INVESTIGATION OF PEAK AMPLITUDE AND PULSE LENGTH SPECTRA OF GROSS EMG SIGNALS BY MULTI-CHANNEL ANALYZATION

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Introduction

The most commonly and easily applied method of packing up myoelectric signals is through skin electrodes. The following properties of myoelectric signals picked up by skin electrodes are well known (see e. g. Ref. 1):

a) With increasing contraction of the muscle the mean amplitude of a myoelectric signal increases.

b) Apparently, the content of higher frequencies in the signal increases with increasing contraction.

Signal processing depends upon the control desired. For simple on/off control no detailed knowledge of signal properties is required. They are amplified, filtered, rectified, and fed into a switching device which is set into operation when the DC signal reaches a given level. In proportional control the increase of the mean amplitude with increasing contraction is evaluated to obtain an analog signal, that can be smoothed only to a certain extent. Although this method led to a remarkable success. [2], the question is allowed whether there might exist a procedure of deriving more information from myoelectric signals and especially whether there might be found a process which yields a better smoothed signal for proportional control, still using skin electrodes.

As a first step in this direction we transformed myoelectric signals into pulses of nearly the same lengths and constant heights. These pulses were integrated with an integrating time of about 0.1 sec and an analog signal was derived. To our surprise the integrated signal showed only weak dependence upon muscle contraction. Furthermore, its momentary deviation from the mean value was so large that it was impossible to use it for proportional control without increasing the integration time to an unbearable magnitude.

In the next experiment we tried to gain a better insight into the information content of myoelectric signals derived from the

skin surface. The likeness between these signals and electronically generated random signals led to the assumption, that perhaps measurements of the probability density curves of both peak amplitudes and pulse lengths might reveal some more details.

A very simple preliminary experiment showed, that indeed a a probability density curve of pulse lengths could be obtained, although the results were too vague to be evaluated systematically. Only with a more precise electronic device, using nuclear instrumentation, could we hope to get more accurate results.

Experimental Arrangement

For the statistical analysis of myoelectric signals a 256 channel pulse height analyser was used*, which required input pulses of the following properties: 1 μsec rise time, approximately 2 μsec fall time, and about 5 μsec pulse length. Therefore, a special circuitry, had to bet set up in order to transform peak amplitudes and pulse lengths of myoelectric signals into pulses of the afore-mentioned properties. Three different parts were designed: preamplifier, pulse stretching and logic circuitries.

Two stainless steel electrodes of 1 cm diameter spaced 1.8 cm apart and connected directly to a differential amplifier stage with low output impedance were used (Fig. 1). The preamplified signal was further processed by a stage with amplification control and from there fed into the pulse stretching circuitry. The linear frequency response range of the complete amplifier was between 20 cps and 10 kcps (1 dB). At the moment when the myoelectric signal crosses the zero line in an upward direction a Schmitt trigger is activated to open the memory for the peak amplitude. The peak amplitude (a) then is stored and connected to the output gate (Fig. 2). When the myoelectric signal crosses the zero line in a downward direction the output gate is opened for 5 μsec, thus generating a pulse of 5μsec length and of the same amplitude (a) as the myoelecric signal. At the same time the rectangular pulse of the Schmitt trigger is integrated into a triangular waveform. The peak amplitude (b) of this waveform is proportional to the pulse length of the myoelectric signal. It is processed in the same way as the amplitude (a). Because of noise and interference fed in from the pick up amplifier the input voltage level of the Schmitt trigger was adjusted to 40 mV. The maximum output voltage of the two channels, peak amplitudes and pulse lengths, was restricted to 4.0 V. Before taking measurements both channels were checked for linear

* We are very obliged to Prof. Dr. V. Soergel of 1. Physikalisches Institut der Universität Heidelberg for making the experimental facilities of the institute available to us.

performance and calibrated. In all measurements amplification was adjusted in such a way that, on one hand, the myoelectric signal was not distorted by the amplification restriction and, on the other hand, noise and interference did not operate the logic. Sometimes this led to compromises which may perhaps have some effect upon results which we will present later. The arrangement was used without any alteration in all experiments we describe here, so that,

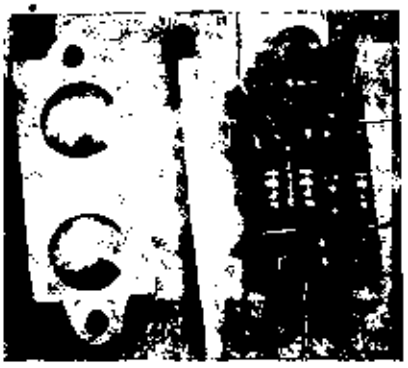

Fig. 1. Differential preamplifier and skin electrodes.

