of samples of this PSD.

$$\sum_{i=1}^{MF} P_i = \sum_{i=MF}^{M} P_i = \frac{1}{2} \sum_{i=1}^{M} P_i$$

In this equation, $P$ is the Power Spectral Density (PSD), $M$ the number of samples of this PSD.

What is called frequency bands (FB) in this chapter represent the relative power of the signal in a given energy band that is determined by the researcher (e.g. between 6 and 30 Hz). Consequently, it is a percentage of the total power of the signal that is 100%.

Merletti et al. (1991) have illustrated the evolution of the EMG parameters during a submaximal contraction (figure 1). The changes in these parameters during time are then characterized thanks to mathematical models which provides indicators illustrating their evolution. Afterwards, relationships between the Tlim and the indicators representing the changes in EMG signal...
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