



# **FIRING OF MOTOR UNITS**

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# SOME THOUGHTS AROUND FIRING OF INDIVIDUAL MOTOR UNITS

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## 1. Basics

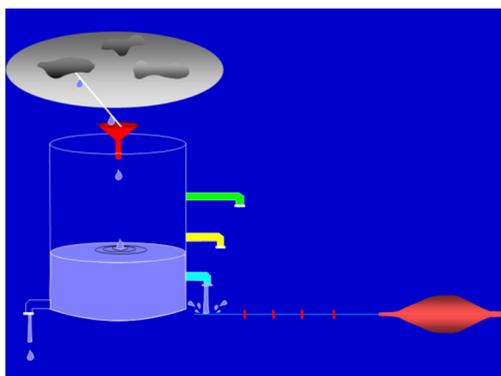
### 1.1. Anatomy

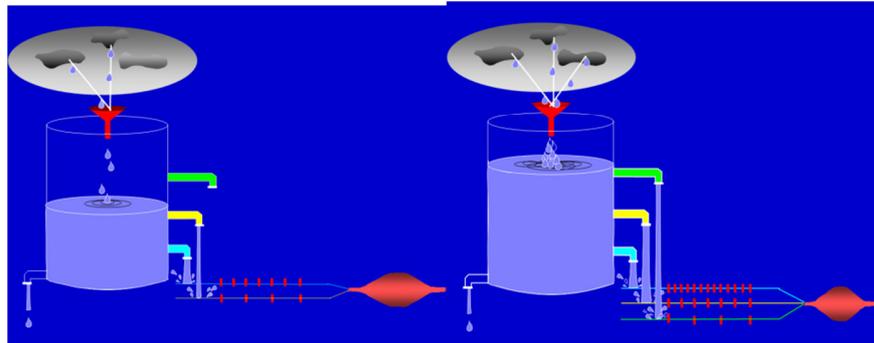
Muscle fibers belonging to the same motor unit (MU) are distributed randomly over a cross section of a diameter of 5-10 mm (Stålberg, Diozeghy), the territory, with many territories overlapping. The extent of a territory varies among muscles, partly dependent on muscle size. Number of muscle fibers in a motor unit may be 25 to a few hundred. The average distance between muscle fibers in a MU is about 200  $\mu\text{m}$  (Stålberg, Gath). In general the muscle is packed with fibers, sharing space with connective tissue, blood vessels.

### 1.2. Recruitment

Normal motor units are recruited in orderly fashion, determined by the size of the anterior horn cell, therefore called size principle (Henneman...). The size of the neurone is positively correlated to its transmembrane resistance, the axonal diameter and most likely also the number of connected muscle fibers, and their territory. Density of fibers within an area is not related to neuron size (FD in SFEMG is the same for small and large MUs).

The first MU is recruited at slight effort with a frequency of 6-8Hz and then additional MUs are recruited with increasing force up to 40-60Hz. During increasing force, the already active MUs increase their firing rate.





The territory for the new recruited MU may be situated in the muscle cross section far away from the just previously activated MU i.e not within recording distance from the electrode. This distribution has not been studied There is probably a tendency that motor units at slight activity are within the same portion of the muscle determined by the particular way the muscle is activated. Such an organization may also be indicated by the term “muscle unit” which sometimes has been used for the functional unit of a MU and the muscle spindles that serve that MU.



## 2. Different methods for assessment EMG at slight increasing and strong activity

Many attempts have been made to express the pattern at increasing and strong activity in EMG. The fact that so many methods have been developed is a sign that none is perfect for all applications.

