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2.2.2: Electrical Stimulation II

Intraneural Stimulation using Wire-Microelectrode Arrays: Analysis of Force Steps in Recruitment Curves

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Abstract – **In acute experiments on six Wistar rats, a wire-microelectrode array was inserted into the common peroneal nerve. A 5-channel array and a 24-channel array were available. Each electrode in the array was used to generate a twitch contraction force recruitment curve for the extensor digitorum longus muscle. We constructed a histogram of the pooled force steps in all recruitment curves. From a comparison of this experimental histogram with one estimated from literature data, we found that the force steps encountered in our experiments are in the same range as those from the literature-based estimated distribution. Discrepancies between the experimental and the literature-based histogram might be ascribed to an approximation used in the estimated distribution. We conclude that force step histograms appear to provide a simple means for estimating motor unit twitch force distributions, and thus are of value in studies of intraneural selective stimulation.**

INTRODUCTION

Recent years have shown a growing interest in selective stimulation of the peripheral neuromuscular system. The highest level of selectivity would be achieved when each nerve fiber in a nerve trunk can be activated at will.

It is obvious that selective stimulation of an *arbitrary* motor fiber is best served by approaching that fiber closely, preferably by putting an electrode in close proximity of one of its nodes of Ranvier. This implies that the electrode has to be positioned inside the nerve.

The ultimate case of fiber selectivity would result if it were possible to stimulate each motor fiber independently. In this ideal situation the minimum number of electrodes equals the number of nerve fibers to be activated. Since motor fiber activation is established at a node of Ranvier, these electrodes should be arranged in a three-dimensional pattern, such that the first node of Ranvier activated by each electrode belongs to a different motor fiber for each electrode. As the actual positions of the nodes of Ranvier are not known, this prerequisite will be hard to meet. Therefore, selective stimulation of *arbitrary* motor fibers (or a spatially limited small group of them) requires an intraneural multi-electrode with a redundant number of electrodes.

As a first step towards increasing the number of intraneural electrodes we have employed one- and two-dimensional wire-microelectrode arrays (WMEA's) in acute animal experiments. A topographical map of recruitment curves, obtained for each individual electrode in such an array, was presented earlier [1].

The purpose of this investigation is to analyze the force steps in the recruitment curves obtained for the electrodes in a WMEA. Ideally, such an analysis would result in identification of the motor units and their twitch force distribution for the muscle under investigation.

METHODS

Acute experiments were conducted on Wistar rats maintained under sodium pentobarbital anesthesia. Both tendons of the extensor digitorum longus (EDL) muscle of the right hindleg were cut. To ensure isometric conditions the proximal tendon was mechanically fixed and the distal tendon connected to an isometric force transducer.

The common peroneal nerve was positioned on a support table and an incision was made using a pair of tweezers and an ophthalmic knife. The incision was directed along the longitudinal axis of the nerve and long enough to allow easy insertion of a WMEA. A one-dimensional 5-channel array and a two-dimensional 24-channel array were available, consisting of 5 rows of 1 electrode and 6 rows of 4 electrodes, respectively. The individual electrodes in the arrays were insulated NiCr wires with a diameter of 25 μm; interelectrode spacing was 120 μm. The experimental setup is shown in Figure 1.

Rectangular depolarizing current pulses of 100 μs duration were generated in order to stimulate α-motoneurons of the EDL muscle. For each electrode in the array a series of stimuli was applied with amplitudes increasing from

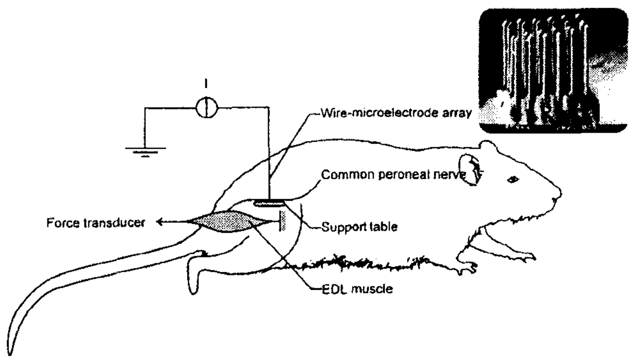

Figure 1. Experimental setup. Inset: 24-channel wire-microelectrode array.

subthreshold to supramaximal. Stimulus current step size was 0.1 μA. Stimulus frequency was 1 Hz. The elicited twitch contraction forces were measured, one for each stimulus amplitude. Recruitment curves were constructed off-line by determining the peak values of the series of twitch forces.

