Comparative study of the EMG signal of human vastus lateralis and soleus muscles during fatigue and recovery


*Exercise Research Laboratory, Federal University of Rio Grande do Sul, Brazil
_o Health Science Center, University of Vale do Rio dos Sinos, Brazil

Introduction
Skeletal muscle fatigue is a continuous process that starts in the beginning of the neuromuscular activity and might be responsible for changes in the electrical activity, electrical transmission, excitation-contraction coupling and in various elements of the contraction process (Basmajan & De Luca, 1985; Clamann, 1990; Bigland-Ritchie et al., 1992). In addition to changes in the mechanical response, electrical aspects of the neuromuscular function and the role of the fiber type composition have been related to muscle fatigue (Häkkinen & Komi, 1986).

Analysis of the electromyographic (EMG) signals in the frequency domain has been used in the study of muscle behavior during sustained contraction to assess local muscle fatigue (De Luca, 1993). Factors that affect the EMG power spectrum during fatigue are: changes in the characteristics of the action potential, motor unit firing rates, additional recruitment of motor units and force level (Häag, 1992). The median frequency (MF) is a widely used index of fatigue, and many studies indicate that during muscular fatigue in sustained contraction there is a decrease in the MF (Kadefors et al., 1968; Lindström et al., 1977).

The magnitude of the EMG signals, expressed by means of the root mean square (RMS) values, can also be used to evaluate muscular fatigue (Nigg & Herzog, 1994). However, a gap appears to exist in the literature with respect to the behavior of the RMS of the EMG signals during sustained contractions. Vaz et al. (1996) showed evidences that the RMS values increased in the vastus lateralis muscle during a fatigue protocol when the level of voluntary effort was maintained (70% of the maximal voluntary contraction – MVC), while it decreased when the voluntary effort could not be maintained.

Muscle with different fiber type composition (slow x fast twitch) or motor unit distribution may show a distinct behavior in their EMG signals during a fatigue protocol. The purpose of this study was to compare the EMG signal behavior both in frequency (MF) and in the time (RMS) domains of muscles with assumed different fiber type distribution during a fatigue–recovery protocol. It was assumed that the vastus lateralis muscle, composed of approximately 67.3% of fast twitch fibers (Johnson et al., 1973) would be less resistant to fatigue than the soleus muscle, composed primarily of slow-twitch fibers (86.4%; Johnson et al., 1973). Four hypotheses were formulated based on the above differences: (1) the MF of the vastus lateralis muscle should show a larger decrease than the MF of the soleus muscle with fatigue; (2) the MF should return to pre-fatigue values fifteen minutes after fatigue in both muscles; (3) the RMS values of the vastus lateralis should show a larger increase than the RMS values of the soleus with fatigue; (4) the RMS values should return to pre-fatigue values during the recovery period only in the soleus muscle.

Methods
EMG signals and knee extensor and plantar flexor torques were obtained from vastus lateralis (fast twitch) and soleus (slow twitch) muscles of thirteen male subjects. EMG signals were obtained using an 8-channel EMG system (Bortec Inc., Canada), and torque signals using an isokinetic Cybex Norm dynamometer. Bipolar surface electrodes were placed on the distal third of the two muscles using standard procedures. Previous to the fatigue test, all subjects warmed up using a bicycle ergometer for five minutes. The protocol consisted of three maximal isometric voluntary contractions (MVC), one 70% MVC contraction up to exhaustion (fatigue test) and one 70% MVC contraction, fifteen minutes after the fatigue test (recovery period). Plantar-flexion torques were obtained at an ankle angle of 10 degrees of dorsi-flexion from the anatomical position, and knee extensor torques at a knee angle of 90 degrees. The fatigue test was interrupted when the torque values reached a level of 50% MVC. Visual feedback from
the produced torque was supplied to the subjects during the contractions through an oscilloscope to help the subjects to keep the desired torque level. The root mean square (RMS) and the median frequency (MF) values were calculated from windows of four seconds in four distinct moments of the protocol: (1) from the beginning of the protocol; (2) from the last four seconds while 70% MVC was maintained; (3) from the last four seconds of the fatigue protocol (at a level of 50% MVC) and (4) from the middle of the recovery test (at a level of 70% MVC). A two-way analysis of variance for repeated measures was used to determine statistical difference for each measured parameter and to test for an interaction effect among the muscles and the trials. Contrasts were used to evaluate the difference between the trials when interaction was not identified. The level of significance adopted was of 0.05 in all cases.