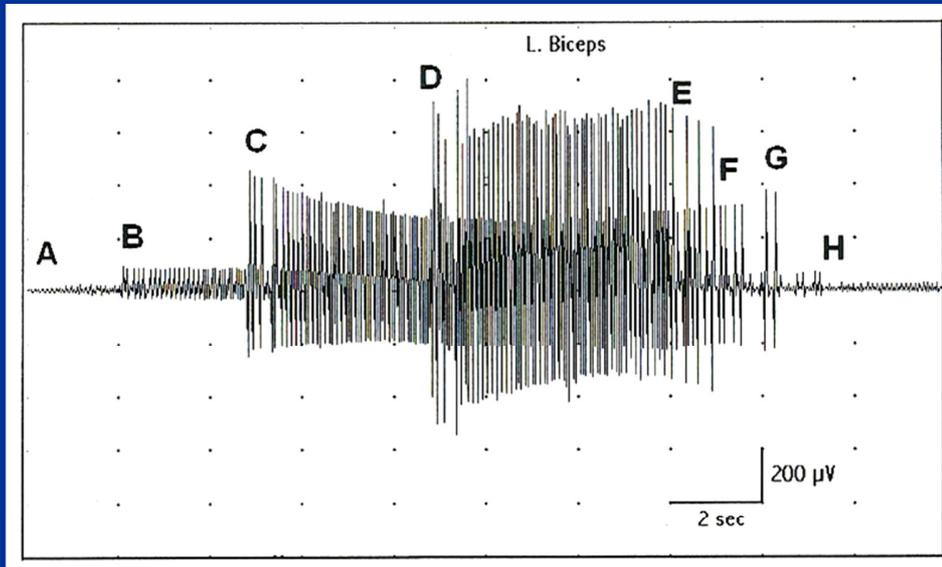
## Different methods for analysis of EMG at increasing and strong effort

- Recruitment analysis
- Turns/ampl and modifications
- Signal length (not used)
- Power spectrum
- RMS
- Cluster index

This discussion only concerns Recruitment analysis

### 3. EMG during increasing force

The well-known pattern of continuously increase in fullness of the EMG signal is seen in fig below. Usually the seemingly increase in signal amplitudes has been taken as the EMG correlate to the size principle. This is however not correct since the EMG electrode, (monopolar or concentric) has an uptake area much smaller than the total territory. The eye is misled by only noticing the highest amplitudes and so missing MUPS of lower amplitude that can be found in the trace (Bischoff, Stålberg). Why does the signal envelope amplitude (highest amplitude) often seem to increase. My unproven explanation is simply that by increasing force, more MUs are active, some of which have fibers located really close to the electrode tip, thus a statistical reason. Particularly if the initial recording is not exactly optimized to record from a site giving highest possible amplitude.



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EMG trace during increasing and decreasing force, giving the impression of a recruitment of MUP with continuously higher amplitude with increase in force. Note however that MUPs of low amplitudes are also activated during the trace e.g. between B and C and between C and D. (copyright @CASA engineering, with permission)

#### 4. Visual assessment of recruitment order

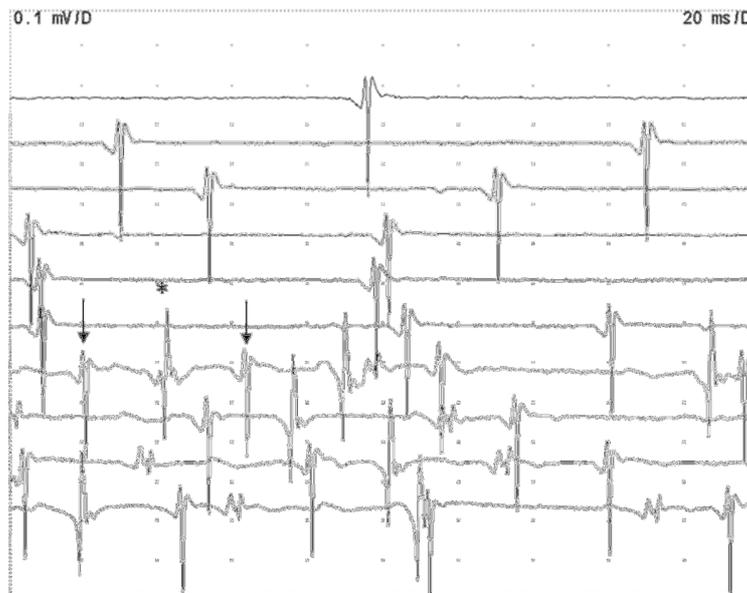
The principle for assessing recruitment semiquantitatively at slowly increasing voluntary activation is basically as follows.

The electrode is placed in a position with only one MU active at slightest contraction. This position is kept throughout the study.

