THE MEASUREMENT OF ADEQUATE SENSORY AND MOTOR STIMULATION IN MAN

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It was Lapicque who suggested the measure of excitability applicable to all excitable objects, which he called the "chronaxie." During the subsequent decades a wide range of investigations has been undertaken in various countries, some supporting, some criticizing and others extending the concept of chronaximetry. The last of these three subdivisions includes our own investigations. We have introduced the following amendments into the concept of the chronaxie.

1. The chronaxie is not lengthened during the relative refractory period of a nerve, as followed from Lapicque's theory, but on the contrary is shortened, with a considerable increase of the rheobase.

2. The cycle of recovery after each excitation is determined by the degree of mutual adequacy between the test stimulus and the functional condition of the biological substrate at the given moment. The recovery of excitability after excitation is characterized not by one single curve, but by a whole family of curves [3, 4, 6, 7]. Hence the concept of differential excitability arose.

3. Differential excitability shows itself as a selective reaction of cells to particular forms of natural or artificial stimulus in relation to the current functional state, and the more easily and clearly the resulting effect develops. Measurement of the energy of electrical stimuli and of stimuli adequate for the respective analyzers, applied to various objects, has shown [5, 6, 7] the presence of a minimum of threshold stimulating energy. This minimum, which has also been observed by other workers, does not correspond to the magnitude of the chronaxie and has an independent biological meaning. In order to determine the excitability by electrical stimuli and by stimuli adequate for the organs of the senses, and taking into consideration the minimum of stimulating energy, we measured in the first place the rheobase, and in the second place the threshold durations of the stimuli within the zone of the utilization time, i.e., at the level of 1.3 rheobases, within the zone of chronaxie, i.e., at the level of 2 rheobases, and at the level of 4 and 8-10 rheobases.

We know from the biophysical investigations of the excitability of different biological objects carried out by I. P. Shelkov [8], B. F. Verigo [1], Hoorweg [9], and others, that the curve of the relationship between strength of stimulation with an electric current and the time of its action is hyperbolic in character and may by expressed by the equation:

$$i = \frac{a}{t} + b,$$

where i is the threshold intensity of the current when in action for the time t; a and b are constants for a particular test-object and a given functional state.

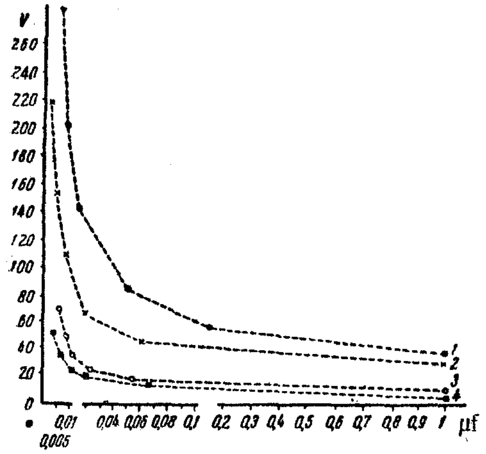

Fig. 1. Voltage–time curves. Along the axis of abscissas–capacity (in μ f) equivalent to duration of stimuli; along the axis of ordinates–threshold voltage of current; breaks in the axis of abscissas denote changes in the scale. 1) Thresholds for extensor digitorum communis; 2) threshold for flexor digitorum communis; 3) sensory thresholds in the extensor region; 4) sensory thresholds in the flexor region.

