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Università Politecnica delle Marche

Extended summary

Muscle Fatigue Assessment during Flexion – Extension Movements

Curriculum: Electromagnetism and Bioengineering

Author

Manuela Savini

Tutor

Sandro Fioretti

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Abstract. Muscle fatigue represents a complex phenomenon encompassing various causes, mechanisms and forms of manifestation. Continuous monitoring of local muscle fatigue during performance of certain work is possible by measuring myoelectric activity of particular muscles by the method of surface electromyography. Biochemical and physiological changes in muscles during fatiguing contractions are reflected also in properties of myoelectric signals recorded on the surface of the skin above the muscle. It is well know that the spectral analysis of surface myolelectric signals, through the mean and median frequency values, is a valuable tool for the quantification of the electrical manifestations of muscle fatigue. Specifically, it has been demonstrated that during an isometric muscle contraction the power spectrum of the signal is progressively scaled towards the power lower frequencies. Although important results have been obtained in the past by assessing fatigue under static conditions, fatigue assessment during dynamic tasks is here taken into consideration because are likely more relevant to daily functions and clinical applications. In particular, the dynamic conditions were controlled by an isokinetic machine that allowed to compare the electrical manifestations of muscle fatigue during concentric and eccentric contractions. The purpose the our study is to evaluate the isokinetic principle in rehabilitation through time-frequency analysis to understand of muscle behavior during two modalities of contraction.

Keywords. Cyclic contractions, isokinetic exercise, muscle fatigue, sEMG, time-frequency analysis.

1 Time-frequency analysis

1.1 The Cohen's Class

When the muscle contracts in dynamic conditions, the myoelectric signal generated by the muscle can no longer be considered as a stationary process. This observation is crucial, since it follows that the classic spectral estimation techniques adopted when working in isometric condition must be substituted by techniques suitable to analyse nonstationary processes. Among the different possible approaches for the analysis of nonstationary signals, Cohen class transformations have recently received considerable attention, particularly in biomedical signal processing [1]. This class of time-frequency representations is particularly suitable to analyse surface myoelectric signals recorded during dynamic contractions, which may be modeled as realizations of nonstationary stochastic processes [2-4]. Cohen's class time-frequency spectrum $S(t,f)$ may be written as

$$S(t,f) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E\left\{x(t'+\tau/2)\,x^*(t'-\tau/2)\right\} g(\theta,\tau) \cdot e^{-j2\pi\theta(t'-t)} e^{-j2\pi f\tau}\, d\theta\, dt'\, d\tau \tag{1}$$

where $E\{\}$ = expectation operator; $x(t)$ = realization of the stochastic process under consideration; $x^*(t)$ = complex conjugate; t = time; f = frequency; τ = time-lag; t' = auxiliary variable; $g(\theta, \tau)$ = kernel of the transform.
The formulation presented in (1) may also be utilised when a single realization of the analysed stochastic process is available, as is the case when processing surface myoelectric signal recorded during dynamic contractions. Therefore the expectation may be removed.
The Choi-Williams transform, thit is a member of Cohen's class, is a good candidate for the analysis of sEMG signals.
Its kernel is defined as $g(\theta, \tau) = e^{-(2\pi\theta\tau)^2/\sigma}$. In the analysis of sEMG signals recorded during dynamic contractions the parameter σ has been chosen equal to 1 as this value appeared to be satisfactory for processing myoelectric data.

