MOTOR UNIT TEMPORAL RECRUITMENT AS A PATTERN OF CONTROL OF HUMAN LIMBS

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Summary

In this paper, the temporal recruitment of motion units (M.U.) was studied in isometric, as well as in anisometric, voluntary submaximal elbow flexion in normal man.

Three platinum bipolar wires, 150 in diameter were inserted into the belly of the biceps brachii.

It was shown that there exists a consistent hyperbolic relationship between the mean firing interval of a single M.U. and force, in anisometric contraction.

Physiologically, the shape of the relations indicates that the temporal recruitment of M.U.'s plays a particularly important role in the gradation of the contraction at low values of force. On the other hand, the similarity of the relations for both isometric and anisometric contraction implies in no way that either the same M.U.'s or the same type of M.U. is firing in firing in either case.

For the application of human limbs, the consistency of the relations as well as the form of these relations seems to suggest the use of the temporal recruitment of M.U.'s as a pattern of control of humen limbs. However, it has been emphasized that these results are only valid for normal man and under well-deffined experimental conditions and that they are susceptible to variation depending upon the working conditions of the muscle.

In all myoelectric control systems so far introduced for clinical use, surface EMG has been employed, and the use of skin electrodes was believed to be the only practical solution /1/. However, implantable transmitters /2/ and stable inserted electrodes /3, 4, 5/ seem to allow the use of intramuscular EMG in order to control human limbs. Thus two possibilities can be considered, depending on the selectivity of the electrodes being used. Either an interferential EMG, or an intermediate or a simple EMG, can be led off. In the first case, the EMG is quantifiable by intergrated surface EMG /6, 7/. In the second case, the activity of the different firing M.U.'s should be kept in consideration. This last possibility has been considered by a number of authors /8, 9, 10, 11/, who have applied it to the study of the possibility of the voluntary control of M.U.'s. The use of M.U. activity would thus allow the number of available sites to be multiplied /12, 13/. However, as pointed out by Herberts /14/, no attention has been paid to the extent to which a single motor unit participates in the total muscle contraction.

The object of this paper has been study the relationship between M.U.´s firing frequency and force for the two extreme types of contraction, isometric contraction and anisometric contraction.

Methods

The method which has already been described in detail /6,15/ will be summarized here.

Bipolar electrodes were used. They are made up of two platinum wires 100µ in diameter which are sharpened to a point of about 20µ and which are entirely insulated with Araldite. Their lateral lead is obtained by a notch in the insulation at about 0.5mm from the tip. They are used with amplifiers having an input resistance of 1MΩ and thus introduce into the circuit a time constant of 80ms for frequency signals greater than 15Hz /16/. Three of these electrodes were inserted into the belly of the right biceps brachii.

After amplification by push-pull amplifiers bandwiths linear between 20Hz and 10kHz, the EMG signals were recorded on magnetic tape using FM recording equipment.

The subjects sat with the forearm firmly fixed in a horizontal splint that formed part of a mechanical system which rotated about a vertical axis. The elbow coincided approximately with this axis. The arm and the forearm are in the same horizontal plane. The movable mechanical system was equipped with transducers which recorded the angular displacement, angular speed, and the tangential acceleration of the movement.

Weight from one to nine kilograms could be added to the mechanical system at a distance 25.5cm from the rotation axis in order to vary its inertia. On the other hand, a strain gauge attached at the same distance allowed measurement of the static force exerted by the subject when the system was immobilized.

Two types of test were carried out:

a) Tests of static contraction were isometric and isotonic. They consisted of maintaining a constant force between 1 and 21kg, applied at 25.5cm from the rotation axis, with the elbow fixed at 90°. The subject could control the amount of force exerted by watching the signal from the strain gauge displayed by an oscilloscope. Between each 30 second test a suitable amount of rest was given to avoid fatigue.

b) Tests of dynamic contraction were anisometric and anisotonic. They consisted of carrying out, at different voltages, flexion movements from a point A to point B, A and B being situated 15° to either side of the orthogonal position of the forearm and the arm (Fig. 1).

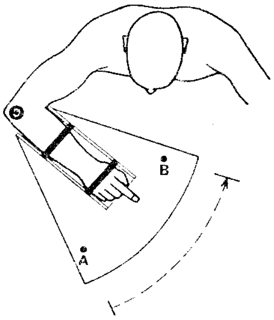

Fig. 1. Diagram of the experimental situation as viewed from above.

The movement is performed from A to B, which are 30 degrees apart, in the direction of the broken arrow. The forearm is fastened to a splint with two straps. The axis of rotation of the elbow coincides with that of the movable mechanical system and is indicated by the two concentric heavy black circles.