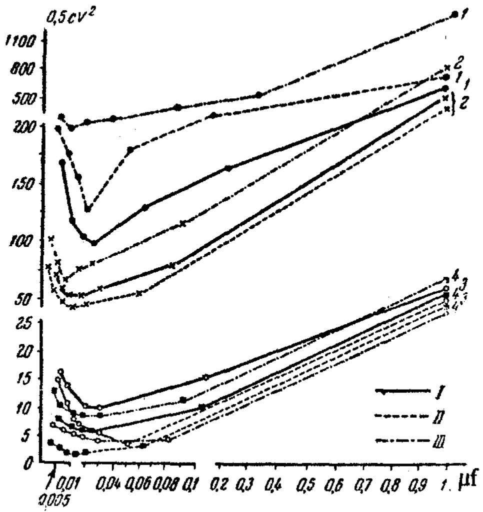

Fig. 2. Relationship between energy and duration of threshold stimuli. Along the axis of abscissas–capacity (in μ f) equivalent to duration of stimuli; along the axis of ordinates–energy of threshold stimuli–0.5 cV^2. I, II, III) results of testing of 3 different subjects. Notation for sensory and motor thresholds for flexor and extensor regions as in Fig. 1.

If a value of i is taken of twice the threshold value $i = 2b$, then,

$$i = \frac{a}{t} + b = 2b,$$

whence $2b = \frac{a}{t} + b$, or $2b - b = \frac{a}{t}$;

and consequently $b = \frac{a}{t}$.

From this equation the value of the second constant $a = bt$, and of the chronaxie–chr $= t = \frac{a}{b}$ is determined, which is usually done simultaneously from three zones of the strength–duration curve: 1) the zone of the utilization time at 1.3 rheobases, 2) the zone of relative adequacy with a minimum value of the threshold energy at 2-4 rheobases, and 3) the zone of the curve asymptotic to the axis of ordinates at 10-20 rheobases.

The object of the present investigation was to determine the laws of excitability: the strength–duration curve, taking into consideration the minimum value of the stimulating energy, i.e., measuring the relative thresholds of the extensor and flexor muscle groups of the upper limb in man, and their relationship to the excitability of the cutaneous receptor systems of the same area.

METHOD

In order to solve this problem we made use of the ordinary condenser chronaximetry with a Bourguignon shunt. The duration of the discharge of the condenser, of capacity 1 μf, was 4 msec, that of the 0.1 μf condenser was 0.4 msec and so on. Silver chloride electrodes were used. The method of stimulation was pseudo-unipolar. An indifferent electrode, 54 cm^2 in area, to the forearm, in the region of the motor points of the flexor and extensor digitorum communis, where the sensory and motor thresholds were determined. By changing the duration of the stimuli, we determined the threshold voltage of the current necessary to evoke a sensory and motor reaction, and we then constructed voltage–time curves and also curves showing the relationship between the energy of the threshold stimuli and their duration and intensity. The energy of the threshold stimuli E was calculated from the equation:

$$E = 0.5 cV^2,$$

where c is the capacity of the condenser and V the voltage of the current by which it is charged.

The investigations were carried out on three healthy human subjects: 2 men–V. A., aged 26 years and E. G., aged 28 years, and one woman–T. K., aged 47 years. From 10 to 15 observations were made on each subject. The results obtained were treated statistically. We determined the arithmetic mean threshold value for stimuli of a given duration, and also the magnitude of the coefficient of variation.

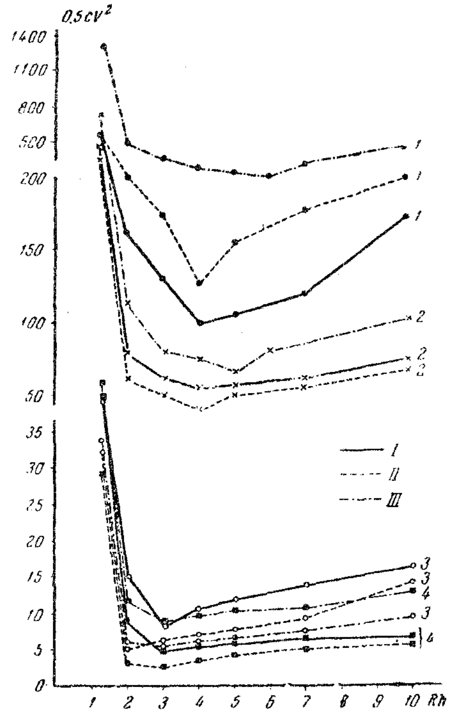

Fig. 3. Relationship between energy and intensity of subthreshold stimuli. I, II, III) results of testing of 3 different subjects.

