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Slovenian-Italian Workshop on Quantitative Needle and High Resolution Surface EMG

University Medical Centre Ljubljana, Division of Neurology

Basic concepts and applications of multichannel surface EMG

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Prof. Lojze Vodovnik has been one of my many mentors and has strongly influenced my career, my approach to research and my way of thinking about problems.

He has also been a very good friend.
I am in debt with him for his teachings.

This lecture is dedicated to his memory.

WHAT SURFACE EMG IS AND IS NOT

1. Surface EMG is not a diagnostic technique and is not intended to replace needle EMG.
2. Surface EMG is a monitoring technique suitable to study movement and neuromuscular control and to assess muscle changes due to aging, pathology, therapy, training, immobilization, lack of gravity, occupational disorders, etc.
3. Standards are lacking: there have been successful EU efforts to reach consensus and disseminate recommendations (SENIAM, h.hermens@rrd.nl), and develop applications (PROCID, roland.kadefors@niwl.se; NEW, roberto.merletti@polito.it; OASIS, paul.enck@uni-tuebingen.de; CYBERMANS, alessandro.levizzari@crf.it)
4. There is a need for teaching and training in the medical schools.

With respect to the needle technique, the surface technique:

1. Is non invasive, non painful and without risks
2. Is global (provides global information)
3. Is simple and inexpensive
4. Is applicable by non medical personnel
5. Can be used over long times during work and sport activities
6. Allows the measurement of quantities not measurable with needles
7. Does not allow the measurement of quantities measurable with needles
8. Is complementary (not a replacement) to the needle technique

At this time (a.d. 2006) the limitations of surface EMG are:

1. Signals are dominated by the contributions of superficial motor units
2. The thickness of skin and subcutaneous fat causes strong blurring
3. Crosstalk from nearby muscles may be a serious problem
4. Artifacts due to muscle movements (in dynamic contractions) may be very strong

Main applications of needle EMG

1. Diagnostics based on observations of single (or very few) motor unit action potentials and of their morphology and “sound”.

2. Fibrillation potentials in denervated fibers

3. Identification of MU territory (macro EMG)

4. All the above can be done or observed in either superficial or deep muscles.

Main applications of surface EMG

1. **Biomechanics and movement analysis:**
   Identification of muscle activation intervals and levels, muscle coordination
2. **Muscle fatigue and non invasive fiber typing:**
   Monitoring myoelectric manifestations of muscle fatigue, electrical and mechanical responses of single motor units
3. **Muscle physiopathology:**
   Monitoring muscle fiber conduction velocity, motor unit recruitment order
4. **Occupational medicine:**
   Monitoring the “Cinderellas”, postural problems, muscle hyperactivity
5. **Rehabilitation, space and sport medicine:**
   Assessment of effectiveness of treatments and training, monitoring microgravity related changes and effectiveness of countermeasures
6. **Pelvic floor analysis:**
   Detection of sphincter asymmetry, prevention of episiotomy related lesions.
7. **Biofeedback:**
   Tension headache, muscle retraining, coordination retraining

Why EMG processing ?

To document differences between individuals and conditions (young-elderly, before-after treatment or training, etc) by reporting EMG "descriptors", that is physical variables associated to the EMG signal. To observe central and peripheral phenomena (such as myoelectric manifestations of muscle fatigue, activation patterns, control strategies, etc), to assess effectiveness of treatments.

What descriptors ?

2 electrodes: Amplitude (ARV, RMS), frequency (MNF, MDF), amplitude envelope, activation times during isometric or dynamic contractions.

4 electrodes: as above plus conduction velocity (CV), correlation coefficient (CC) between the signals used for CV estimation.

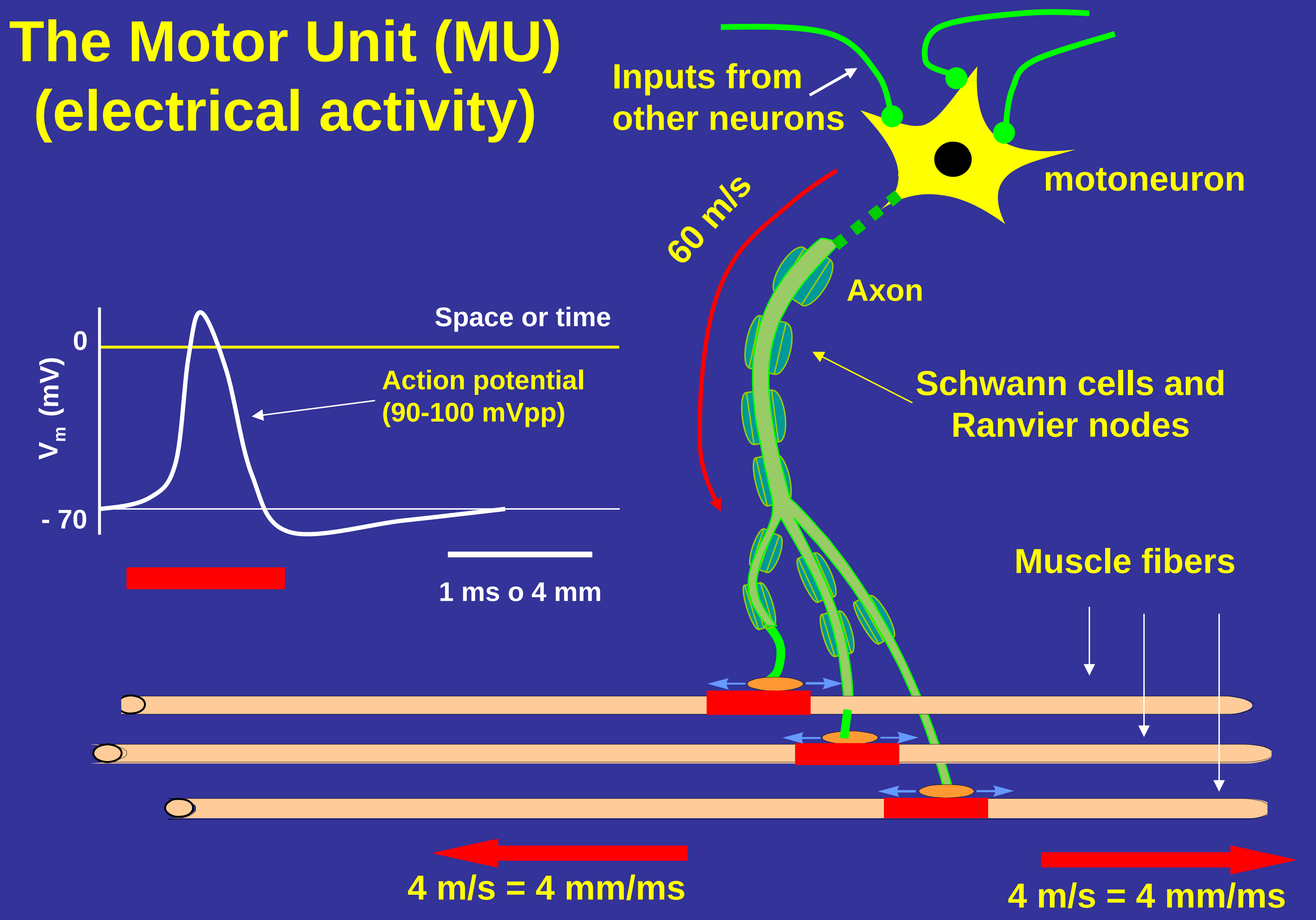
5-16 or more electrodes in a linear array: descriptors of individual motor units such as location of innervation zone, fiber length, highly accurate CV estimates, firing rate, recruitment pattern, etc.