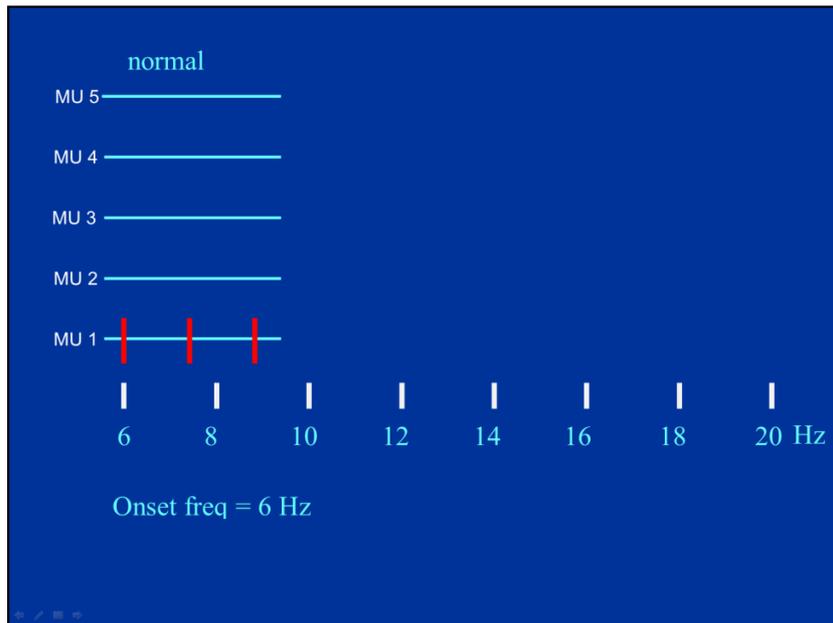
During slight increase in strength, the EMG is recorded with slow sweep speed in raster mode, usually 200 msec per trace displayed on 10-20 traces. The data collection is paused, and the EMG section is analyzed, according to the following simple schematic protocol for recruitment analysis.

### 5. Trace during slight increase in force

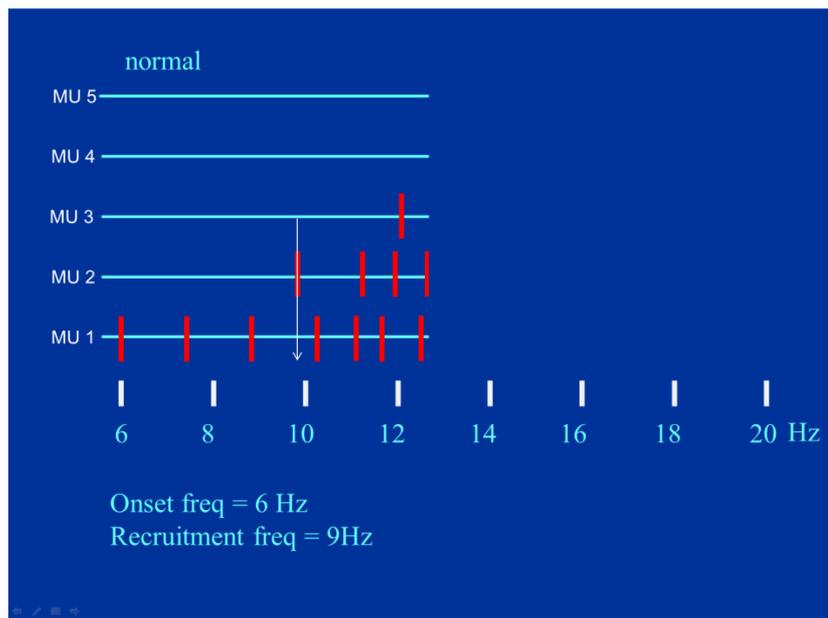
Individual MUPs are recording during slowly increasing force. A MUP from a given MU has constant shape throughout the recording (except for some small jitter) and different from MUPs from other MUs.