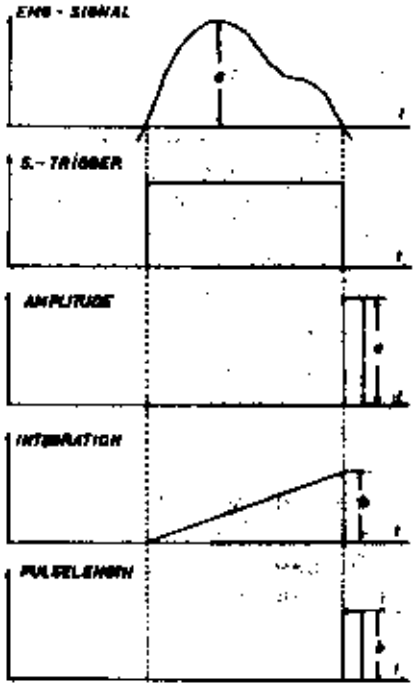

Fig. 2. Signal processing and logic.

if electrode geometry has some influence, our measurements can at least be regarded as being obtained under standard conditions.

Experimental Procedure and Results

It is evident from the problem under investigation and from the experimental method applied, that only isometric contraction of muscles can be tested, because of the large number of events required for a statistical analysis. Therefore, the results and the conclusions reached in our experiments refer only to isometric contraction. From earlier experiments we mentioned above we knew, that the mean pulse length as shown in Figure 2 had an order of magnitude of 10 msec. Accordingly, we decided to set the

counting time of the pulse height analyser to one minute, if not otherwise specified, and thus approximately 6000 events per run could be expected. This number we considered sufficient for statistical analysis.

The following topics were selected for investigation:

a) Qualitative measurements to survey probability density curves.

b) Electrode position influence on the shape of probability density curves.

c) Quantitative measurements of statistical distributions of peak amplitudes and pulse lengths by using signals from M. biceps br. in one subject with quantitative variation of isometric contraction.

d) Quantitative measurements as to the influence of fatigue on the shape of both probability density curves.

We felt that with these experiments it should be possible to gain an insight into relationships between muscle contractions and statistical properties of myoelectric signals.

Qualitative measurements

In these experiments the pick up electrodes were placed on the maximum bulge of the muscle under investigation. Contractions were classified into three degrees: weak, medium, and strong. Various probability density curves from different muscles were taken and plotted. Typical examples are shown in Figure 3. In these figures we plotted

$$w_i^A(n) = \frac{\text{number of peak amplitudes counted by channel } i}{\text{number of all amplitudes}} \tag{1}$$

$$w_i^P(n) = \frac{\text{number of pulse lengths counted by channel } i}{\text{number of all pulse lengths}} \tag{2}$$

as a function of the channel number i which is proportional either to peak amplitudes or to pulse lengths. To all amplitude probability density curves we were able to fit a Gaussian function of the form

$$w_i^A(n) = \frac{1}{\sqrt{2\pi}} \quad \frac{1}{\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right) \tag{3}$$

with varying σ depending upon the individual muscle and its degree of contraction, x being proportional to the channel number i.

We were unable to find a uniform mathematical expression to describe the probability density curve $w_t^F(n)$ of pulse lengths, but all examples definitely revealed that the shapes of our experimental curves depend upon contraction.

