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Time and frequency domain analysis of electromyogram and sound myogram in the elderly

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Abstract The aim of this work was to evaluate the influence of the ageing process on the time and frequency domain properties of the surface electrical and mechanical activity of muscle. In 20 healthy elderly subjects (10 men and 10 women, age range 65---78 years) and in 20 young controls, during isometric contractions of the elbow flexors in the 20%--100% range of the maximal voluntary contraction (MVC), estimations were made of the root mean square (rms) and the mean frequency (MF) of the power density spectrum distribution, from the surface electromyogram (EMG) and sound myogram (SMG) signals, detected at the belly of the biceps brachii muscle. Compared to the young controls, the MVC was lower in the elderly subjects (P < 0.05); at the same %MVC the rms and the MF of EMG and SMG were lower (P < 0.05) in elderly subjects; the rms and MF of the two signals increased as a function of the effort level in all groups. Only in the 80%--100% MVC range did the EMG-MF level off and the SMG-rms decrease; in contrast the young controls, at 80% MVC the high frequency peak in the SMG power spectrum density distribution was not present in the elderly subjects. The results for MVC and %MVC can be related to the reduction in the numbers of muscle fibres in aged subjects. In particular, the lack of fast twitch fibre motor units (MU), attaining high firing rates, might also explain the result at 80% MVC. In 80%--100% MVC range the two signals rms and MF behaviour may have been related to the end of the recruitment of larger MU with high conduction velocity, and to the further increment of MU firing rate in the biceps brachii muscle beyond 80% MVC, respectively. Thus, the coupled analysis of the EMG and SMG with force suggests that in the elderly subjects the reduction of the number of muscle fibres may have co-existed with a MU activation pattern similar to that of the young subjects.

Key words Muscle sound · Surface electromyogram · Soundmyogram · Isometric exercise · Ageing

Introduction

Loss of strength is a characteristic of elderly people and it has been associated with a shrinking of the muscle mass and reduction of the muscle cross-section area (Lexell et al. 1983; Frontera et al. 1991). These changes have been attributed to the influence of ageing on the neurological (Brown et al. 1988; Howard et al. 1988; Merletti et al. 1992) or morphological (Lexell et al. 1983; Frontera et al. 1991) properties of the motor units (MU). However, it has been reported that the ageing process does not seem to affect the relative proportion of the MU with type I and type II fibres in the biceps brachii muscle (Grimby 1988; Doherty et al. 1993).

The MU activation pattern adopted by the muscle to increase strength consists, basically, of a combination of recruitment and an increased firing rate of the active MU. The percentage of the maximal voluntary contraction (MVC) at which recruitment is completed and the firing rate is the sole tool of providing further increases in force is specific to each muscle. It has been shown that for the small hand muscles this value is about 50% MVC; for larger muscles, such as biceps brachii, between 60% and 80% MVC (Kukulka and Clamann 1981; Basmajian and De Luca 1985).

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The investigation of muscle performance is commonly carried out by measuring the output force and by the analysis of the electrical activity during contraction. The surface electromyogram (EMG) is an
interferential signal in which the action potentials of each active MU are summated. In particular, the EMG time and frequency domain analysis has been shown to provide data on the degree of activation of the muscle MU pool and on the changes in the overall muscle fibre conduction velocity (Basmajian and De Luca 1985).

In addition to the force developed during contraction, another signal having a mechanical origin, the sound myogram (SMG), can be detected from a muscle. This is also an interferential signal which has been shown to derive from the composition of the mechanical activities of the fibres of the recruited MU (Gordon and Holbourn 1948; Barry et al. 1985; Orizio 1993). It can be detected at the muscle surface by contact sensors or microphones (for a review on the SMG detection techniques see Orizio 1993). These transducers have been shown to record the pressure waves generated by the dimensional changes of the active fibres during contraction (Oster 1984; Orizio 1993). It has been suggested that information about MU recruitment and firing rate is retrievable from analysis of the SMG time and frequency domain (Keidel and Keidel 1989; Orizio et al. 1989, 1990; Zhang et al. 1992).