What conditions ?

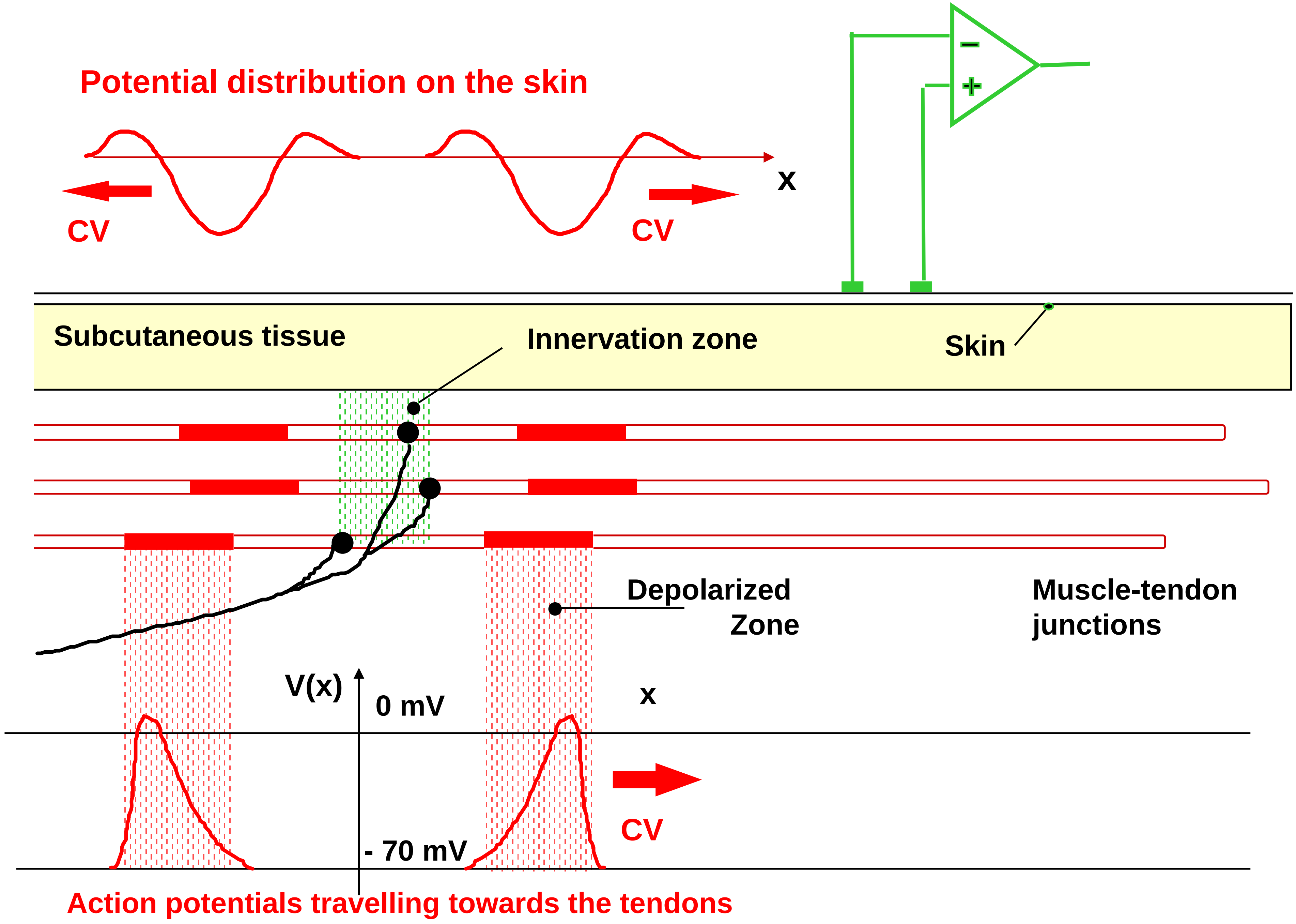
Isometric conditions: these are special "bench-tests" to estimate values that are much more difficult to estimate in dynamic conditions (rates of change of descriptors, single Motor Unit features, etc).