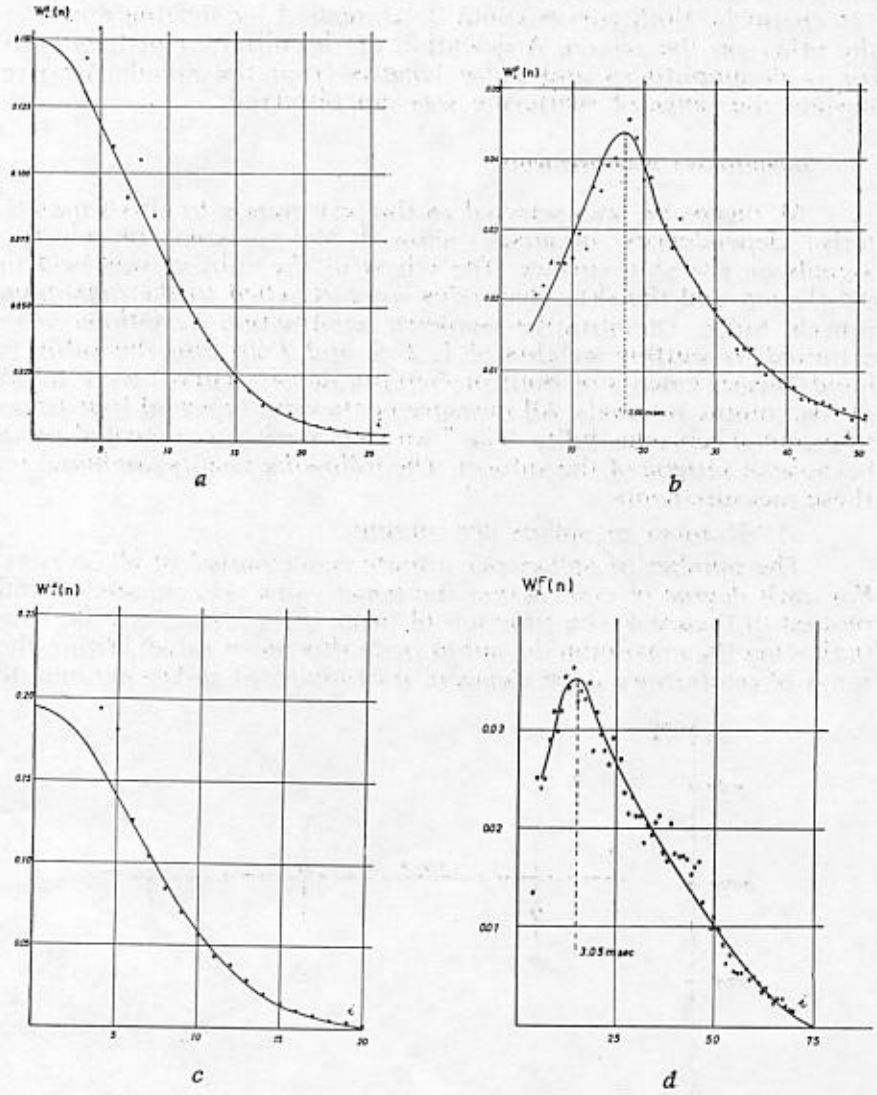

Fig. 3. a — Amplitude probability density curve M. masseter; **b** — Pulse length probability density curve M. masseter. Both strong contraction; **c** — Amplitude probability density curve M. triceps br; **d** — Pulse length probability density curve M. triceps br. Both strong contraction.

Electrode position influence

The influence due to different electrode location on the shape of the probability density curves was checked directly on the screen of the pulse height analyser. A standard distribution curve taken from the maximum muscle bulge was stored in 128 channels out of 256. Measurements of other electrode sites were fed into the other 128 channels. Both curves could be compared by shifting one over the other on the screen. A deviation of the different distributions for peak amplitudes and pulse lengths from the standard curve beyond the range of scattering was not observed.

Quantitative measurements

M. biceps br. was selected as the test muscle to check quantitative dependences, because it showed high original myoelectric signals on the skin surface. The elbow of the subject was held in 90° flexion and the skin electrodes were attached to the maximum muscle bulge. Quantitative isometric contraction variations were achieved by putting weights of 1, 2, 5, and 7 kp into the subjects hand. Measurements of both probability density curves were taken at five minute intervals. All measurements were repeated four times to examine reproducibility. The 7 kp runs were only repeated twice because of fatigue of the subject. The following results are based on these measurements:

a) Number of spikes per minute

The number of spikes per minute was counted in all 36 runs. For each degree of contraction the mean value was calculated and plotted in Figure 4 as a function of isometric contraction, the bars indicating the maximum deviation from this mean value. Within the range of scattering a dependence of the number of spikes per minute

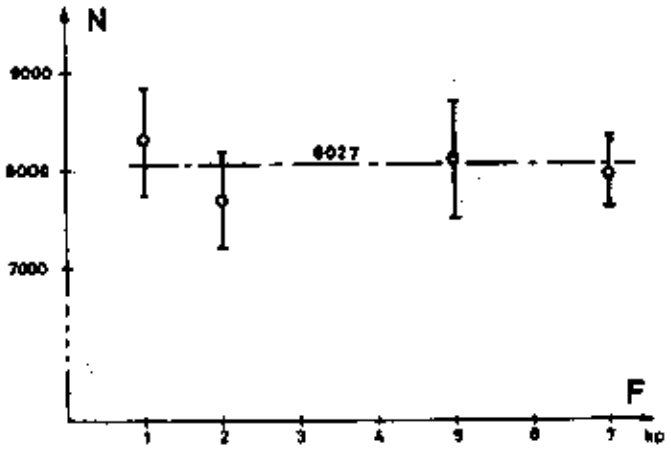

Fig. 4. Number of spikes per minute as a function of contraction.

upon isometric contraction was not stated. If we take mean value of all 36 measurements we arrive at 8027 spikes per minute. This corresponds to a mean pulse length of 7.5 msec or a mean frequency of 65 cps for myoelectric signals from M. biceps br. under all conditions.

Also, this gives us clues as to why the afore-mentioned integration experiments failed, which showed that the DC signal was only slightly dependent upon contraction.

