AGGREGATED BIOELECTRICAL RESPONSES OF THE MUSCLE MECHANORECEPTORS TO VIBRATIONS OF VARIOUS PARAMETERS

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Investigations have shown [3, 4, 6, 7] that the muscle mechanoreceptors can detect vibration besides performing their proprioceptive function. The prolonged action of vibration on the human body leads to the development of vibration disease, the pathogenesis of which, in the modern view, rests on a reflex mechanism [1]. The study of the behavior of vibroreceptors in response to stimulation by vibrations of various parameters is thus of considerable interest. Since little attention has been paid to this problem in the literature, investigations in this direction were justified.

EXPERIMENTAL METHOD

Experiments were carried out on 29 cats anesthetized with nembutal (50 mg/kg intraperitoneally). The lateral head of the gastrocnemius muscle and the nerves to it were isolated. The hind limb was fixed at two points. Investigations were carried out both on t[illegible] [illegible]act muscle and after removal of its efferent nerve supply.

Vibrostimulation was [illegible] to the muscle by means of a specially constructed electrodynamic vibrator, to the moveable head of which a plexiglas rod was f[illegible]d. The contact surface of this rod had an area of 47 mm². The vibr[illegible]r was set in motion by pre[illegible]arily amplified rectangular (from a type ISE-01 apparatus) or sinusoidal (Z[illegible]-10) pulses of current. The am[illegible]litudes of vibration were calibrated by means of a type VR-1 vibrograp[illegible].

If the vibrator we[illegible]e supplied with rectangular pulse[illegible], the acceleration of the vibration at all frequencies had the consta[illegible] value of 2.85 ± 0.049 g when signals of a voltage of 50 V and duration 2 msec were fed into a vacuum-tube [illegible]mplifier. The accelerat[illegible]n was calculated by two different methods, both of which ultimately yielded similar r[illegible]sults. The amplitude of vibration diminished with an increase in the frequency from 1 to 150 cps from 1[illegible]9 [illegible]o 33 μ.

If pulses of sinusoidal currents were supplied to the vi[illegible]rator, the vibration also was sinusoidal in shape. With a frequency [illegible]f 30 cps, the amplitude* ranged from 0 to 640 μ, at 50 cps – from 0 to 415 μ, at 100 cps – from 0 to 265 μ, and at 150 cps – from 0 to 20[illegible]. The acceleration was calculated from the formula:

$$Ig = \frac{A \cdot 4\pi^2 \cdot f^2}{9810}$$

where Ig is the acceleration, A the amplit[illegible] of the vibration (in mm), and f the frequency.

During the experiment the a[illegible] [illegible]s kept in a scr[illegible]e[illegible] chamber. The index of the synchronized responses of the muscle mechanor[illegible]ptors during the [illegible] [illegible]he vibration was the bioelectrical discharges recorded from the gastrocnemius ner[illegible]. Th[illegible] [illegible] d[illegible]tected by platinum electrodes on which the gastrocnemius nerve was placed, connecte[illegible] [illegible] [illegible]epeater to a type UBP1-01 ac amplifier and a type MPO-2 loop oscillograph. In every [illegible] unless specially mentioned, the recordings were made on film moving at a speed of 250 mm/sec. To [illegible] [illegible]g of [illegible]e nerve, it was immersed in mineral oil.

* For sinusoidal vibrations double amplitudes are given in ever[illegible]

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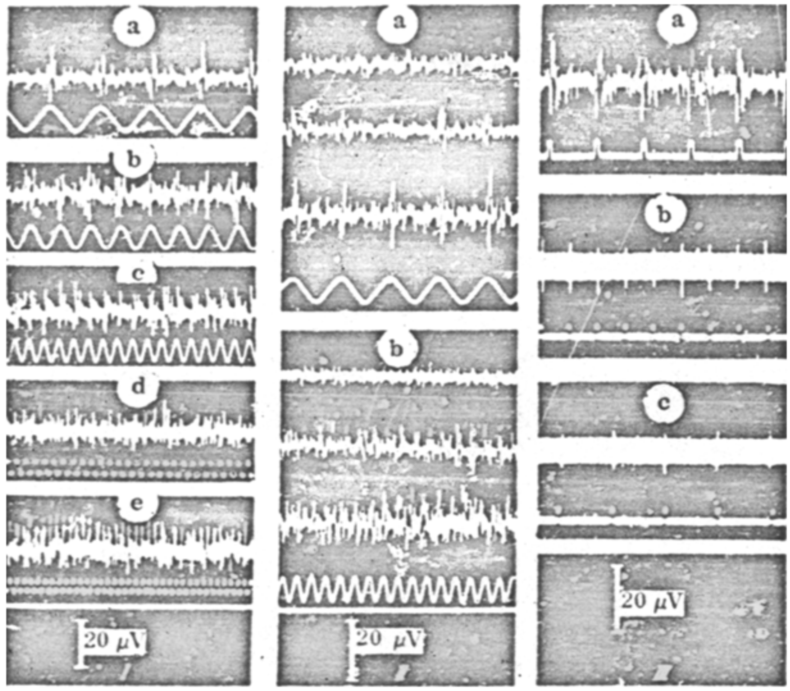