These movements were carried out against the inertia of the forearm plus hand and the moving part of the mechanical system which was increased or not by the addition of weights of 1 or 5kg. Under these conditions, knowing the total inertia (I) and the maximum angular velocity (V), the value of the work can be expressed $W = 1/2\ I \cdot V^2$.

Nineteen normal male subjects between 30 and 66 years old were studied. Some were studied more than once, giving a total of 25 tests.

Results

Temporal Recruitment of M.U.'s for Static Contraction

The activity of 75 different M.U.'s was observed in the tests of isometric contraction. The EMG's were either simple or intermediary depending up on the intensity of the contraction (Fig. 2).

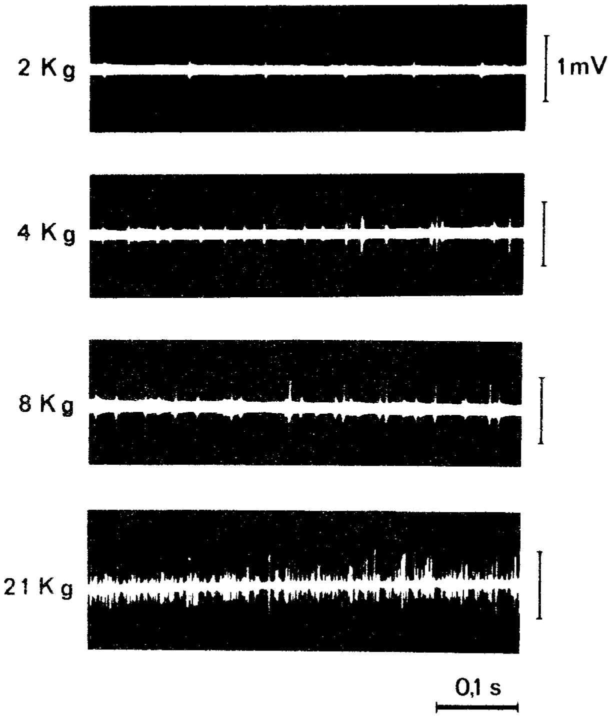

Fig. 2. Motor unit records for isometric contraction.
The four sets of records (from top to bottom), correspond to increased loads. Amplitude calibrations to the right of the records (time calibration below the record).

Considering the variation of the mean interval between successive impulses of the same M.U. ($\overline{T}$) in relation to the force (F), it appears that as F increases, $\overline{T}$ decreases rapidly from 100 - 150 ms (Fig. 3) to 30 - 40 ms where it tends to stabilize. These values correspond to a frequency range 6 - 30 c/s.

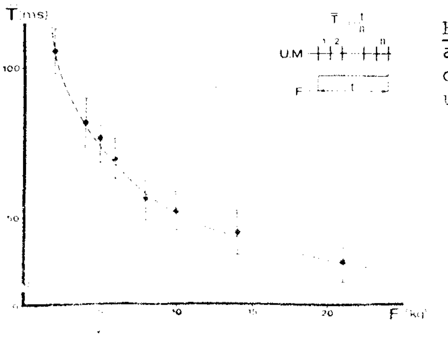

Fig. 3. Relationship between force and the mean interval between successive impulses of the same motor unit.

$\overline{T}$: mean interval, in ms. F, force, in Kg. The insert shows the significance of T. It indicates the temporal variation of electrical activity of a motor unit (U.M.) and force (F). The values of standard deviation are indicated on either side of each mean value

Temporal Recruitment of M.U.'s for Dynamic Contraction

The activity of 72 different M.U.'s observed in the tests of dynamic contraction. The EMG's were either simple or intermediary for low or average forces (Fig. 4).

