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Surface EMG model of the bicep during aging: A preliminary study

Katherine A. Wheeler, Dinesh K. Kumar, Hirokazu Shimada, Sridhar P. Arjunan, Chandan Kalra.

Abstract—**Reduction in the median frequency and the amplitude of surface electromyogram (sEMG) has been observed among older subjects compared with the younger cohort. These changes in sEMG have been associated with a reduction in the number of muscle fibers and a drop in the ratio of type II muscle fibers. However, the details of this association are not known.**

This paper has experimentally determined the difference between the magnitude and spectrum of sEMG of the younger and older cohorts, and estimated the changes to the muscle by populating a lifelike model with the experimental data. Experiments were conducted on subjects belonging to younger (20-28 years) and older (61-69) age groups. From the simulated results, it is shown that experimental sEMG signals are matched by the model representing the older cohort with a substantially reduced number of motor units compared to the younger people. In the model, the best match with experimental results was observed when the ratio of the bicep motor units between the older and the younger subjects was 0.5. The results also indicate a substantial reduction in the ratio of fast fibers, from 0.45 in the younger cohort to 0.11 in the older cohort.

I. Introduction

The muscle fibers of skeletal muscles in the human body are arranged into motor units. A motor unit (MU) is defined as a collection of muscle fibers and a single controlling motor neuron. All muscle fibers in a MU belong to one type only; slow fibers (type I), fast fibers (type II) or an intermediate fiber type.

Fast muscle fibers contract very rapidly (<10 milliseconds) and also fatigue rapidly. They are larger in diameter and contain densely packed myofibrils, which result in powerful contractions. Slow fibers are smaller in diameter, produce smaller force, and are capable of contraction over extended periods, as they do not fatigue as quickly as fast fibers. This is largely due to an increased oxygen supply that allows contraction to continue.

The effect of aging on skeletal muscles is dependent on the muscle fiber types. With age, type II fibers decrease in fiber number and size much more than type I fibers. This accounts for the observed results with age [1];

- A loss of muscle size
- A loss of maximum force
- No loss of endurance
- No reduction in fatigue resistance

Magnitude and spectral features of a recorded surface electromyogram (sEMG) signal can provide information about the strength of contraction and the fatigue state of the muscle. SEMG provides for non-invasive investigation of the neuromuscular behavior.

Earlier studies have revealed that during non-fatiguing contractions, the magnitude of the sEMG of an older patient is lower than that of a younger patient. This has been explained based on the reduction of the total number of muscle fibers or age-related atrophy and the reduction of the size of the remaining fibers [2]. Based on analysis of age-related changes to the muscles, it has been shown that older people (over 60 years old) have around half the numbers of motor units in the biceps muscles as young people (under 60 years old) [3].

In this work, it is expected that these changes with age will be reflected in the magnitude characteristics of the sEMG signal. In addition, it is expected that the signal spectrum will shift to lower values as the number of fast fibers is reduced [4]. This spectral shift will be characterized by the median frequency of the signal power spectrum.

In the work reported here, the magnitude and spectrum of the sEMG signal recorded from the bicep muscles of healthy young adults and elderly subjects is investigated. A sEMG model is used to simulate signals with varying ratios of slow and fast fiber types. The simulated signals and their corresponding fiber type ratios can provide information about the muscle fiber changes during the aging process.

Although preliminary in nature, this study shows that a physiologically accurate model, together with a set of experimentally recorded data, allows us to learn about the effects of aging on the neuromuscular system.

II. Experimental Methodology

A. Subjects

Eight female subjects with no history of neuromuscular disease or injury participated in this study. Only female subjects were studied, to eliminate variation due to gender. The subjects were divided into two groups;

1. Group 1: Younger - Four subjects; age 20-28 years
2. Group 2: Older – Four subjects; age 61-69 years

B. Experimental Protocol

Each subject was seated in a sturdy, adjustable chair with their feet placed firmly on the floor to reduce the activation of postural muscles. The dominant arm was placed on a table, with the upper arm resting on the surface in a

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K. A. Wheeler, D. K. Kumar, S. P. Arjunan and C. Kalra are with the School of Electrical and Computer Engineering at RMIT University, Melbourne Australia. (e-mail: kathwheeler@student.rmit.edu.au; Phone: +613 9925 5232).

H. Shimada is with the Department of Computer and Control Engineering, Oita National College of Technology, Oita City, Oita, Japan (hshimada@oita-ct.ac.jp.

horizontal position. The elbow was fixed at 90 degrees, with the fingers in line with a wall mounted force sensor. A cable extended from the sensor to a wrist strap to record the force exerted during isometric contraction. Refer to Fig 1.