1.2 The time-frequency representations for discrete-time signals

When one is dealing with sampled signals, it is necessary to consider a discrete version of the time-frequency distributions. The generalized discrete-time time-frequency distribution approach was utilised [5]. Using discrete-time samples $\{x(n)\}$ and a temporal-correlation domain kernel $\Psi(n,2k)$, the generalised autocorrelation and the generalised discrete-time, time-frequency distribution can be defined as

$$R^G(n,2k) = \sum_{m\in Z} x(m+k)\,x^*(m-k)\,\psi(n-m,2k) \tag{2}$$

$$C^G(n,\omega) = \sum_{k\in Z} R^G(n,2k)\,e^{-j2k\omega} \tag{3}$$

where Z is the set of integers, $n \in Z$, and $\omega \in [-\pi,\pi]$. The sampling of the time-lag axis is half of the sampling of the time axis. Hence the generalised discrete-time, time-frequency distribution is periodic with respect to ω with period π. The signal is therefore required to be sampled at no less than twice the Nyquist rate in order to avoid aliasing. It is worthwhile noting that Eq. (3) can be implemented by Fourier transforming the instantaneous autocorrelation function.

2 Materials and methods

2.1 Experimental setup

Nine healthy volunteers (six males and three females, 33 ± 3 years) participated in the study. Each subject performed the test using an isokinetic system (Biodex SYSTEM 4 PRO, Fig. 1). Subjects were secured by body straps and seated comfortably in the dynamometer chair. Before the test started each subject practiced a warm-up test consisting of ten minutes of cycling and a series of ten concentric contractions aimed at instructing the subjects about the isokinetic movement. The two contraction modalities in the same movement have been analysed. The test consisted of two series of isokinetic knee flexion-extension (each series consisting on ten concentric and eccentric contractions) at 60°/s. The range of motion was set equal to 80° (from 100° to 180°). Four signals have been acquired: knee angular position and sEMG signals recorded from the following three muscles: rectus femoris, vastus lateralis and vastus medialis. Both the electrogoniometric and the sEMG signals were recorded at a sampling frequency f_c of 2 kHz, by means of STEP-32 electromyographic system (DemItalia),

Figure 1. Isokinetic and SEMG systems

Figure 2. Experimental setup

2.2 Signal processing

The electrical manifestations of muscle fatigue were investigated by tracking the changes of the instantaneous mean and median frequency (IMNF and IMDF) of the sEMG signal during the flexion-extension cyclical exercise. We adopted the Choi-Williams transform to study the characteristics of the instantaneous power spectrum within each single signal "burst". To improve the estimation stability of the instantaneous spectral parameters, for each kind of contraction, a limited part of the sEMG signal "burst", corresponding to a fixed portion of the contraction cycles, was analysed (Fig. 3). Taking identical portions of the sEMG signal "burst", the effects of muscle force, of muscle length, and of movement of the electrodes with respect to the active muscle fibers, are assumed to be the same across cycles.