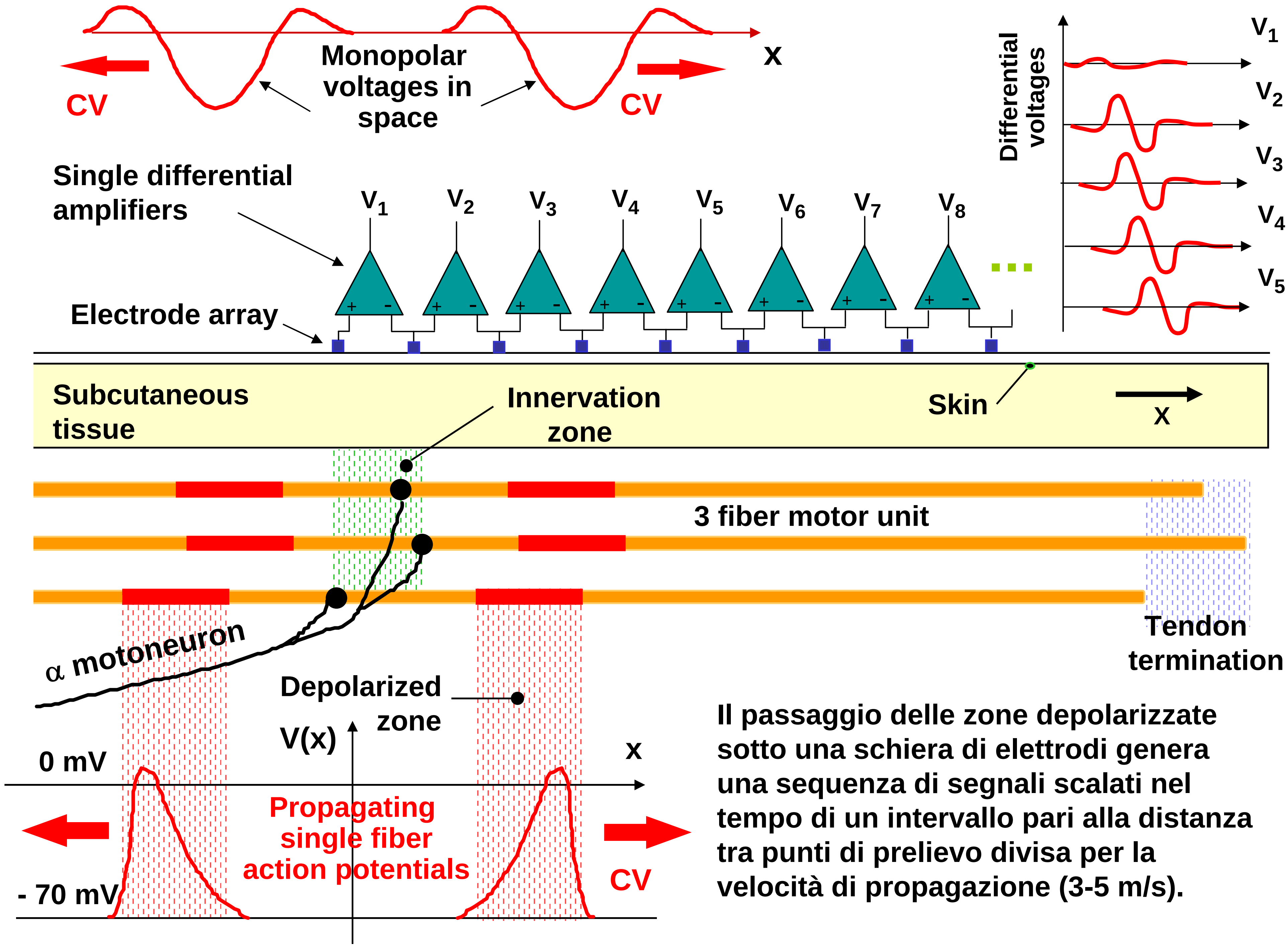
Dynamic conditions: activation intervals (muscle on-off timing) during movements, envelope detection, etc. These conditions are of greater physiological interest but are affected by artifacts and may not produce reliable results.

The Motor Unit (MU) (electrical activity)