RESULTS

In Fig. 1 a series of typical curves for the three subjects is given, showing the relationship between the voltage and duration of the threshold current (in Fig. 1 and in subsequent figures mean values are given—coefficient of variation within limits of 10 and 35%). It is clear from Fig. 1 that the voltage—time curves for both the sensory and motor effect have the usual hyperbolic appearance. Attention is drawn to the fact that the sensory thresholds are smaller for the flexor region than for the extensor. We observed this, however, only in the two subjects T. K. and V. A., and in the third, E. G., on the other hand, the thresholds for the extensor region were smaller than for the flexor. We may also mention that in all the subjects the difference between the values of the sensory thresholds for the flexor and extensor region increased as the length of the stimulus was decreased.

When the voltage—time curves for the motor and sensory effect obtained during stimulation of the same region are compared, it is clear that for all points on the curves the sensory thresholds are lower than the motor, and the difference between the sensory and motor thresholds is greater the shorter the duration of the test stimulus.

Comparison of the motor thresholds for the flexor digitorum communis and extensor digitorum communis shows that for the former it is less than for the latter, and in this case, moreover, the difference between the threshold values increases as the duration becomes shorter. Bourguignon's coefficient for the three subjects was 2-3 (3.3 in E. G., 2.5 in V. A., and 2.3 in T. K.), which agrees with data in the literature.

The curves given in Fig. 2 show the relationship between the energy and duration of threshold stimuli in all three subjects. We can see that the energy of the threshold current for both sensory and motor effect passes through a minimum at a definite duration of the stimulus. Comparison of the energy curves of the sensory effect obtained during stimulation of the flexor and extensor region corresponds to longer durations (0.03-0.7 μf) than that of the flexor region (0.02-0.03 μf). The same pattern is also observed for the motor thresholds; the minimum for the extensors corresponds to 0.014-0.034 μf and that for the flexors to 0.009-0.018 μf. We may also note that in all the three subjects the minimum zone of the sensory curves during stimulation of both flexor and extensor regions corresponds to a longer duration than the minimum zone of the curves obtained by recording the motor effect.

The relationship between the energy of threshold stimuli and their intensity, expressed in rheobases, is shown in Fig. 3. Results for all three subjects are given. It is clearly seen that, as the intensity of the stimulus increases, the curves pass through a minimum. For the majority of the curves the energy minimum falls at 3-4 rheobases (for the sensory effect at 2 and, more often, at 3 rheobases, and for the motor—at 4-5 rheobases).

These facts differ from those obtained by Lapicque, who claimed that the energy minimum is located at 2 rheobases. It may be seen from Fig. 3 that the parameters of a stimulus in the minimum zone (its intensity and duration) often do not correspond to the parameters of the chronaximetric stimulus.

SUMMARY

To characterize excitability the authors used the method suggested by P. O. Makarov elsewhere. It consists of determining the threshold duration of the stimulus at 3 zones of the strength-duration curve: a) at the utilization time zone, i.e., at the intensity level of 1—3 rheobases, b) at the minimal energy zone (at the level of 2—4 rheobases) and c) at the level of 8—10 rheobases. With the aid of condenser discharges the voltage-duration curves for the motor thresholds of flexors and extensors of the forearm and for the sensory thresholds of the corresponding skin regions were measured. In contradistinction to Lapicque's opinion, the minimum threshold energy is not always in proportion to the chronaxie duration of the stimulus, but corresponds to a rather wide region at the level of 2—5

rheobases. The minimal energy zone of the flexor muscles corresponds to shorter stimuli than that of the extensors. The difference between the sensory and motor thresholds for both flexor and extensor regions is the greater, the shorter the duration of the stimuli applied.

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