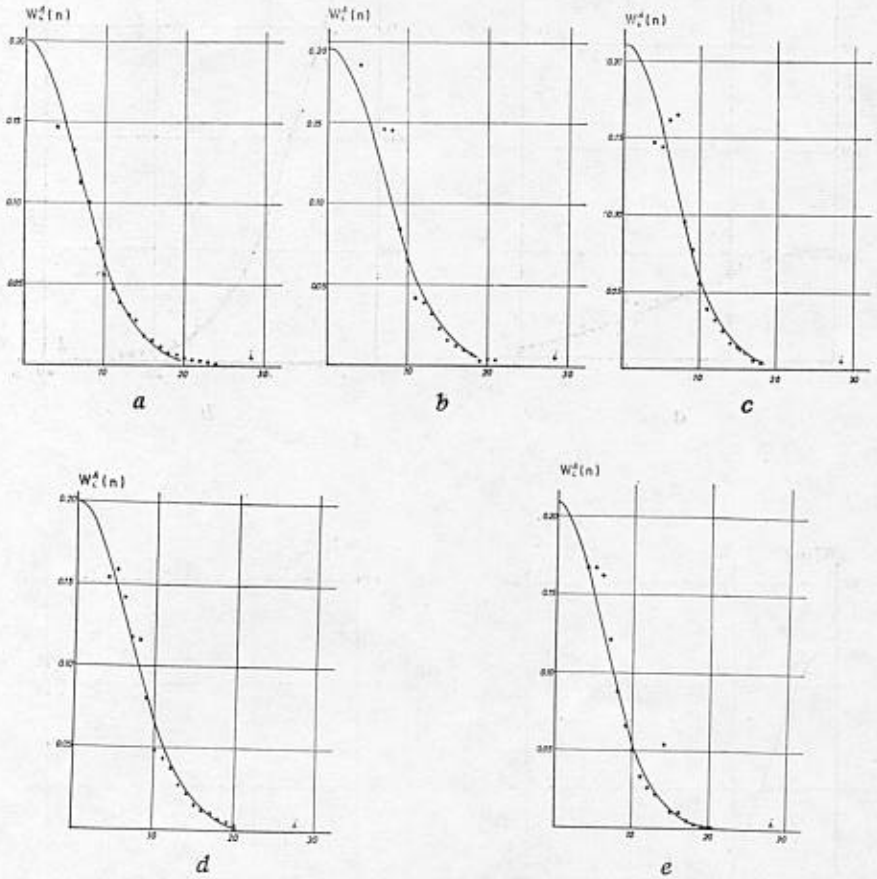

Fig. 5. Reproducibility of amplitude probability density curves of. M. biceps br. contraction corresponding to 2 kp.

b) Amplitude probability density curves.

Figure 5 shows amplitude probability density curves $w_i^A(n)$ for an isometric contraction corresponding to 2 kp. Gaussian functions (Eq. 3) fitted to the measurements are indicated by full lines. These curves demonstrate the reproducibility of our measu-

rements. As stated by Parker [3] the amplitude probability density curve can easily be expressed by a Gaussian function with varying σ and an expectation value of zero.