Fig. 1. Rhythmic activity of the muscle mechanoreceptors during the action of vibrations of different parameters. I: a-e) Vibrostimulation with frequencies of 30, 50, 100, 150, and 200 cps. II: a) Frequency 30 cps (top oscillogram – amplitude 200 μ, middle – 440 μ, bottom – 640 μ); b) frequency 100 cps (top oscillogram – amplitude 100 μ, middle – 140 μ, bottom – 265 μ). III Stimulation by nonsinusoidal vibration with an amplitude of 100 μ and acceleration 2.8 g: a) 30 cps; b) 10 cps; c) 5 cps (in b and c the film winding speed was 50 mm/sec). The frequency of oscillations of the vibrator is indicated below the oscillogram.

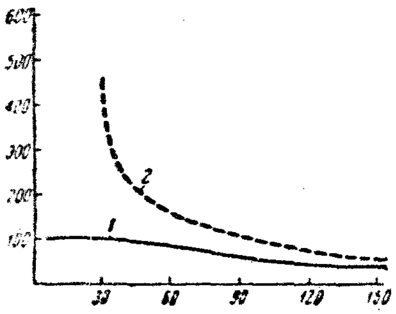

Fig. 2. Relationship between threshold amplitudes and frequency of sinusoidal and nonsinusoidal vibration. 1) Nonsinusoidal vibration with an acceleration of 2.8 g; 2) sinusoidal vibration. Along the axis of ordinates – amplitude (in μ); along the axis of abscissas – frequency (in cps).

EXPERIMENTAL RESULTS

The discharges in the muscle mechanoreceptors generated in response to the action of vibration were grouped into afferent volleys which corresponded to the frequency of stimulation. The functional state of the mechanoreceptors was judged from the spontaneous activity of the gastrocnemius nerve. If the background activity was less than 16 μV, indicating a low level of excitation of the receptor apparatus of the muscle, the maximal reproducible frequency was 60 cps. A further increase in the frequency of stimulation desynchronized the rhythmic responses. With a background activity higher than 16 μV, the maximal reproducible frequency reached 150-200 cps (Fig. 1, I, a-e).

The relationship between the character of the synchronized responses and the amplitudes of the sinusoidal vibrations was also investigated. When the frequency of stimulation was 100 cps, synchronized discharges appeared when the amplitude was 140 μ (Fig. 1, II, b, middle oscillogram) and their height increased with an increase in the amplitude to 265 μ (bottom oscillogram). Lower amplitudes were ineffective. The same pattern was observed in the response to vibro-

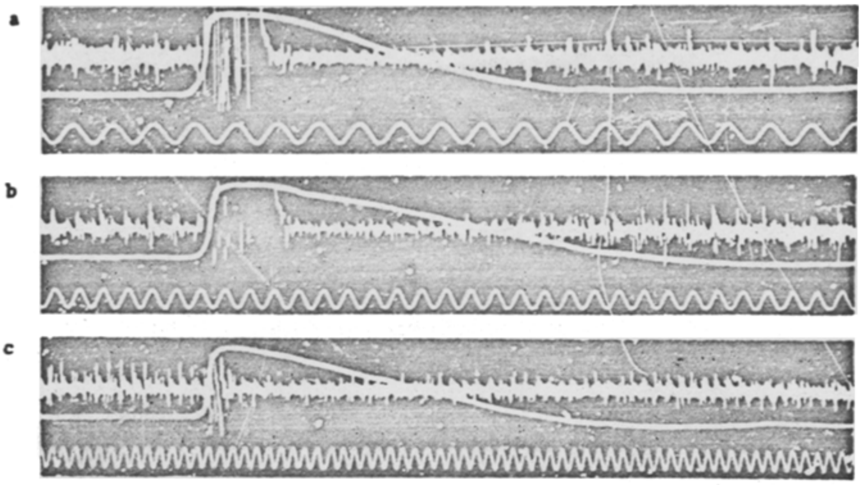

Fig. 3. Reception of vibration in various phases of contractile activity of the gastrocnemius muscle. The maximal deviation of the continuous line upward corresponds to maximal contraction. Frequency of vibrations: a) 30 cps; b) 50 cps; c) 100 cps. (c). Calibration 20 μV.

stimulation with a frequency of 30 cps, but the synchronized discharges in this case appeared only when the amplitude was 440 μ or higher (Fig. 1, II, a). With a decrease in the frequency of vibration to 20 cps, even an amplitude of 440 μ no longer evoked rhythmic responses.