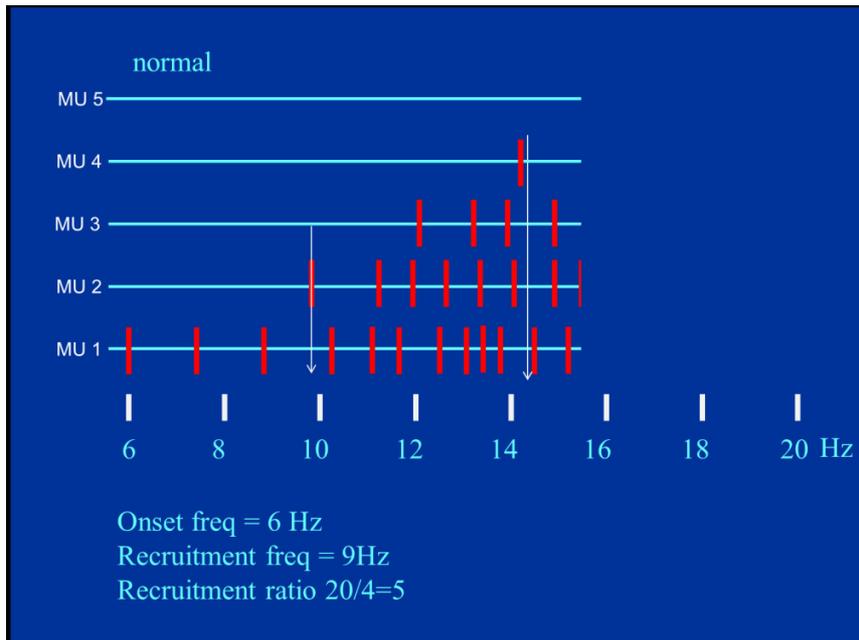
This techniques has not been general popularized, since there is no definition of "next MU". In this example why is the double peaked signal not included?



