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Differences in activation patterns between eccentric and concentric muscle contractions

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Abstract. The purpose of the article is is to compare the frequency of the power spectrum and the amplitude of the surface electromyographic (EMG) signal of the biceps during eccentric and concentric contractions of different intensity to indirectly evaluate possible differences in movement recruitment. Materials and methods: the bioelectric activity of the biceps was studied during the flexion of the forearm with a bar. Eight trained men and one woman performed the exercise in eccentric and concentric modes of muscle contraction with an intensity of 100%, 80%, 50% and 25% of the maximum voluntary contractions. Results: analysis of the surface electromyogram showed that the average frequency was higher for the eccentric, compared with the concentric contractions of the biceps for the studied intensities. Conclusion: the data obtained suggest that a higher average frequency in the eccentric mode of contraction indicates a higher activity of rapidly contracting motor units compared to the concentric mode.

Key words - electromyography, EMG, fast fibers, spectral analysis, average frequency.

I. Introduction

The development and improvement of training methods in speed-strength sports are inextricably linked with obtaining and using objective information about physiological processes that occur in the neuromuscular apparatus under the influence of various modes of muscle contractions. The search for the most effective mode or the most effective combination of various muscle modes used in the athlete’s strength training has always been in the center of attention of experts in sports science. The mode of movement, that is, the conditions in which a person's motor activity is carried out, is determined by a change in length and tension. In resistance training, the moment of muscle strength is greater than the moment of opposite force, i.e., the muscle, contracting, overcomes resistance and shortens. This mode is called concentric. The eccentric mode of muscle performance is determined by the fact that the moment of applied muscle effort is less than the moment of opposite force, that is, the latter “stretches” the muscle, leading to its lengthening. Therefore, lesser neural activity is required in the eccentric mode compared to the concentric one if the same external load applied both when rising and lowering an object. Muscle activity, as measured by surface electromyography (EMG), during the eccentric phase of movement, is usually lower [1], but the muscle produces significantly greater strength than a muscle that contracts isometrically or concentrically, all other things being equal. A single sarcomere under tension develops a force exceeding purely isometric forces at an optimal length by an average of 20-50% [2, 3]. The titin protein, spanning half the sarcomere from the Z-line to the M-line, makes a significant contribution to active stress when the muscle lengthens, resisting external stress. In the I-region, titin acts as a molecular spring, which increases its stiffness by binding calcium and shortening the free length of the spring by attaching the proximal region of titin to actin myofilaments [4–10]. This phenomenon causes a significant increase in strength observed in actively (compared to passively) stretched myofibrils and single sarcomeres [3, 11].

Active lengthening is a difficult task, as it implies a decrease in the muscle traction force, despite the greater production of mechanical force by the working fibers. A compromise between the reduced strength of the whole muscle and the increased production of strength by each active muscle fiber is possible due to the activation of a smaller total number of fibers and / or performance of motor units with a lower frequency of discharge of action potentials. A question arises - which fibers are active in the eccentric phase. In studies using intramuscular needle electromyography, it was found that high-threshold motor units are selectively recruited during eccentric contractions [12–15] with a discharge rate of action potentials corresponding to approximately 20% of their maximum tetanic tension [13]. The change in the pattern of recruitment of muscle fibers is explained by the fact that the nervous system plans eccentric actions differently from concentric ones. The magnitude of neuromuscular activation is regulated by central descending pathway and sensory reflex pathway. It is assumed that with eccentric contractions, autogenic inhibition of alpha-motor neurons by Renshaw inhibitory interneurons increases significantly. At the same time, Ib afferent nerve fibers from Golgi tendon organs induce increased presynaptic inhibition of Ia afferent fibers of muscle spindles. Afferents Ia are known to have the lowest excitability threshold among all nerve fibers and activate small motor neurons. This suggests that during active lengthening, slow motor units become less excitable, which is experimentally confirmed by a decrease in the amplitude of the monosynaptic H-reflex of the elongating muscle, which includes a pool of motor neurons with a small soma size and innervating slowly contracting muscle fibers [16 - 20]. Disabling the background activity of slow fibers is also advisable from the point of view that their reduction would make elongation more difficult due to the long relaxation time. And the recruitment of rapidly contracting fibers having a short relaxation time is most appropriate for better control of fast movements [13]

Selective recruitment of high-threshold fast muscle fibers is also confirmed by studies using biopsy methods, where a significant increase in the cross section of fast fibers in response to an eccentric load was found [21 - 29].

The frequency content of the electromyogram was also used to indirectly assess the recruitment of motor units during various contraction modes [30, 31]. The relationship between frequency content and recruitment is based on the fact that the average frequency reflects the speed of the pulses of active motor units [32]. An increase in the average frequency indicates the involvement of rapidly contracting motor units, since they have a higher pulse rate [33]. Therefore, if more fast fibers are recruited during the eccentric phase, then the average frequency of the myogram will be higher with eccentric contractions than concentric ones with a given intensity.