Each subject contracted the bicep to their maximum effort and maintained this contraction as long as possible [5]. Resisted by the wrist strap, this effort resulted in an isometric contraction. The output from the force sensor was shown to the participants, to encourage them to maintain the maximum force for as long as possible.

C. sEMG recording

During the contractions, both the sEMG and the force outputs were measured. To record the sEMG, the skin above the biceps brachii was cleaned and lightly abraded with alcohol wipes. Delsys differential surface electrodes were affixed to the prepared skin. The electrodes have two bipolar silver (99.9%) contacts (dimensions 10 mm x 1 mm) at a fixed inter-electrode distance of 10 mm [6]. The electrodes were placed on the line between the anticubital fossa and the acromion process, at 1/3rd distance from the anticubital fossa [7]. The Delsys (Boston, MA, USA) EMG acquisition system used has a fixed bandpass filter range of 20-450 Hz and was set to a sampling rate of 1000 samples/second.

The force output is measured directly by the force sensor.

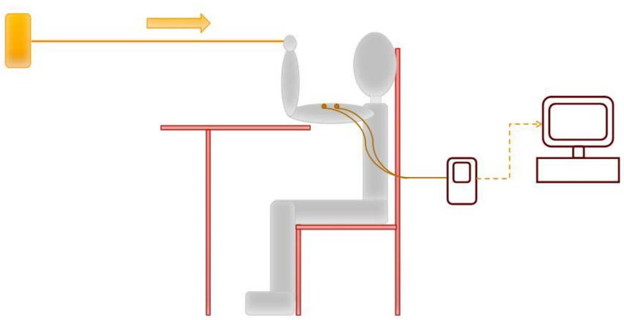

Fig 1. The subjects were seated with their elbow at 90 degrees and the fingers in line with a wall-mounted force sensor to record the strength of the isometric contraction. sEMG data was acquired by a Delsys device that relayed the data wirelessly to a desktop PC.

D. sEMG Data Analysis

For the work reported here, data from non-fatiguing muscle contractions was required. The first 5-10 seconds of data, where a stable force was observed, were extracted from each data set. To compare signals between the subject groups, two features of the data were calculated; the root mean square (RMS) and the median frequency (MNF).

The RMS of a sEMG signal represents the magnitude and in the non-fatigued state, is associated with the force exerted by the muscle [8].

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}}$$

The MNF is the frequency at which the signal spectrum is divided into two regions with equal amplitude.

$$\sum_{j=1}^{MDF} P_j = \sum_{j=MDF}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j$$

III. Simulation Methodology

A bicep muscle model populated with lifelike parameter values (Table I) and with particular emphasis on the differences in motor unit types has been implemented by the authors. The model parameters and variables are fully detailed in [9, 10].

The model is based on earlier work by Rosenfalck [11] and Merletti [12], and simulates the sEMG signal of a whole muscle with multiple MUs. This implementation provides distinct values for the parameters of fast and slow twitch muscle fibers. MU firing frequency and conduction velocity are dependent on the MU type. This allows us to study the age-related changes in the neuromuscular physiology.

The described model was firstly simulated to generate sEMG signals representing a young, healthy adult (in this case, the 20-28 year old age group). For this case, a population of 110 motor units with a fast fiber ratio of 0.45 was used [13]. The total number of units and the ratio of fast fibers were then altered to simulate the older subject group. The variations made are detailed in the results section.

TABLE I: BICEP MODEL SIMULATION PARAMETERS

Parameter	Value for biceps brachii simulation
Number of motor units (MU)	110
Conduction velocity (fast fibres) [14]	4.9 ± 0.3 m/s
Conduction velocity (slow fibres)	3.9 ± 0.3 m/s
Muscle fiber diameter [8]	25 µm
Depth of MU from surface [15]	35 mm ± 2 mm
Duration of AP along fiber [16]	16 mm
Cutaneous tissue [15]	Single, isotropic, 3-mm layer
Muscle half-fiber length [14]	65 mm

IV. Research Objectives

With a set of experimental data from the bicep contractions of older and younger subjects, and an sEMG model capable of simulating different fiber types and different ratios of fast and slow fibers – this work endeavors to determine the influence of fiber numbers and fiber types on the sEMG signal and determine if such modeling studies can reveal information about the changes in muscle physiology with age. To reduce the impact of other factors such as gender [17], all subjects were females.