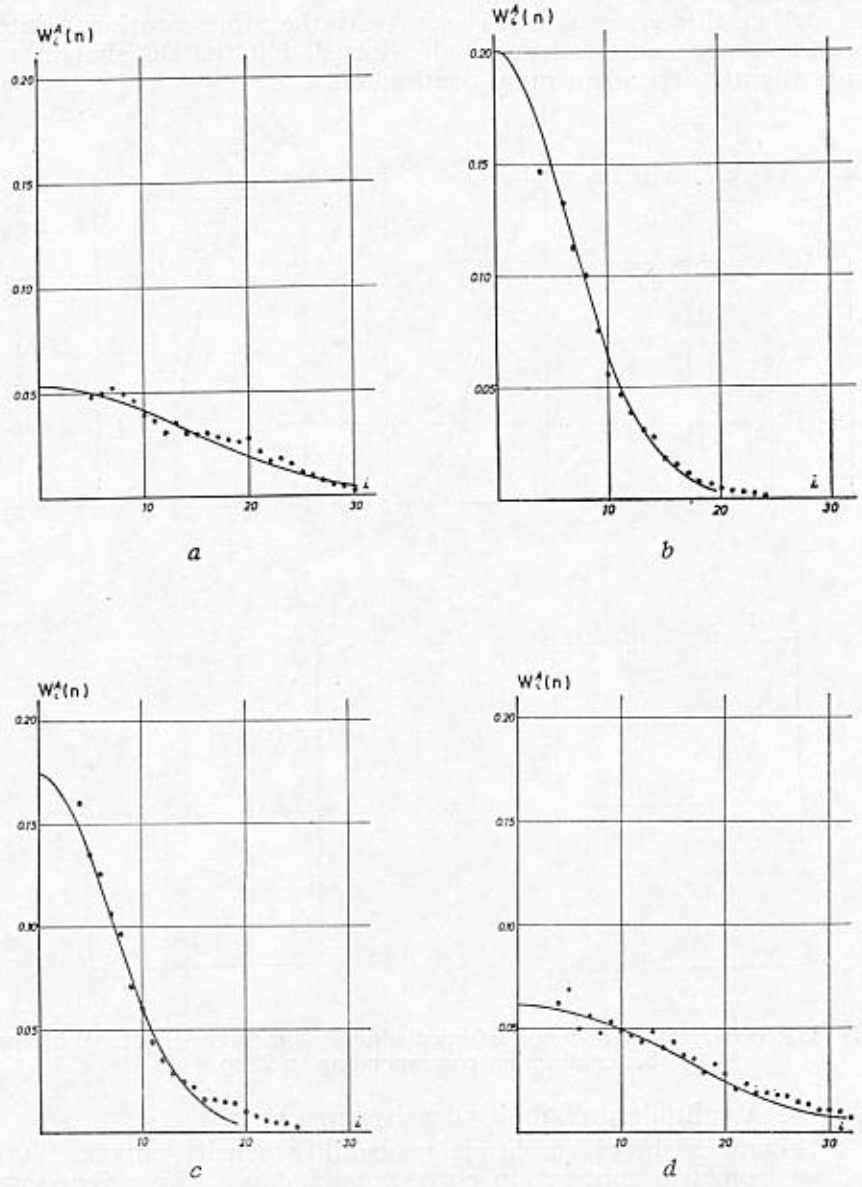

Fig. 6. Amplitude probability density curves for different contractions, 1 kp (a), 2 kp (b), 5 kp (c), 7 kp (d).

This is further demonstrated by Figure 6 which shows the dependence of these curves upon contraction. Initially, with slight isometric contraction we obtained broad distributions corresponding to large σ. Increasing contraction is accompanied by decreasing σ, and in the state of contraction corresponding to 7 kp the scattering of σ becomes very large and σ itself more or less indefinite. (Fig. 7). Although it seemed desirable to derive a quantitative rela-

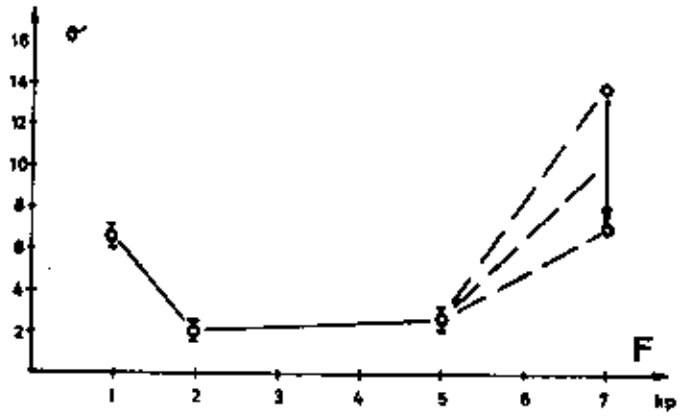

Fig. 7. σ of amplitude probability density curves for M. biceps br. as a function of isometric contractions.

tionship between σ and isometric contraction we avoided any speculation in this stage of our experiments.

c) Pulse length probability density curves

Reproducibility of probability density curves for pulse lengths is shown in Figure 8. It is obvious from these plots that reproducibility is acceptable in shape and site of the distribution of the distribution maximum. Figure 9 represents the dependence of the site of the maximum upon contraction.

Curiously enough, the maximum of the probability density curves is not shifted by increasing contraction. The pulse length probability density curve is asymmetrical with a steeply ascending part from zero pulse length to the distribution maximum. Its sharp peak at weak contractions is broadened by increasing load on the muscle. The variation of the site of the maximum is shown in Figure 10, deviations are indicated by bars. A satisfactory mathematical description of this behaviour could not be found till now.