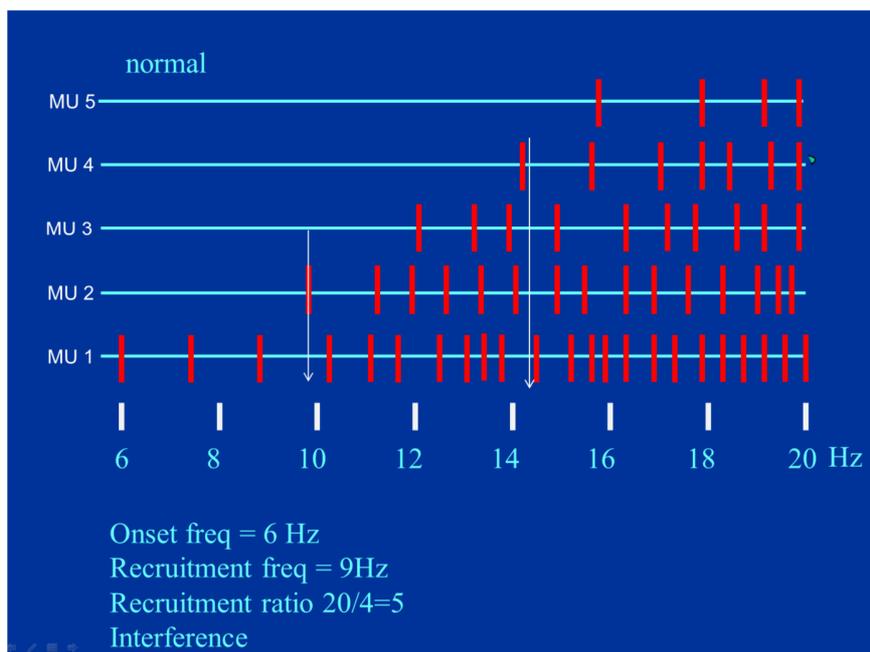
minimal contr



second MU starts

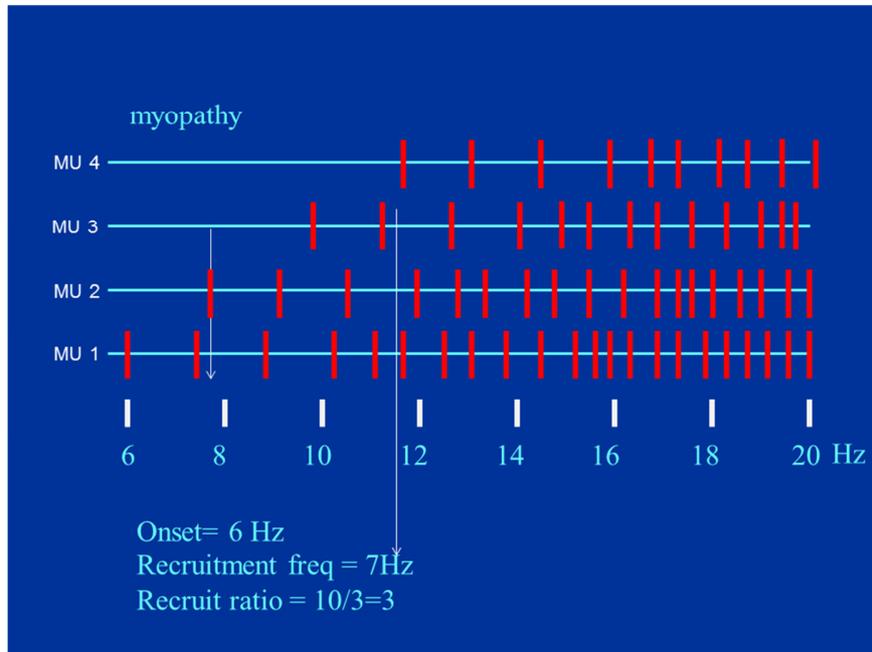


more MUs with stronger contraction

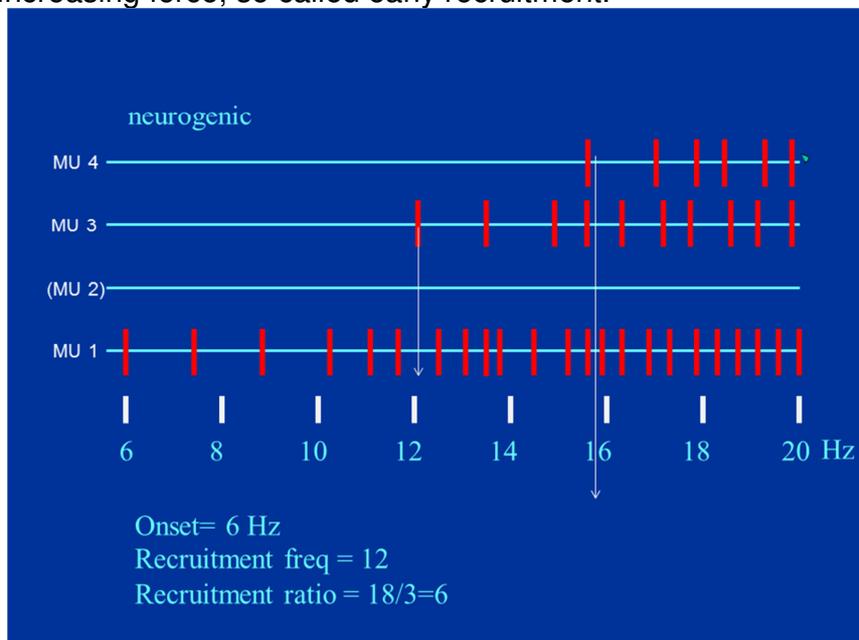


Pattern at moderate-strong contraction. Many MUs are active and their MUPs superimpose and analysis of individual firing rate cannot be done in a simple way.

Here we use other principles for signal analysis.



Pattern in myopathy. Note that MU 2 and successive MUs become active early during increasing force, so called early recruitment.



With loss of neurons, some MU do not fire (in this case MU2) and the Recruitment freq I increased. This is called Late recruitment, which means that next firing MU after the first, is activated when the first already has a relatively high firing rate. In this case 12Hz..

## 6. Special details in the firing pattern

Already with manual analysis it is possible to detect some physiological phenomena indicating how activity in one MU influences other Mus. With recruitment of a new MU there is an unloading of the neighboring spindle(s) which will influence the firing of already active MUs. This is seen in fig below