At the end of the experiment, the electrode array was carefully removed from the nerve and the quality of insertion visually assessed. We generally found that the electrode array was firmly attached to the nerve and the electrodes were clearly positioned inside the fascicle.

RESULTS

A total of 102 recruitment curves was recorded from six animals. The 5-channel electrode array was used in one animal, at three different positions along the nerve. The 24-channel electrode array was used in five animals; only one position was evaluated for these animals. Consequently, eight sets of recruitment curves were obtained in total.

As a first step towards extracting motor unit forces, histograms were generated of the force increments and decrements corresponding to the stimulation current increments in the recruitment curves. The force step histograms for all recruitment curves were pooled and are represented in Figure 2. The bin width of this histogram has to be small enough to be able to detect the smaller force steps, but large enough to allow discrimination between noise and signal. For the equipment used in the experiments the minimum bin width was determined to be 2.5 mN.

DISCUSSION AND CONCLUSION

The distribution of motor unit twitch forces for the EDL muscle of the rat is not exactly known. Frieswijk *et al.* [2] constructed an estimated distribution, based on scarce literature data [3], [4]. Basically, this distribution is the product of the diameter distribution presented in [4] and a logarithmic relationship between cumulative force and the number of recruited motor units [3]. This estimated distribution consists of 69 motor units producing a total twitch force of 90 g, with many units contributing small forces and only few contributing large forces. Figure 3 shows the estimated distribution and the strengths of the individual motor units. The force step histogram for motor units recruited in ascending-force-order is also shown.

It is clear that the experimentally encountered force step range (~ 0 mN - ~ 100 mN) is comparable to that resulting from the estimated distribution. However, the experimental histogram (Figure 2) is monotonically descending for force steps increasing from small to large, whereas the estimated distribution (Figure 3) has a peak for force steps slightly greater than zero. This discrepancy might be ascribed to the notion that the logarithmic relationship between cumulative force and the number of recruited motor units breaks down for weak forces [3].

We conclude that force step histograms appear to provide a simple means for estimating motor unit twitch force distributions, and thus are of value in studies of intraneural selective stimulation.

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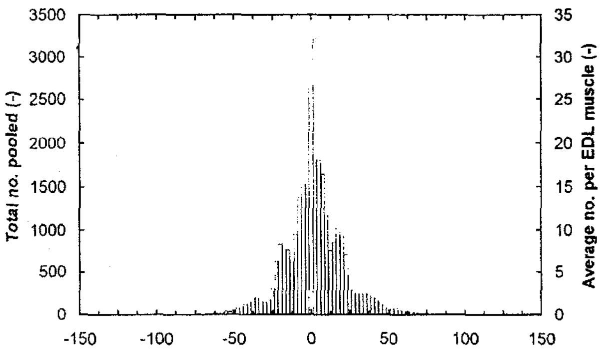

Figure 2. Force step histogram for the EDL muscle of the rat. The data were extracted from a total of 102 recruitment curves, which were obtained from six animals by intraneural stimulation with a wire-microelectrode array. Bin width is 2.5 mN. The central bin is suppressed since it merely contains noise.

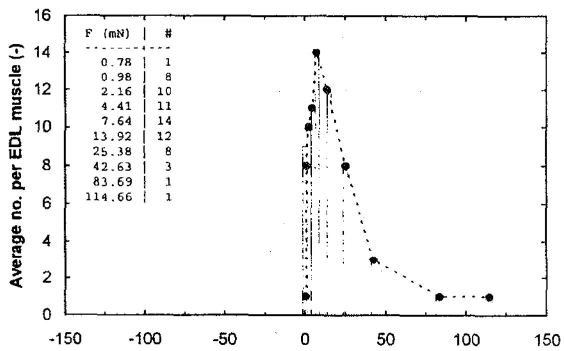

Figure 3. Estimated distribution of motor unit twitch forces for the EDL muscle of the rat. This distribution was constructed by Frieswijk *et al.* [2] on basis of literature data from three animals [3], [4]. The strengths of the individual motor units are listed in the inset table. The force step histogram for ascending-force-order motor unit recruitment is also shown. Note that the central bin contains valid force steps in this case.