**Results & discussion**

The total contraction time during the 70% MVC fatigue trial for the knee extensors and plantar flexors was $30.30 \pm 8.06$ s and $29.73 \pm 9.77$ s respectively. The contraction time under 70% MVC for the knee extensors and plantar flexors was $15.69 \pm 12.54$ s and $19.42 \pm 15.03$ s respectively. The mean peak torque values for the knee extensors and plantar flexors was $328.77 \pm 62.51$ N.m and $243.3 \pm 29.86$ N.m respectively.

The MF and RMS mean values and standard deviations from the four moments of the fatigue and recovery test of both muscles are presented in Table 1.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vastus lateralis</strong></td>
<td>$72.03 \pm 11.20$</td>
<td>$54.64 \pm 9.24$</td>
<td>$47.97 \pm 5.98$</td>
<td>$69.12 \pm 8.62$</td>
</tr>
<tr>
<td>MF (n=13)</td>
<td>$0.32 \pm 0.17$</td>
<td>$0.44 \pm 0.16$</td>
<td>$0.43 \pm 0.17$</td>
<td>$0.43 \pm 0.16$</td>
</tr>
<tr>
<td><strong>RMS (n=13)</strong></td>
<td>$127.04 \pm 25.28$</td>
<td>$111.43 \pm 27.22$</td>
<td>$103.50 \pm 20.45$</td>
<td>$123.43 \pm 27.09$</td>
</tr>
<tr>
<td><strong>Soleus</strong></td>
<td>$0.24 \pm 0.08$</td>
<td>$0.27 \pm 0.07$</td>
<td>$0.26 \pm 0.05$</td>
<td>$0.27 \pm 0.12$</td>
</tr>
<tr>
<td><strong>RMS (n=10)</strong></td>
<td>$0.24 \pm 0.08$</td>
<td>$0.27 \pm 0.07$</td>
<td>$0.26 \pm 0.05$</td>
<td>$0.27 \pm 0.12$</td>
</tr>
</tbody>
</table>

Table 1. Mean values and standard deviations from MF (Hz) and RMS (mV) values of the vastus lateralis and soleus muscles, in the three moments of the fatigue test and during the recovery period.

The pattern of change of the RMS values and MF was similar ($p=0.66$ and $p=0.99$, respectively) for both muscles during the fatigue protocol and recovery test. The RMS values were similar among all four trials while the MF was different between trials 1-2 and 1-3. The RMS results were not in accordance with the literature (Vaz et al., 1996), which indicates an increase in the RMS values with fatigue, probably as a result of the recruitment of extra motor units (MU) and/or increasing in the firing rates of the previously active MU. The large variability of our data might have influenced these results. The MF results, however, are in accordance with what has been reported in the literature, as they show a decrease during sustained isometric contraction and return to initial levels during the recovery test.

Analyses in the frequency domain have been associated to the action potentials conduction velocity, and the MF has been used (and accepted) as a sensitive index of alterations in the motor units firing rate (Hägg, 1992). The results of the fatigue test, when analyzed in the frequency domain, showed a decrease of the MF for both muscles from the beginning of the test. This result agrees with what has been reported in the literature (Bigland-Ritchie et al., 1981; Vaz et al., 1996). Our results however, did not confirm the hypothesis (1), since the vastus lateralis muscle did not show a significant decrease in the MF when compared to the soleus muscle during the fatigue protocol.

RMS values have also been used as an index to determine the installation of muscular fatigue (Vaz et al., 1996). The results presented in this study did not show differences in the RMS values among the four moments analyzed in both muscles, which was not expected.

During fatigue, additional recruitment of fresh motor units and with larger fibers can occur (Häag, 1992). The additional recruitment of motor units would reflect in the RMS values. It has been speculated that this additional recruitment would occur in the vastus lateralis muscle, due to its fiber type distribution (predominantly fast twitch), while the soleus muscle would resist more to fatigue for the same reason (predominantly slow twitch). The hypothesis (2) has been confirmed, since the MF in the recovery trial
was similar to the pre-fatigue MF values in both muscles, which means that some kind of recovery occurred in the muscle.

The hypothesis (3) was not confirmed, since the vastus lateralis muscle did not show a significant increase in the RMS values when compared to the soleus muscle. The hypothesis (4) was also confirmed, since the RMS values of the soleus muscle during recovery were similar to the pre-fatigue values. However, the large variability of the data did not allow for the detection of fatigue using the RMS as an index.

The results of this study showed that the behavior of the EMG signal of the vastus lateralis and soleus muscles was similar when analyzed in the frequency and time domains during a sustained contraction fatigue protocol and during the recovery period.

References