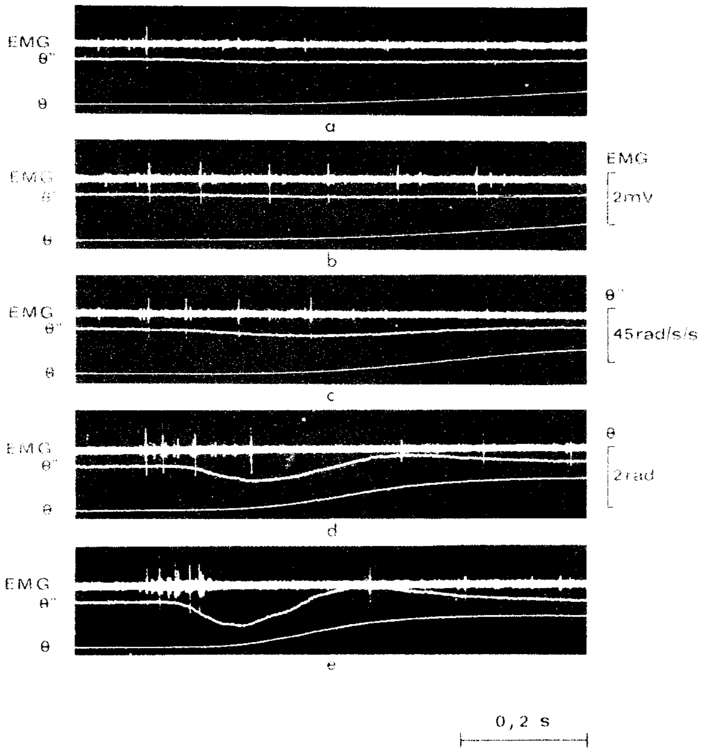

Fig. 4. Motor unit records for flexion movements.
The five sets of records (from top to bottom) correspond to increased velocities. θ, angular displacement in rad. θ'', tangential acceleration in rad /s/ s. Calibration to the right of the record (time calibration below the record).

Considering the variation of the mean interval between successive impulses of the same M.U. ($\bar{T}$), in relation to mechanical work, it appears (Fig. 5) that as W increases, $\bar{T}$ decreases rapidly from 100 - 150 ms to 20 ms where it tends to stabilize.

In other words, dynamic work being equal to force in our experimental conditions it can be seen that as force increases the mean frequency of M.U.'s increases from about 6 c/s to about

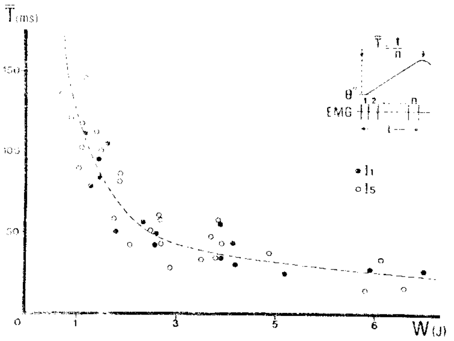

Fig. 5. Relationship between work and the mean interval between successive impulses of the same motor unit. $\overline{T}$, mean interval, in ms. W, work, in joules. The insert shows the significance of $\overline{T}$. It indicates the temporal variation of electrical activity of a motor unit (EMG) and acceleration (θ'').

50 c/s. This relation appears to be independent of the opposing inertia.

Discussion

Physiologically the results call for two comments:

(1) The shape of the relations implies that the temporal recruitment of M.U.'s plays a particularly important role in the gradation of contraction at low values. When contraction is low, only a small number of M.U.'s are firing and for these low values of force it is seen that the slope of the relation between $\overline{T}$ and F is greatest; or, in other words, the variation of the M.U.'s frequency as a function of force is greatest when contraction is low. (Figs. 3 and 5).

(2) It is known that the biceps brachii is composed of at least two different types of M.U.'s which differ in their electromyographical and myographical characteristics /17,18/. However, neither the similarity of the shape of the relation for static contraction or dynamic contraction, nor the fact that a characteristic activity pattern for these types of contraction could be found of the same point in the muscle, implies that the same M.U.'s or even the same type of M.U. are firing in either case.

For the application of control of protheses and orthoses a number of ideas can be brought out.

The consistency of the relationship between the mean firing frequency of the M.U.'s and the force for the two types of contraction, isometric and anisometric, should allow the use of temporal recruitment as a pattern of control of human extremities. In fact: (1)Scattering of the results, or the variation of the frequency around the mean, seems low in relation to the variation of the frequency as a function of force. (2) Having inserted the electrodes in different places and depths of the muscle depending up on the test, it seems that such patterns of activity could be found at a number of points in the muscle. (3) Although the biceps brachii is composed of at least two different types of M.U.'s, only one type of temporal recruitment pattern was seen for each of the two types of contraction.

The shape of relations also seems to present a certain interest. The increase of the firing frequency of the M.U.'s as a function of force is particulary important for low values of force. This is an advantage perhaps if we consider it reasonable to think that prostheses and orthoses can be controlled by low relative forces.

The fact that a stable relationship exists between $\bar{T}$ and F for isometric contraction, and at the same time another relationship of the same order exists for anisometric contraction seems particulary important. It suggests that such a relationship could be found for stump muscles for which the contraction in never isometric when they are attached to only one extremity. In this case. the signal constituted by the repetitive activity of the M.U.'s could be used to control prostheses. It also suggests that for orthoses, the activity of the M.U.'s of normal muscles could be used either to stimulate paralyzed muscles or to control orthosis itself.

However, at this time, it must be remembered that these results are valid only for normal subjects. In stump muscles, frequently there are pathological changes in the appearance of the myoelectric signal /14, 19/ and for paralyzed muscles, it seems that the onset of a fatigue process is particularly rapid /20/. It is also necessary to remember that these results were obtained in very precise experimental conditions and that they are susceptible to variations depending upon the working conditions of the muscles.

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