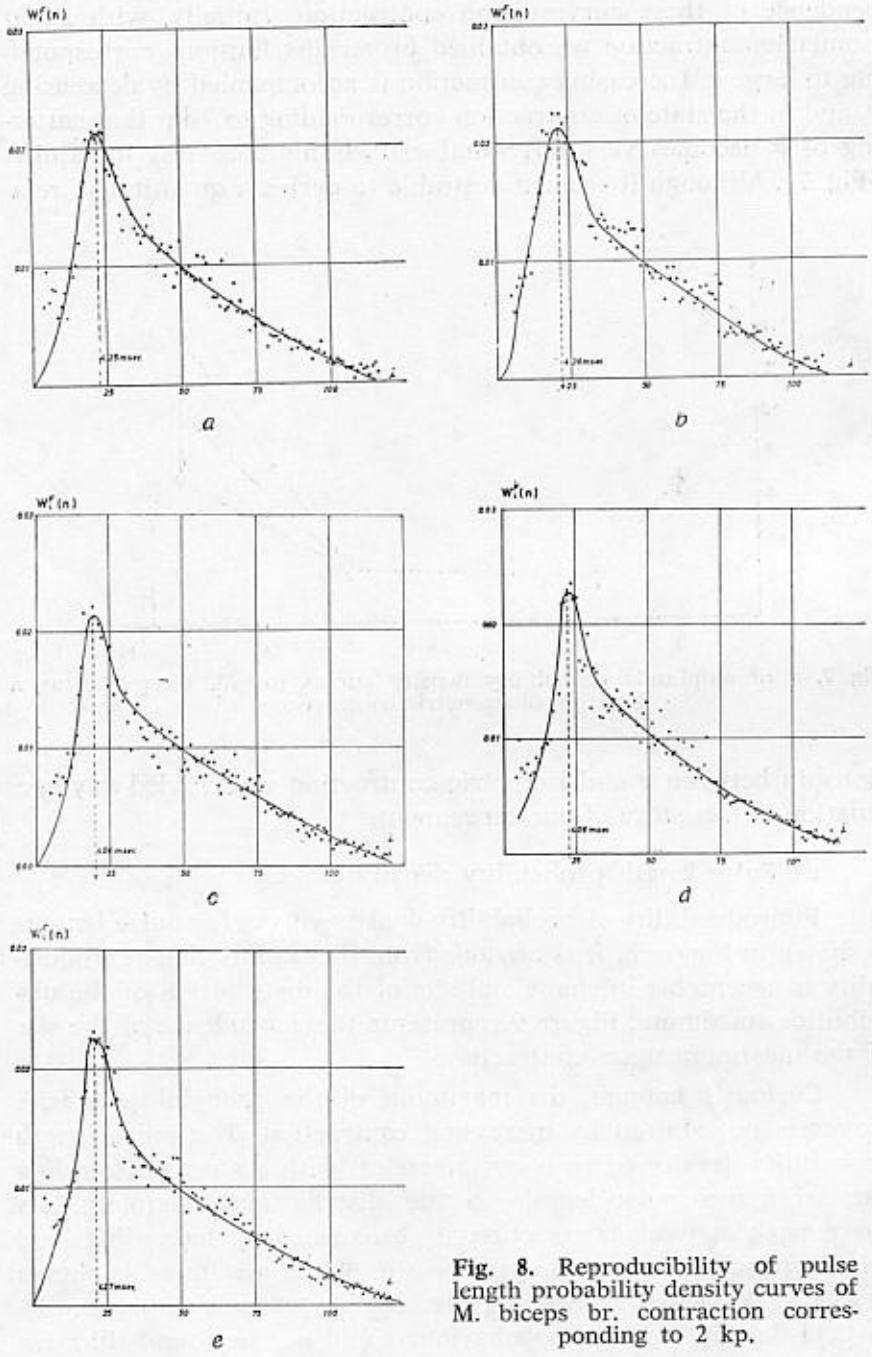

Fig. 8. Reproducibility of pulse length probability density curves of M. biceps br. contraction corresponding to 2 kp.