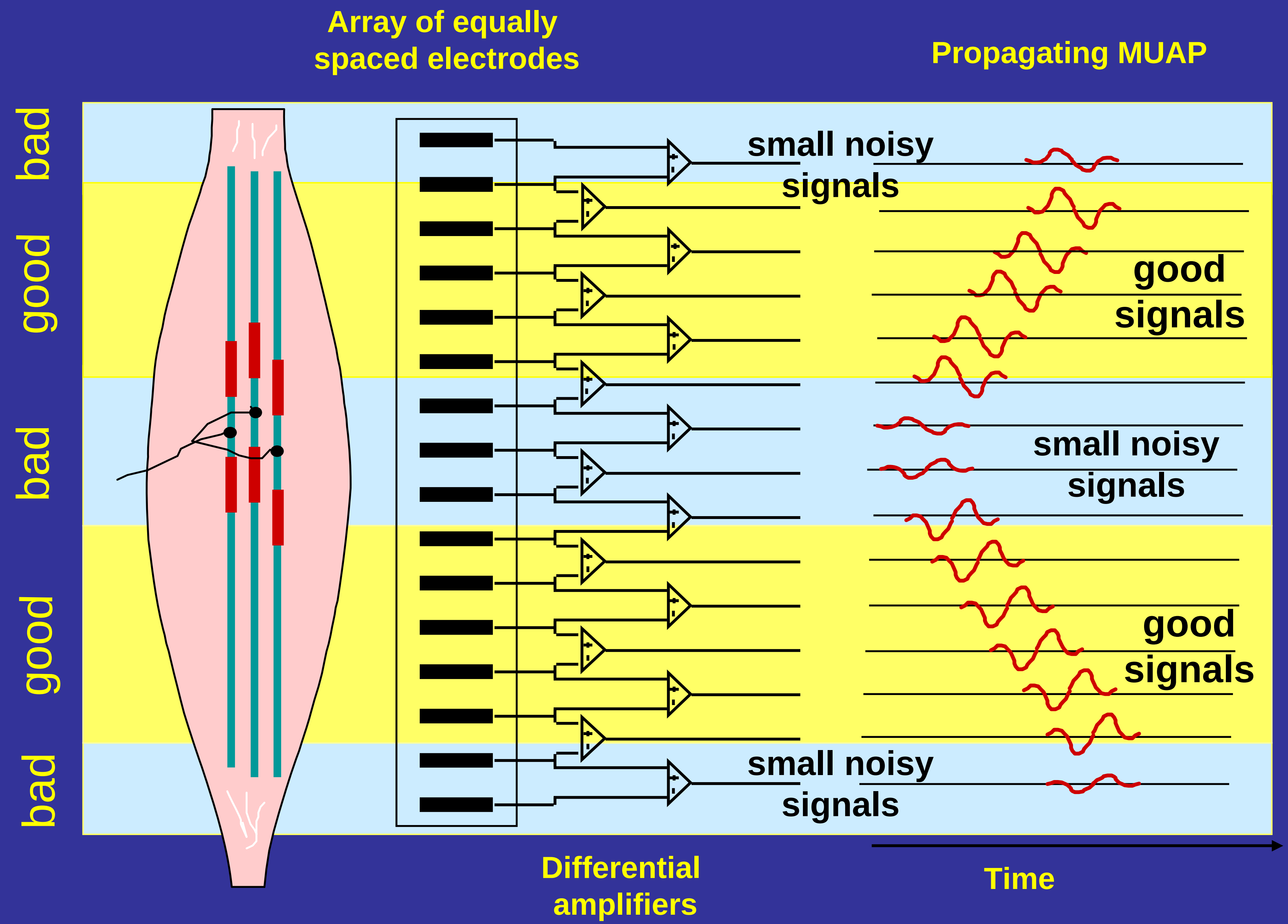


One muscle: 10-1000 MU One MU: 50-1000 fibers of the same type (I o II)


Potential distribution on the skin
x
CV
CV
Subcutaneous tissue
Innervation zone
Skin
Depolarized
Zone
Muscle-tendon
junctions
V(x)
0 mV
x
CV
- 70 mV
Action potentials travelling towards the tendons

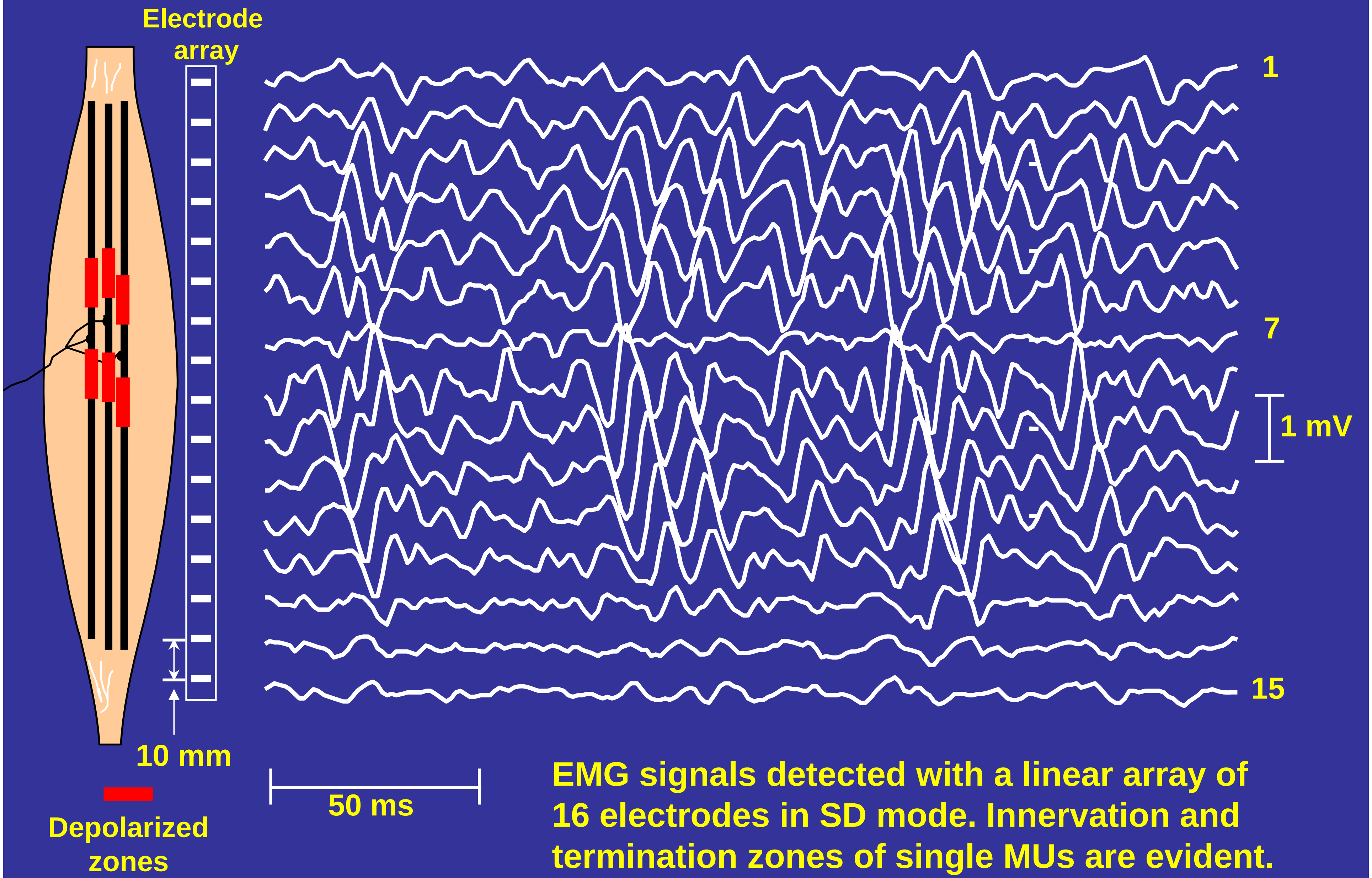


Il passaggio delle zone depolarizzate sotto una schiera di elettrodi genera una sequenza di segnali scalati nel tempo di un intervallo pari alla distanza tra punti di prelievo divisa per la velocità di propagazione (3-5 m/s).



Two electrodes placed symmetrically over the I.Z. give unreliable information.