V. Results

A. Experimental studies

The first 5-10 seconds of data from each subject was extracted and the RMS and MNF values calculated. The mean and standard deviation of these features was found across all subjects and is included in Table 2.

To compare date from experimental and simulated results, a ratio of feature values was used. From the experimental results in Table 1, it is calculated that the ratio of RMS in older subjects to the RMS in younger subjects is 0.569. The ratio of MNF in older to younger subjects is 0.9033. It is evident that both of these features reduce with age, particularly the magnitude features.

TABLE 2
MAGNITUDE AND SPECTRAL AVERAGES FOR OLDER AND YOUNGER SUBJECTS

	Younger	Older
RMS	0.172 mV ± 0.132	0.098 mV ± 0.089
MNF	70.05 Hz ± 21.00	63.28 Hz ± 7.35

B. *Simulation studies*

In young, healthy human subjects, the biceps brachii has a fast fiber ratio (FFR) of approximately 0.45 [13]. The total number of motor units (nMU) is simulated here as 110, meaning that (varying randomly for each subject) there will be around 50 fast fiber MUs and 60 slow fiber MUs in each simulation.

To investigate the effects of varying these parameter values, data for ten subjects has been simulated for the following experimental cases;

1. Healthy young adult (nMU = 110, FFR = 0.45)
2. Less total muscle fibers (nMU = 80, FFR = 0.45)
3. Less fast fibers (nMU = 110, FFR = 0.3)
4. No fast fibers (nMU = 110, FFR = 0.0)
5. Both less muscle fibers and a lower FFR (nMU = 80, FFR = 0.24)

The results of these simulations (averaged across all ten subjects in each case) are shown in Fig. 2 and Fig. 3.

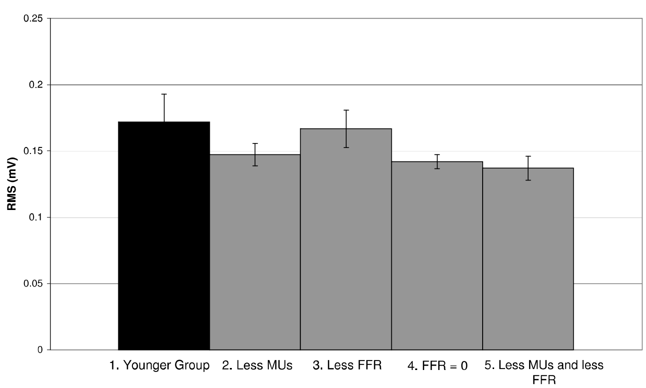

Fig 2. The average RMS across 10 subjects for five simulation studies. The black column shows the younger age group. The grey columns show the results of the alternate simulations describes in points 2-5 above.

Following these experiments, a series of simulations were conducted until the spectral values were close to those found for the experimental subjects (Table 1).

The ratio of average MNF of older subjects to average MNF of younger subjects in the experimental results is 63.28/70.05 = 0.910. To achieve the same kind of ratio in the simulated data sets, the following parameters were used;

nMU = 55
FFR = 0.11

A simulation with these parameters gives a MNF ratio of 0.917. These parameters, in comparison to those used to model a younger subject, would correspond to an approximate loss of 44 fast fiber MUs and 10 slow fiber MUs.

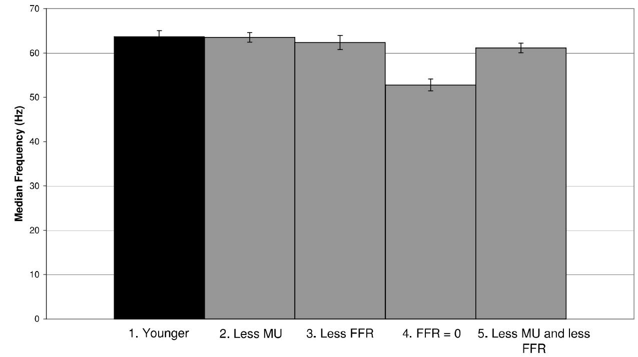

Fig 3. The average MNF across 10 subjects for five simulation studies. The black column shows the younger age group. The grey columns show the results of the alternate simulations describes in points 2-5 above.

This data set gives a RMS ratio of 0.683, which is higher than the 0.569 ratio calculated from the experimental data. The comparisons of RMS and MNF from this simulated data set are illustrated in Fig. 4.