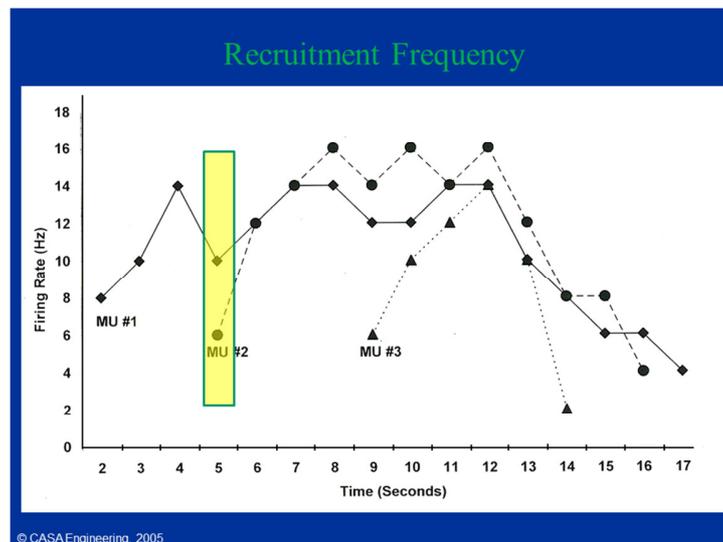


Fig from @CASA engineering, with permission

When MU2 starts. The firing rate of MU#1 is decreased from 14 to 10 Hz.

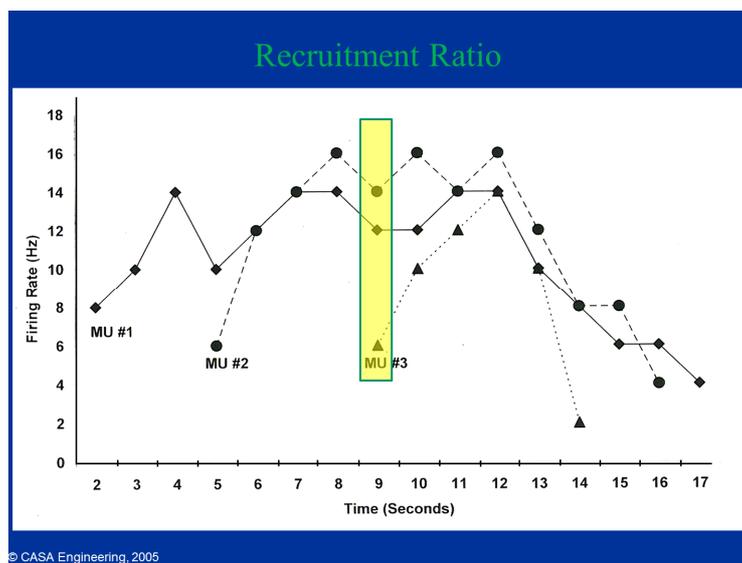


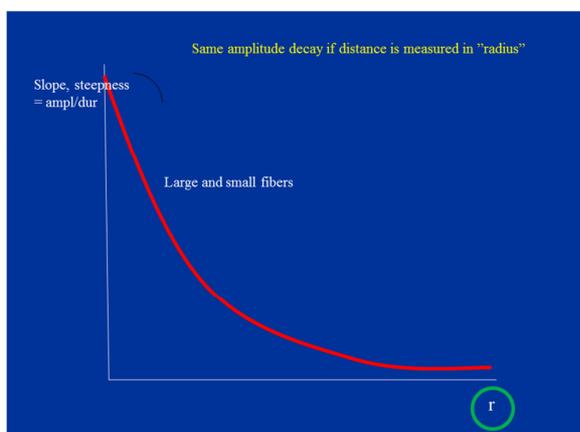
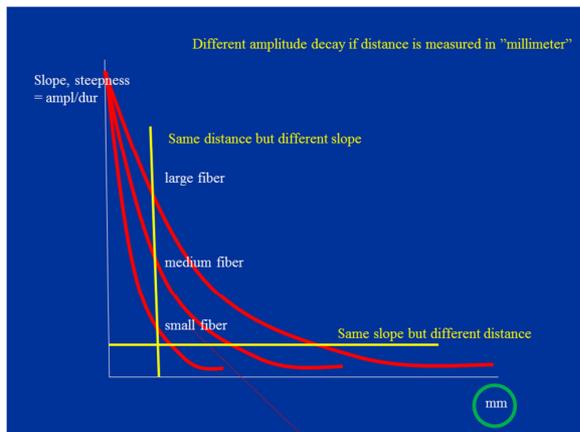
Fig from @CASA engineering, with permission

Similarly, when MU#3 starts, the MUs, already active, will decrease in firing rate