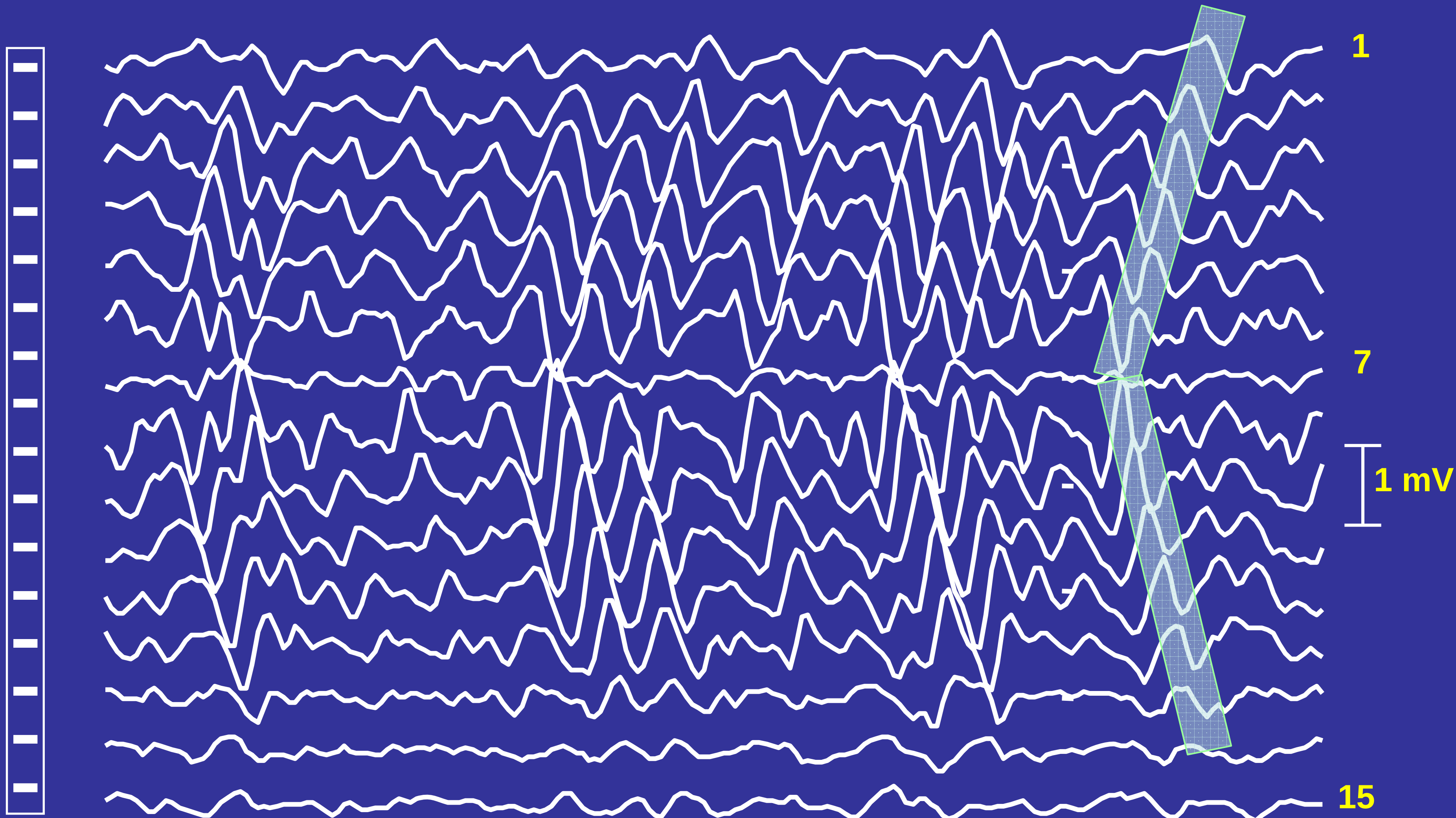
Biceps brachii muscle contracting at 70% MVC



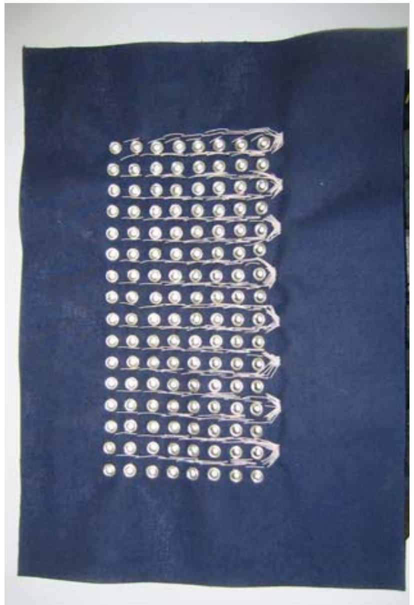
EMG signals detected with a linear array of 16 electrodes in SD mode. Innervation and termination zones of single MUs are evident.