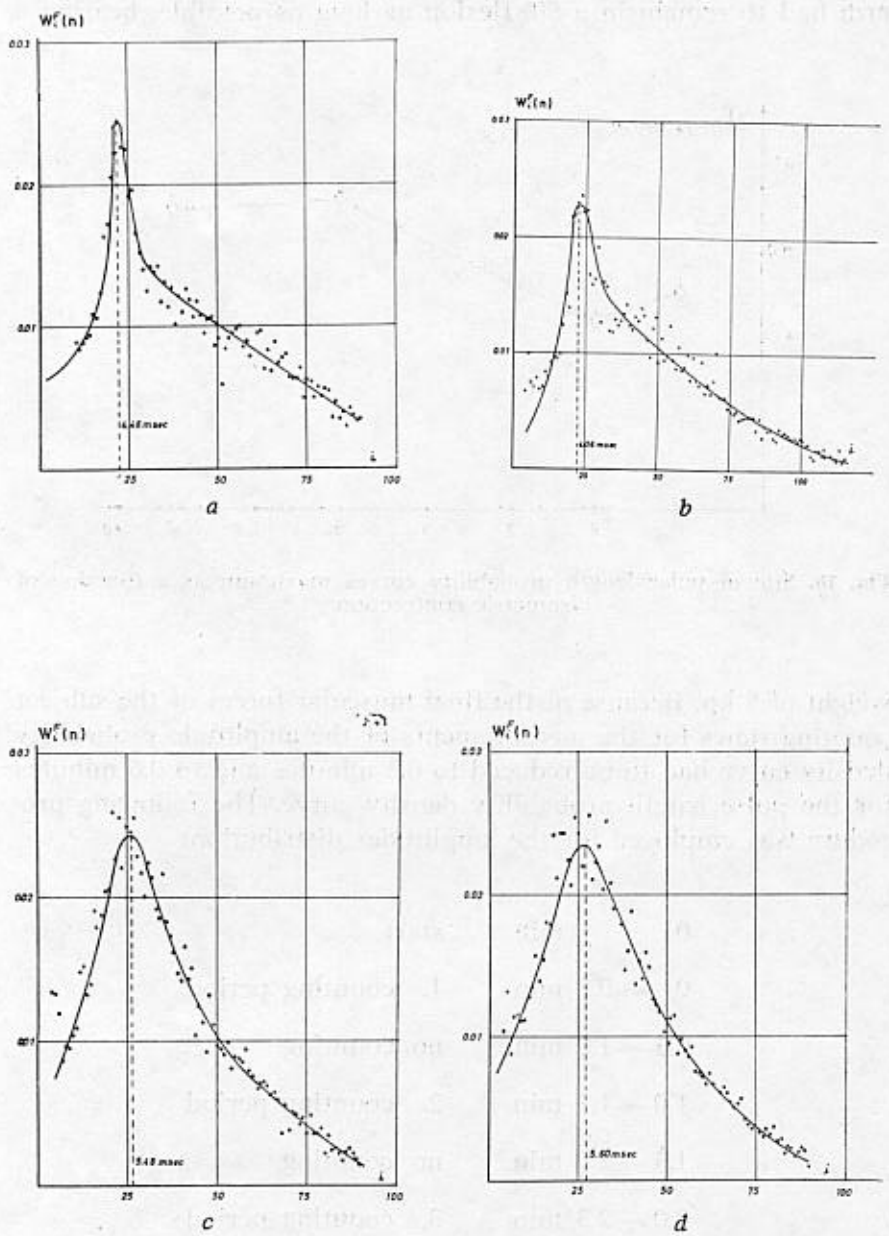

Fig. 9. Pulse lenght probability density curves for different contractions, 1 kp (a), 2 kp (b), 5 kp (c), 7 kp (d).

d) The influence of fatigue

For the evaluation of the influence of fatigue the subject's arm had to remain in a 90° flexion as long as possible, bearing a

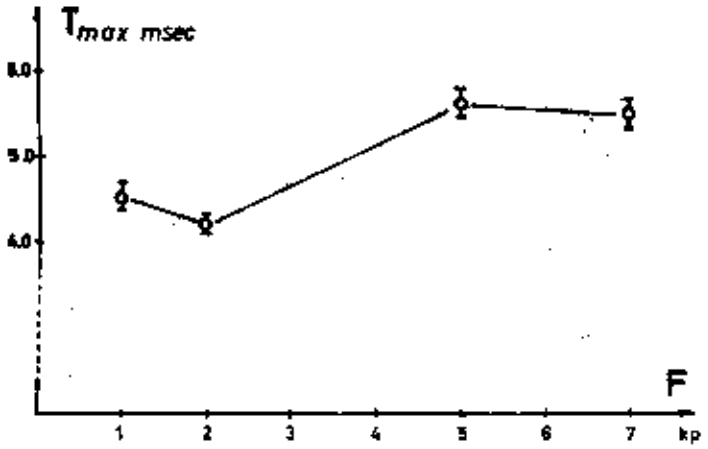

Fig. 10. Site of pulse length probability curves maximum as a function of isometric contraction.

weight of 5 kp. Because of the final muscular forces of the subject counting times for the measurements of the amplitude probability density curve had to be reduced to 0.3 minutes and to 0.6 minutes for the pulse length probability density curve. The following procedure was employed for the amplitudes distribution:

0	min	start
0 — 0.3	min	1. counting period
0.3 — 1.0	min	no counting
1.0 — 1.3	min	2. counting period
1.3 — 2.0	min	no counting
2.0 — 2.3	min	3. counting period
2.3	min	subject gave up

The results are shown in Figure 11. The shape of the amplitude probability density curves is showing a remarkable change with increasing fatigue. Beginning with a broad distribution measured during the first counting period, the curves become steeper with increasing fatigue. Figure 12 shows the time dependence of σ in this experiment.