Following the Gordon and Holbourn (1948) statement that “the muscular sound is the mechanical counterpart of the electrical activity of the motor units”, it appears that simultaneous analysis of EMG and SMG signals may provide a reliable tool to investigate the relationship between the electrical and the mechanical activities of the MU at different intensities of muscle contraction. Such electromechanical analysis has never been attempted in aged subjects. Thus, the aim of this study was to describe the properties of EMG and SMG during increasing isometric effort in the elderly. Moreover, by means of the relationship between the EMG and SMG parameters and the effort level it was intended to gain some insight into the possible influence of ageing on the role played by recruitment and firing rate of the MU in determining the force output during isometric contractions.

**Methods**

Subjects

A total of 40 healthy subjects signed an informed consent and participated in the study after full explanation of the purpose of the experiments and of the procedures to be followed. Of this group, 20 were sedentary elderly individuals (10 men and 10 women, age range 65–78 years) and 20 were young sedentary controls (10 men and 10 women; age range 20–34 years). None of them was involved in any specific training programme of the upper limb musculature, either at the time of the study or in the previous year. Table 1 gives the anthropometric characteristics of the subjects together with values of their MVC, the muscle-bone area (MBA) and the MVC per unit of MBA. The MBA was anthropometrically determined according to the method suggested by de Koning et al. (1986).

Apparatus

The experiments were carried out during isometric contractions of the elbow flexor muscles. The preferred arm of the subject was positioned in an anatomical device allowing an angle of 115° between the arm and the forearm. The hand was maintained in a position halfway between pronation and supination. The output force was recorded using a calibrated load cell (Interface, SM-1000 N, linear from 0 to 1000 N) strapped to the subject’s wrist. The EMG and SMG were detected from the belly of the biceps brachii muscle by means of a purpose-designed probe. This probe was made up of two silver bar electrodes (diameter 1 mm), 1-cm spaced and 1-cm long, and of the tip of a piezo-electric contact sensor transducer (Hewlett-Packard model 21050 A, bandwidth 0.02–2000 Hz) placed in between. The SMG was then amplified by a medium gain amplifier (Hewlett-Packard model 8802 A, filter bandwidth 2–120 Hz). The EMG was amplified by a differential amplifier (Hewlett-Packard 8802 A) and filtered (bandwidth 3–500 Hz). The SMG and EMG were displayed on a two-channel oscilloscope (Tektronics model 2211) to control the quality of the signals on-line and were stored on a portable computer hard disk (Toshiba model T 5200).

<p>| Table 1 Values for age, body mass, height, and muscle-bone area (MBA) of the arm of elderly and young subjects. The mean values of the maximal voluntary contraction (MVC) and MVC per unit of MBA are also given |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th><strong>Age (years)</strong></th>
<th><strong>Body mass (kg)</strong></th>
<th><strong>Height (cm)</strong></th>
<th><strong>MBA (cm²)</strong></th>
<th><strong>MVC (N)</strong></th>
<th><strong>MVC/MBA (N·cm⁻²)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Elderly</td>
<td>Mean 70</td>
<td>73.0</td>
<td>170</td>
<td>50.5</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>SEM 1</td>
<td>2.2</td>
<td>2</td>
<td>1.8</td>
<td>15</td>
</tr>
<tr>
<td>Young</td>
<td>Mean 27</td>
<td>76.2</td>
<td>179</td>
<td>64.3</td>
<td>353</td>
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<tr>
<td></td>
<td>SEM 2</td>
<td>3.0</td>
<td>3</td>
<td>3.4</td>
<td>16</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>Elderly</td>
<td>Mean 71</td>
<td>65.9</td>
<td>158</td>
<td>42.9</td>
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<tr>
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<td>186</td>
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