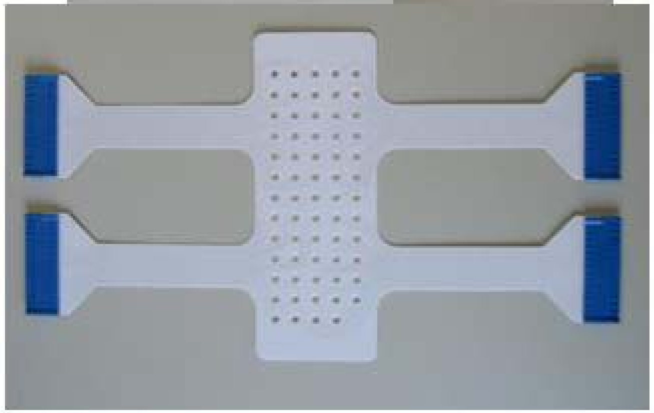
Global analysis and single MU analysis

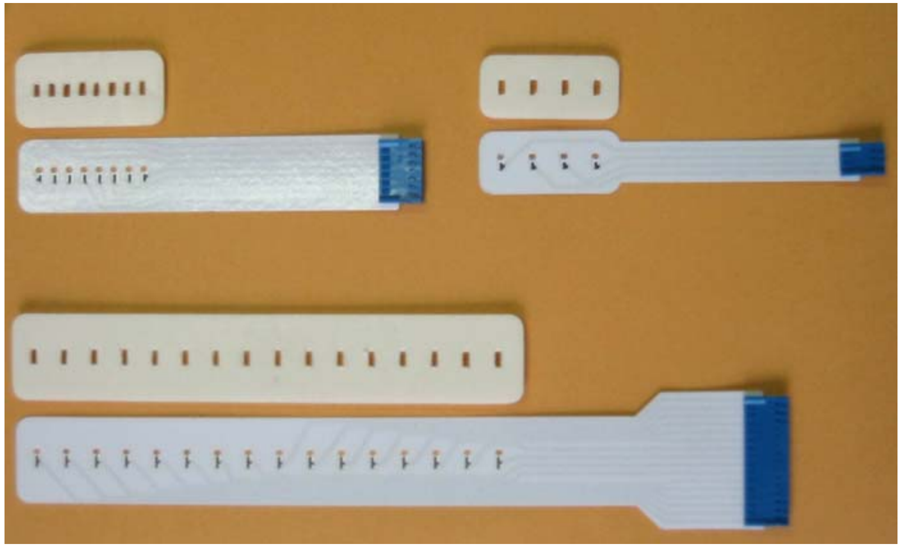
Information may be extracted either from the interferential signal (global level) or from the single MUAP (MU level).