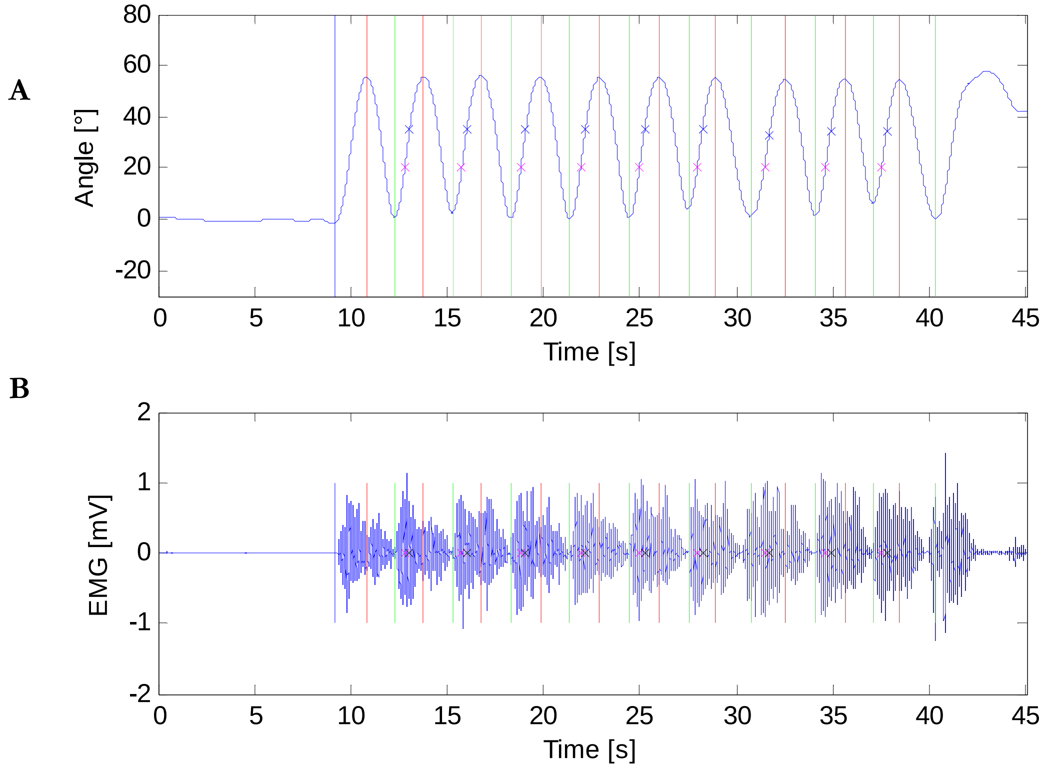

Figure 3. A) Joint angle that represents the knee position during exercise. B) Raw sEMG signals recorded during eight successive repetitions of knee flexion-extension. The crosses identify the segments considered for signal processing.

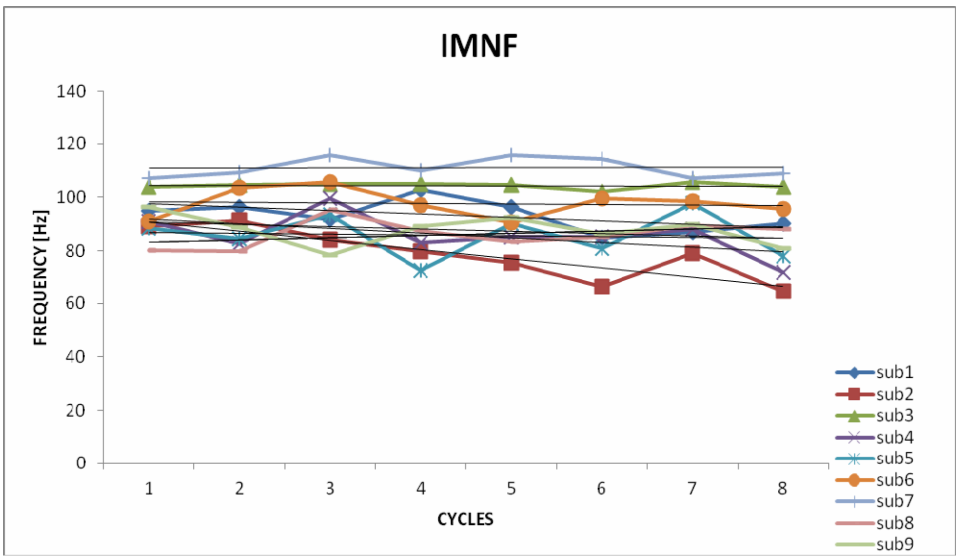

Figure 4. Example of instantaneous mean frequency time trends for nine subjects during concentric contractions of the rectus femoris.

3 Conclusion

Our results show differences in the behaviour of muscles considered. The negative regression slopes fitting the spectral parameters, shown in Fig.4, confirm that the power density function of the sEMG signal of the Rectus Femoris is scaled towards the lower frequency band during a repetitive knee flexion-extension, in agreement with previous studies [6]. The Rectus Femoris was fatigable, in particular, during concentric contractions, although we observed higher values of torque produced during eccentric than during concentric contractions. The behavior of the rectus femoris shows differences attributable to different strategies of recruitment of motor units in the two modalities of contraction.
The Vastus Lateralis and Medialis muscles do not always show manifestations of localized muscle fatigue. To obtain more information about isokinetic exercise, we believe it is important to analyse the isokinetic contractions at different angular velocities.

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