Several studies using frequency analysis of surface EMG have not confirmed greater recruitment of fast motor units with eccentric contractions compared to concentric ones when working with low [34] and maximum intensity [19, 35]. But no solid conclusions can be drawn from the data presented. Firstly, these studies used an isokinetic dynamometer, where the maximum concentric and eccentric muscle strengths were measured as the maximum moments of voluntary extension of the limb, without providing data on the intensity of muscle contraction, expressed as a percentage of 1 repeated maximum (% 1MP). However, it is known that the average maximum voluntary eccentric force or torque exceeds the isometric moment by 1.2–1.4 times, while individual participants demonstrate an eccentric force 1.5–1.8 times greater than the maximum voluntary isometric contractions [36 - 39]. When testing in artificial conditions, participants rarely use their maximum capabilities to achieve maximum eccentric force [40]. Secondly, the samples in the above studies are untrained people and the inability to achieve the maximum eccentric moment is explained by an innate inhibitory mechanism that limits the recruitment and / or discharge rate of motor units, which is not observed in highly qualified subjects [40]. Indeed, in a study by P. Komi et al. (2000) the eccentric maximum force did not exceed the isometric force [35]. Thirdly, comparisons of maximum eccentric and isometric forces are usually performed at the same angles in the joint. However, the same joint angles guarantee only the same lengths of the muscle-tendon complex, and not the same lengths of muscle bundles, which are the length of the contractile elements. With the start of rotation of the joint in an eccentric mode, the preliminary tension of the muscle-tendon complex can lead to the initial shortening of the muscle bundle. This means that the eccentric contraction from rest contains the initial concentric phase, regardless of the lengthening of the muscle-tendon complex [41]. The EMG power spectrum obtained using surface electrodes may not reflect the actual speed of the pulses. Selective recruitment of fast fibers during eccentric contraction could be masked by increased synchronization of motor units, thereby lowering the average frequency. Thus, it is known that the frequency of synchronous discharges is 50% higher during eccentric contractions compared to concentric ones [42]. Research by P. Aagaard et al. (2000) may serve as some confirmation of this idea, since the reduced average frequency at the maximum eccentric contractions was accompanied by very large EMG spikes separated by almost silent interspike periods [19].

Due to the inconsistency of the previous data, the aim of this study was to compare the frequency of the power spectrum and the amplitude of the surface EMG signal of the biceps during eccentric and concentric contractions of different intensity to indirectly evaluate possible differences in the recruitment of motor units.

II. Materials and methods

In the work performance laboratory of the Research Institute of Sports and Sports Medicine on the basis of the Russian State University of Physical Education, Sport, Youth and Tourism (SCOLIFK), the bioelectric activity of the biceps during the exercise was studied. Eight healthy, trained men and one woman participated in the study, each of the participants provided a written informed consent. The age, body length and body weight of the participants were 29 ± 6.2 years, 179.4 ± 4.7 m and 91.4 ± 11.7 kg, respectively. Subjects performed a maximum voluntary contraction (100% MVC) of the forearm flexors, followed by contractions of submaximal intensity (80%, 50% and 25%). This sequence was performed separately in concentric and in eccentric modes in a randomized order. The eccentric maximum corresponded to 140% of the concentric maximum. This percentage was chosen according to the experimental data in the difference between the maximum eccentric and concentric dynamic forces [43]. Five contractions were performed for each contraction mode and for each intensity with 2-minute intervals. The temporal parameters of exercise performance were determined by the duration of the manifestation of the active phases of the bioelectric activity of the studied muscle groups. The exercise was carried out on command with fixing the initial and final posture, which was reflected in the EMG pattern, which determined the time limits of the bioelectric activity of the studied muscles. Skeletal muscle biopotentials were recorded using the 16-channel electromyograph (ME6000 Biomonitor System, Mega Electronics, Finland). The obtained data were processed in a special MegaWin computer program. The EMG signal was recorded using Ag / AgCl electrodes (diameter 50 mm). The sampling frequency of the signal was 1000 Hz. The electrodes were located in the middle of the muscle belly parallel to the longitudinal axis of the muscle fibers with an interelectrode distance of 20 mm. The following characteristics of the electromyograms were used to analyze the oscillographic signals: the moving RMS value (RMS) and the average frequency (MPF), which was determined using the fast Fourier transform algorithm (FFT) with an array of 4096 signal points with the Hann window function. Analysis of variance performed.

III. Results and discussion

To analyze the electrical activity of the biceps, the root mean square value (RMS) was found. As expected, the value of RMS, as an indicator of the average power of the EMG signal, increased with increasing resistance during each contraction mode, which indicates the involvement of an increasing number of muscle fibers. The maximum eccentric contractions showed a large amplitude, which is explained either by the involvement of additional motor units due to the predominance of external forces or an increase in the synchronization of motor units, leading to the simultaneous tension of all active muscle fibers (Fig. 1).