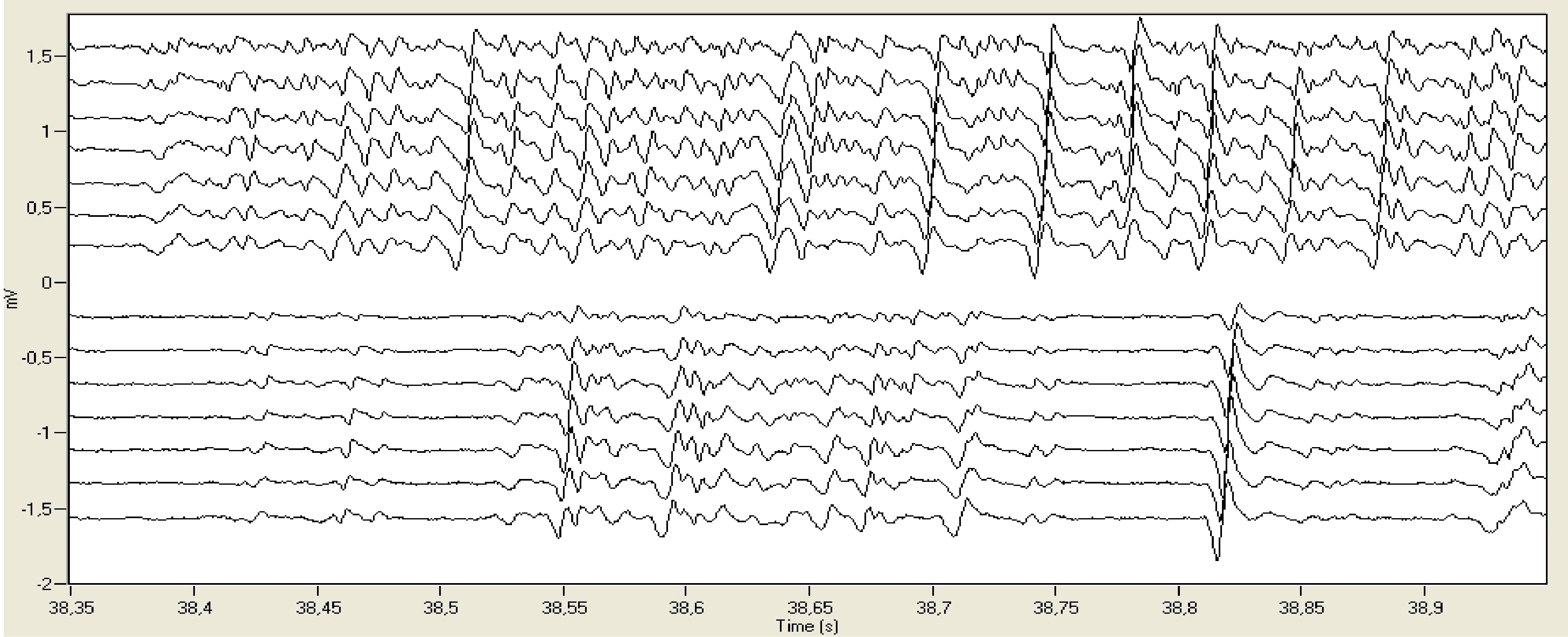
Electrode arrays and amplifiers

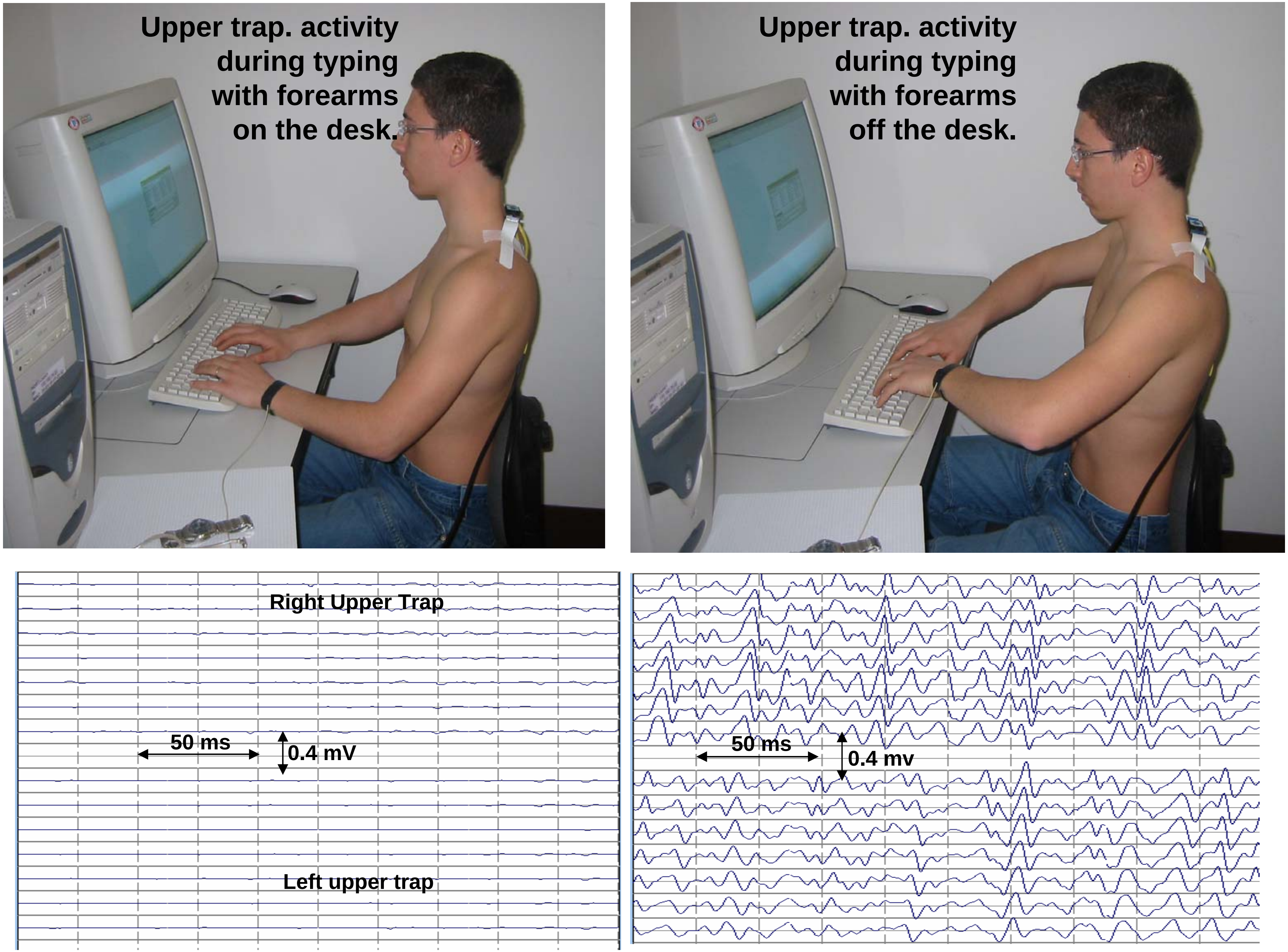




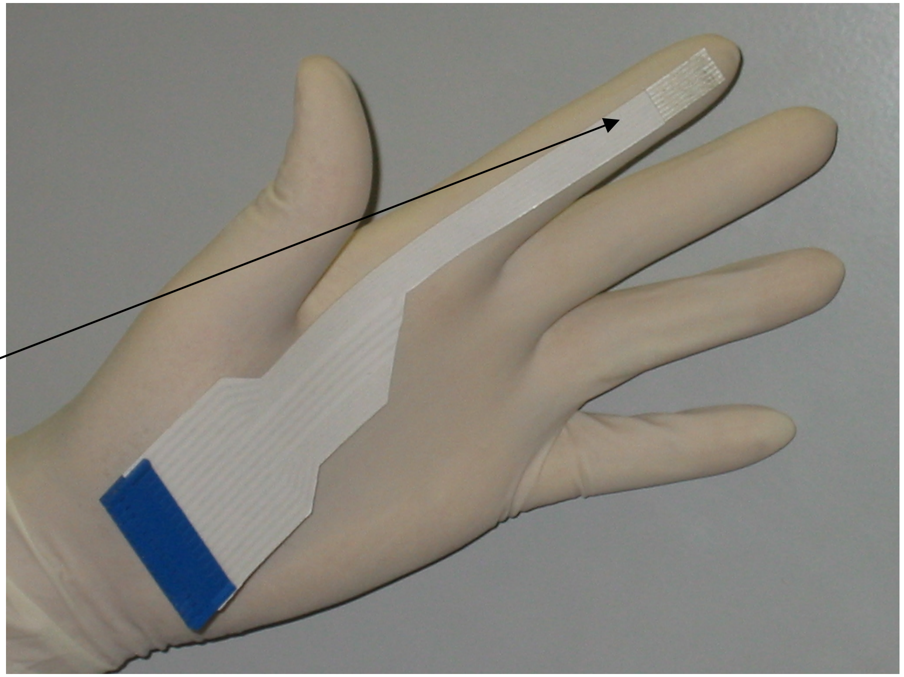


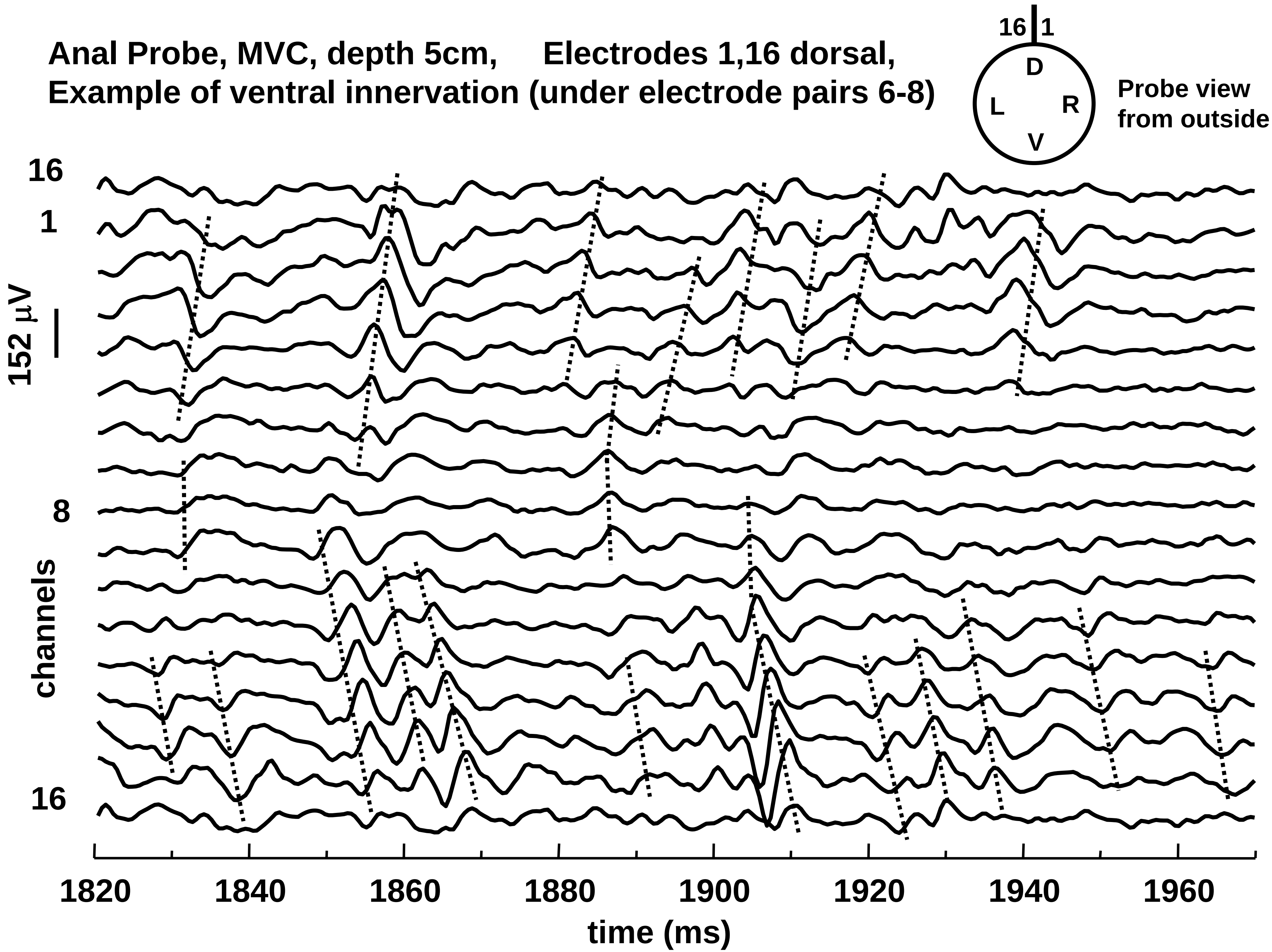
Signals from right and left trapezius during typing (project NEW)