To discover the cause of the increase in the threshold amplitudes of the sinusoidal vibrations in the low-frequency range, nonsinusoidal vibration with a constant acceleration of 2.85 g was used for stimulation. Vibration of the gastrocnemius muscle with a frequency of 30 cps and an amplitude of 100 μ led to the appearance of synchronized responses corresponding to the frequency of mechanical stimulation (Fig. 1, III, a). Furthermore, with a decrease in the rhythm of stimulation to 1 cps, the muscle continued to respond regularly to each beat of the vibrator (Fig. 1, III, b, c).

It follows from these results that sinusoidal vibration with a frequency of 30 cps and an amplitude of 200 μ does not evoke synchronized discharges, whereas nonsinusoidal vibration with the same parameters of frequency and amplitude is accompanied by distinct rhythmic responses. Since sinusoidal vibration of these parameters corresponds to an acceleration of only 0.36 g, it may be concluded that with an increase in its value the perception of vibration by the muscle mechanoreceptors is facilitated.

The relationship between the threshold amplitude and frequency of the vibration stimulus is illustrated graphically in Fig. 2. The marked increase in the threshold amplitude of the sinusoidal vibrations in the low-frequency range is particularly noticeable, whereas during the action of nonsinusoidal vibrations the thresholds differentials were much smaller. Since in the case of sinusoidal vibrations, acceleration is a function of the square of the frequency and amplitude, compensation of the diminishing accelerations required an increase in the amplitude of vibration.

Hence, the parameters of vibration are a quantitative measure of the stimulation acting on the receptor apparatus of the muscle. However, the transformation of mechanical energy into afferent bioelectrical impulses is largely dependent on the functional state of the mechanoreceptors. It is well known that with a change in the length of the skeletal muscles, the excitability of the intrafusal fibers also changes. It was therefore interesting to study the reception of vibration by the muscle both when contracted and when stretched.

As may be seen in Fig. 3, the mechanoreceptors of the relaxed muscle readily followed the rhythm of the mechanical vibrations. During active contraction, a series of high-voltage action potentials was recorded, against the background of which no rhythmic responses could be detected. After the high-voltage discharge had ceased, when the muscle was still in a contracted state, synchronized responses were absent and reappeared only with the development of full relaxation.

Stretching the muscle, on the other hand, increased the ability of the mechanoreceptors to detect vibration, especially when the background activity was below 16 μV. If the background activity in the gastrocnemius nerve was particularly high (over 20 μV), not only did stretching not cause a significant increase in the potentials of the aggregated synchronized responses, but a tendency was actually observed for their depression at a frequency of stimulation of 150-200 cps. Because of the specialized anatomical structure of the spindles the excitability of most of them diminished during contraction of the muscle, and increased during stretching [2, 8]. Because of this, the disappearance of the synchronized responses during contraction of the gastrocnemius muscle and their intensification during stretching can easily be explained.

All the results described above were obtained during the action of vibration on the muscle with its afferent nerve supply intact. In a series of experiments the gastrocnemius nerve was divided. De-efferentation lowered the maximal reproducible frequency from 150-200 to 50-60 cps but did not abolish the responses in the low-frequency range. The frequency of reproduction could be increased to the initial level by stretching the muscle with a force of 200-300 g. The decrease in the maximal reproducible frequency after division of the nerve was associated with removal of the γ-activating influence on the muscle spindles, as a result of which their level of excitability fell [4, 5]. Stretching the muscle increased the excitability of the mechanoreceptors to its initial level.

The results show that the mechanoreceptors of the relaxed muscle receive vibration with frequency characteristics between 1 and 150-200 cps. At frequencies below 30 cps vibration is received only if the acceleration exceeds 0.36 g, and with an increase in acceleration the reception of vibration is facilitated. Increase in amplitudes of vibration also strengthen the aggregated synchronized discharges, for in this case more spindles are involved in the process of excitation. Stretching the gastrocnemius muscle increases the ability of the mechanoreceptors to respond to vibration, but during contraction of the muscle the reception of vibration is more difficult.

The amount of information reaching the central nervous system and, in particular, the structures at the segmental level during the action of vibration depends both on the parameters of vibration and on the functional state of the mechanoreceptors.

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