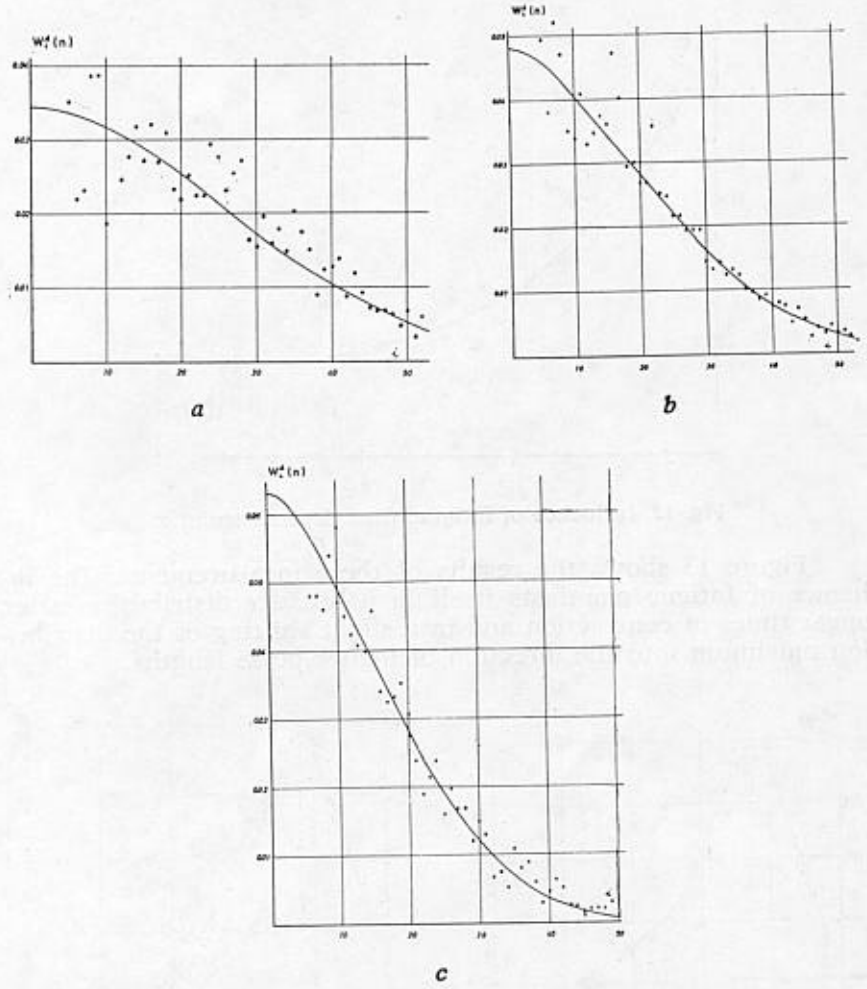

Fig. 11. Influence of fatigue on amplitude probability density curves, (a) first, (b) second, (c) third counting period. Isometric contraction corresponding to 5 kp.

When measuring the influence of fatigue on pulse length probability density curves we had to provide for a counting time of

0.6 minutes because of the higher scattering involved. The following schedule was selected:

0	min	start
0 — 0.6	min	1. counting period
0.6 — 1.7	min	no counting
1.7 — 2.3	min	2. counting period
2.3	min	subject gave up

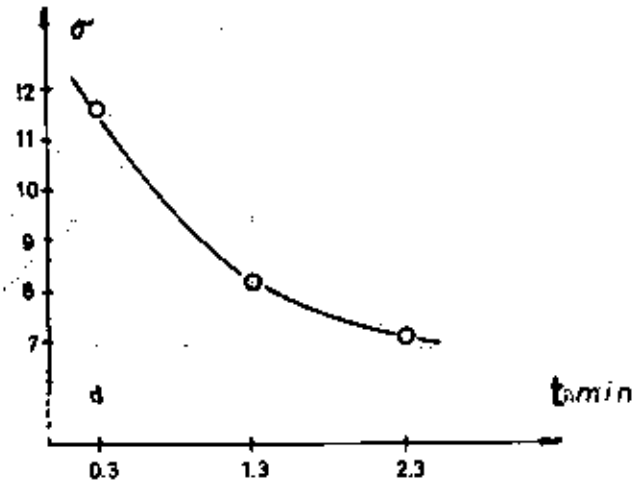

Fig. 12. Influence of fatigue: time dependence of σ.

Figure 13 shows the results of these measurements. The influence of fatigue manifests itself in a broader distribution after longer times of contraction and in a slight shifting of the distribution maximum into the direction of higher pulse lengths.

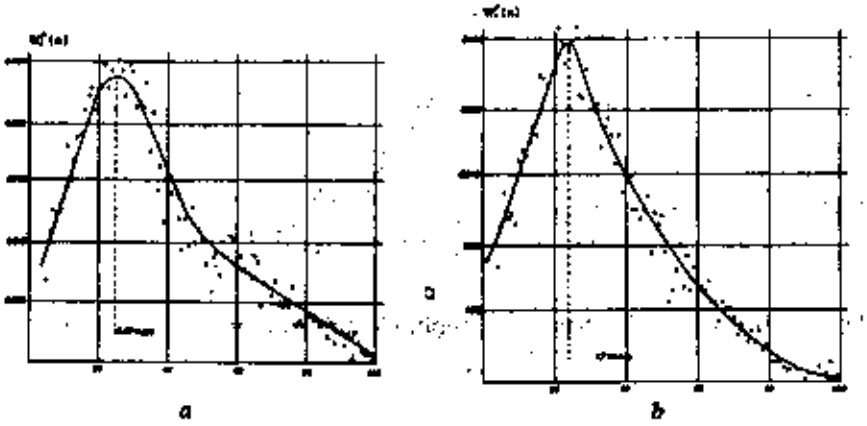

Fig. 13. Influence of fatigue on pulse length probability density curves, (a) first, (b) second counting period. Isometric contraction corresponding to 5 kp.

Conclusions

As it often happens with such investigations more problems are uncovered than actually solved. But we believe that the following conclusions may be deduced from our measurements without contradiction:

The peak amplitude probability density curves can be expressed by Gaussian functions, in which σ depends upon the degree and the duration of isometric contraction.

The mean number of spikes per minute in the myoelectric signal is independent of contraction.

Pulse length probability density curves are asymmetrical with a sharp maximum for weak and a broad maximum for strong isometric contractions. A mathematical description of their behaviour has not been found yet.

The influence of fatigue manifests itself in making peak amplitude probability density curves steeper and pulse length probability density curves broader. The assumption that statistics of independent events can be applied to describe both probability density curves seems not to hold true because of the influence of fatigue.

The concept that frequency variation of myoelectric signals might be evaluated for proportional control can be regarded as disproved by our experiments.

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