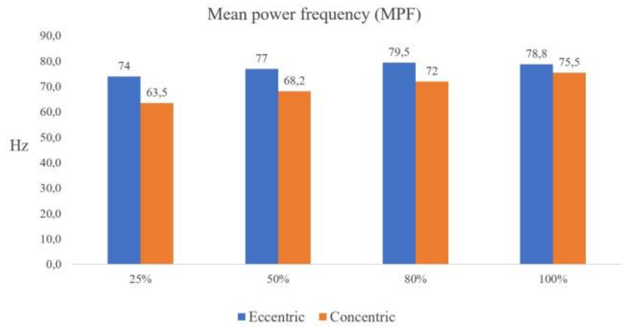

Fig. 1. The dynamics of the RMS values of the electromyogram of the biceps with an increase in intensity from 25% to 100% MVC

The average frequency also increased with increasing intensity of contraction for the concentric mode, indicating the gradual involvement of fast fibers. It is noteworthy that the average frequency did not increase in proportion to the increase in the intensity of contraction during the eccentric mode and even slightly decreased in the range of 80% to 100% of the MVC (Fig. 2, 3).

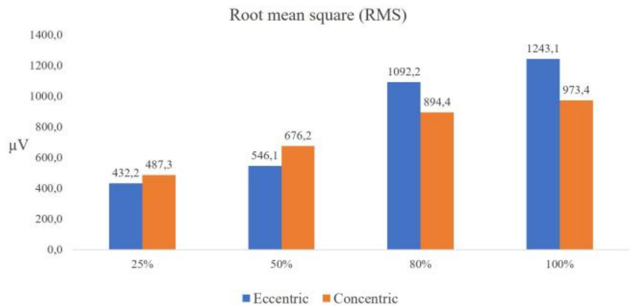

Fig. 2. Dynamics of the average frequency (MPF) of the electromyogram of the biceps of with an increase in intensity from 25% to 100% MVC

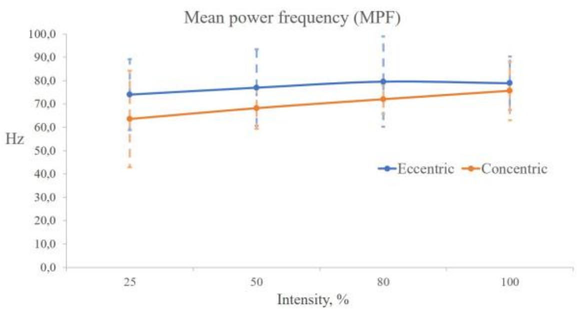

Fig. 3 Dynamics of the average frequency (MPF) of the electromyogram of the biceps with an increase in intensity from 25% to 100% MVC. Values are given as mean ± σ × t (0,95, 9)

Given that the average frequency strongly depends on the degree of synchronization of motor units, it is possible that the observed decrease in the average frequency reflects a more synchronous pattern of motor neurons at maximum intensities. The higher the degree of synchronization, the greater the amplitude of the action potentials and the lower their frequency. The results of the study showed significantly higher values of the average frequency of the EMG signal in an eccentric mode compared to the concentric mode, which indicates a greater activity of rapidly contracting motor units.

IV. Conclusion

Electromyography is an objective method of obtaining information about physiological processes occurring in the neuromuscular apparatus, which allows studying not only the activity of working muscles but also their interaction. So, the temporal evolution of the average frequency of the power density spectrum can provide information related to the recruitment of motor units and the conductivity of nerve fibers of motor units. Based on the results obtained and theoretical justification, we determined a number of provisions characterizing bioelectric activity during various contraction modes with various resistance:

With the increase in resistance, the signal amplitude increases for both modes of muscle contraction.

The maximum eccentric contractions show a large amplitude, which is explained either by the involvement of additional motor units due to the predominance of external forces or an increase in the synchronization of motor units, leading to the simultaneous tension of all active muscle fibers.

A higher average frequency under eccentric contractions is consistent with the theory that rapidly contracting motor units are selectively recruited during eccentric contractions.

The preferred use of fast fibers and the improvement of their contractile activity under eccentric contractions of high intensity can give a competitive advantage for the development of strength indicators and hypertrophy of muscle tissue. The energy costs of eccentric contractions are unusually low, and the magnitude of the force produced is unusually high. As a result, muscles subjected to prolonged eccentric training respond with a significant increase in strength and size. Most researchers attribute the advantage of the eccentric mode mainly to the higher torque (ie, mechanical load) achieved during the exercise, determining the mechanical factor as one of the most important training variables for the development of muscle hypertrophy [44]. One of the potential mechanisms of a noticeable increase in muscle strength after high-intensity eccentric strength training may be a decrease in both the autogenic inhibition of alpha-motor neuron by the Renshaw inhibitory interneuron and a decrease in the inhibitory effect from Golgi organs in the muscle-tendon complex [45].

Further study of the models of the neuromuscular system will provide a holistic view of the adaptive changes in the central and peripheral parts of the neuromotor system.

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