## 7. Why is there no simple automatic analysis of firing pattern?

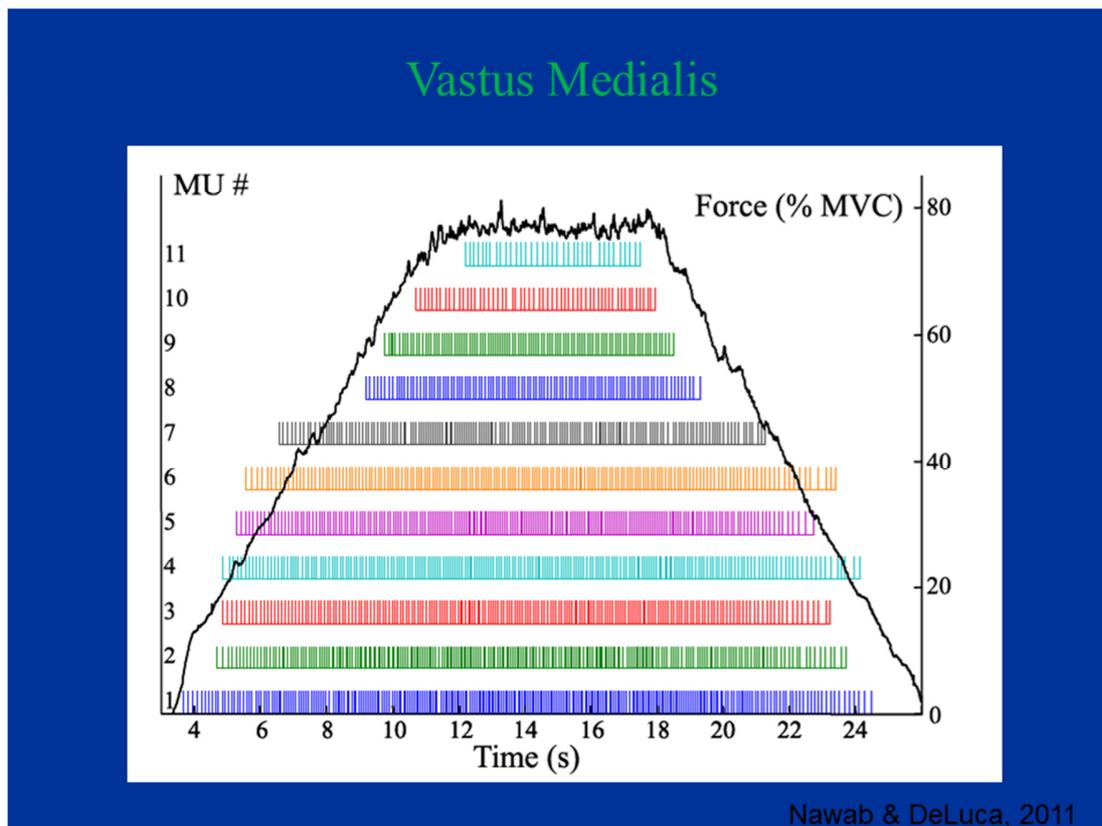
One reason is the lack of definitions of MU#1, MU#2 and so on. The difficulties come from the fact that the MUP shape declines continuously with recording distance. For individual muscle fibers, the decay with distance has been studied by many authors. There is an exponential decay in amplitude and a parallel increase in slope (slope is speed of rising phase). The numerical data are difficult to assess. Large muscle fibers start with a high amplitude close to the electrode but decreases with a curve that is similar to the small muscle fiber, which starts with a lower amplitude. That means that a specific amplitude measure cannot be used, since 200  $\mu\text{V}$  can be generated by a relatively remote large fiber or a close small fiber. The slope also reflects the distance, steepest close to the electrode. Thus the curves for amplitude decay and e.g. slope/amplitude is different for large and small fiber. This difference is not seen when distance is measured as number of fiber radii, see next fig.

In effect, we get a mix of variables that determines the MUP shape. One pragmatic solution is to define a minimal amplitude for different slope values or a minimal amplitude requiring a certain slope. The cut of limits, will thus be arbitrary. In other such situations the limits should have a general fit to the visual impression..



## 8. Advanced firing pattern analysis

With different algorithm for signal decomposition, every MUP can be detected and its firing pattern can be analyzed with high precision. This is so far only implemented in research centers.



Firing rate with increasing and decreasing force. From de Luca, 1964