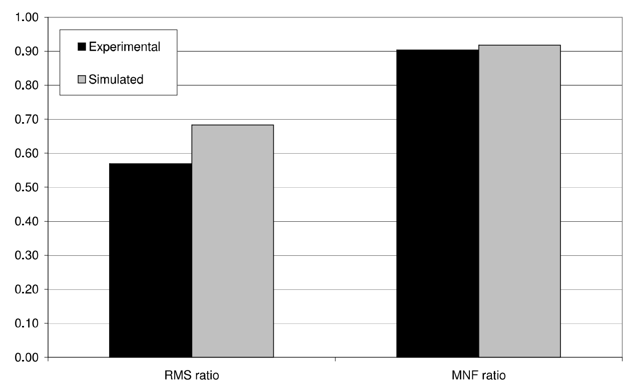

Fig 4. The average RMS and average MNF from experimental and simulated studies, where nMU = 55 and FFR = 0.11.

VI. DISCUSSION

This study has observed age related reduction in the median frequency of the sEMG signal, which is consistent with literature [3]. From Fig. 3, it is evident that in the simulation study, the number of MUs does not have a significant impact on the spectrum of sEMG. When the nMU is changed from 110 to 80, there is no change in MNF.

Fig.3 also shows that when the ratio of fast fibers is changed, there is an observable change in median frequency. A reduction in FFR from 0.45 to 0.3 and 0.24 shows a corresponding reduction in MNF (Fig. 3). When the FFR is reduced to 0.0, there is a large drop in MNF.

In the scenario described and shown in Fig. 4, the MNF ratio of the simulated results is comparable to that found experimentally. The change in FFR from 0.45 to 0.11 has been able to wholly account for the spectral shifts observed.

The experimental results also indicate a significant age-related reduction in the RMS of the signal. The experimental results show a drop in RMS from 0.172 mV to 0.098 mV, giving an older to younger ratio of 0.569. The simulation studies demonstrate that there are number of factors that may contribute towards this change.

From Fig. 2 it can be seen that for the simulated results, a change in the FFR with steady MU numbers does not affect the RMS. A drop in the total number of fibers (nMU), does reduce the RMS, where the larger the reduction in nMU, the larger the drop in RMS. In the case where there are still 110 motor units, but there are no fast fibers, a reduced RMS is also seen. This can be accounted for by the fact that the fast fiber motor units are larger in size and produce larger amplitude action potentials.

In the scenario illustrated in Fig. 4, the reduction in nMU from 110 to 55, combined with the influence of a reduction in fast fiber numbers, resulted in a RMS ratio (older to younger) of 0.683. While this is a clear change between the older and younger subjects, it is not as much change as that observed experimentally. This data is shown numerically in Table 2.

Literature suggests that the reduction in RMS (and corresponding muscle force) observed in older patients is due to a drop in the total number of fibers and the size of these remaining fibers.

TABLE 2
MAGNITUDE (MV) CHANGES OBSERVED BETWEEN YOUNGER AND OLDER SUBJECTS IN EXPERIMENTAL AND SIMULATED STUDIES.

	Younger	Older	Ratio
Experiment	0.172	0.098	0.569
Simulation	0.172	0.117	0.683

It can be posited that the reduction in RMS observed experimentally but not seen in the simulation can be attributed to age related reduction in muscle fiber size.

In future works, these experiments should be conducted with a larger number of subjects to achieve greater statistical significance and distinction of results data. In addition, this work could be increased to investigate observed changes in the lower limbs, where loss of power with age has been shown to be even more significant [18].

VII. CONCLUSION

The spectral shift in sEMG signals observed in the bicep contractions of older subjects can be wholly accounted for in simulation studies by a reduction in the ratio of fast fibers to slow fibers. The reduction in signal magnitude also observed can be partially accounted for in bicep modeling by the known reduction in the total number of muscle fires with age. The remaining reduction in sEMG magnitude is thought to be due to an overall reduction in muscle fiber size.

For the eight female subjects studied in this work, a reduction in average sEMG RMS of 0.07 mV and a reduction in average sEMG MNF of 6.77 Hz were observed.

A sEMG model with lifelike simulation parameters was used to simulate sEMG signals from younger and older subjects. The spectral changes in the simulated data were shown to match the experimental data when the ratio of fast fibers was reduced from 0.45 to 0.11 and the total number of fibers was halved from 110 to 55. These same simulating conditions were shown to largely account for the observed drop in signal RMS.

This work demonstrates that an accurate sEMG model can be used to infer information about neuromuscular structure and function, particularly with regard to changes that occur.

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