Upper trap. activity during typing with forearms on the desk.
Upper trap. activity during typing with forearms off the desk.
Right Upper Trap
50 ms
0.4 mV
Left upper trap
50 ms
0.4 mv

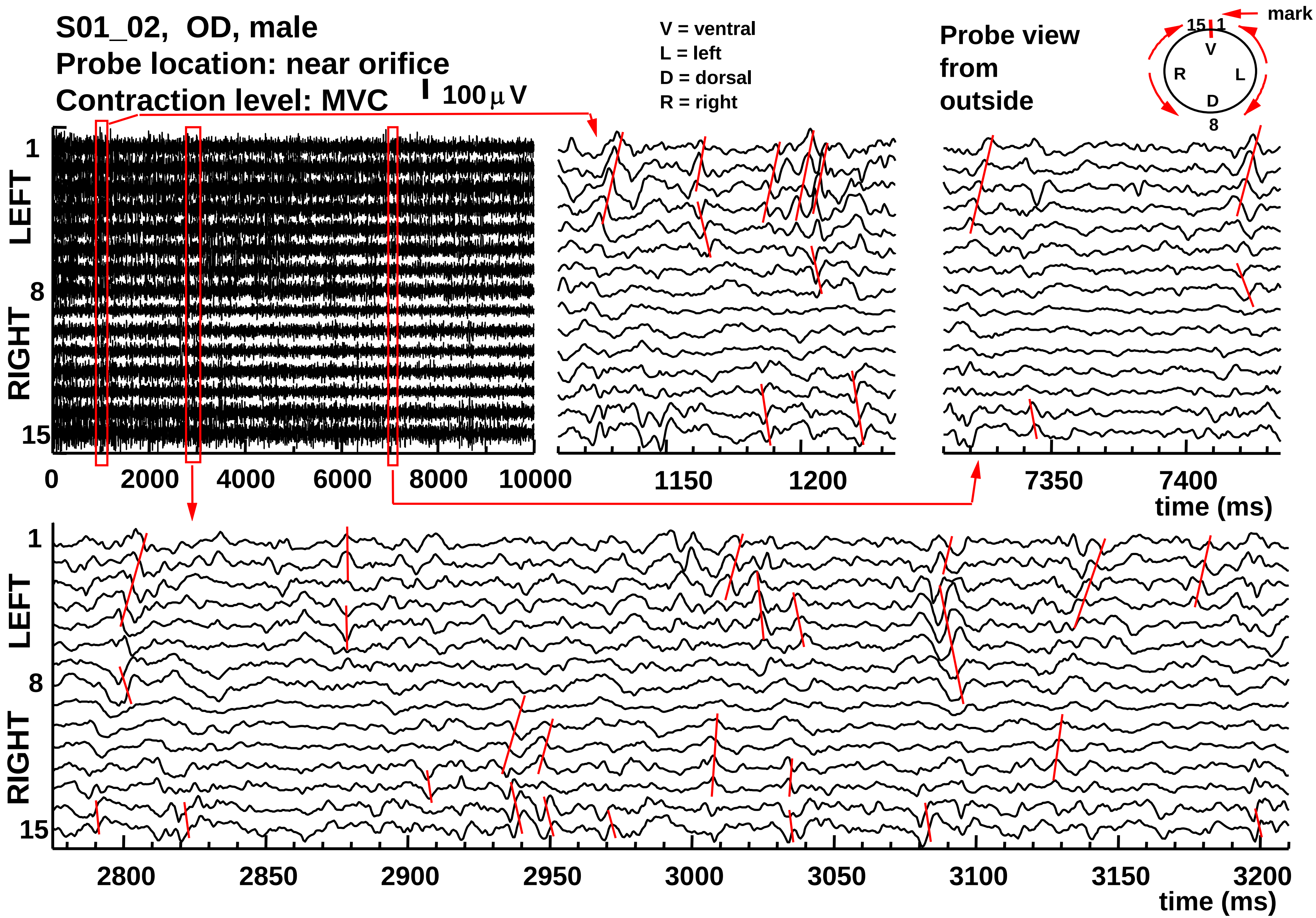

Anal probe
16 Electrodes
Pressure sensor
Anal probes
(1 array and
3 arrays with
16 electrodes
each)
Urethral
probe

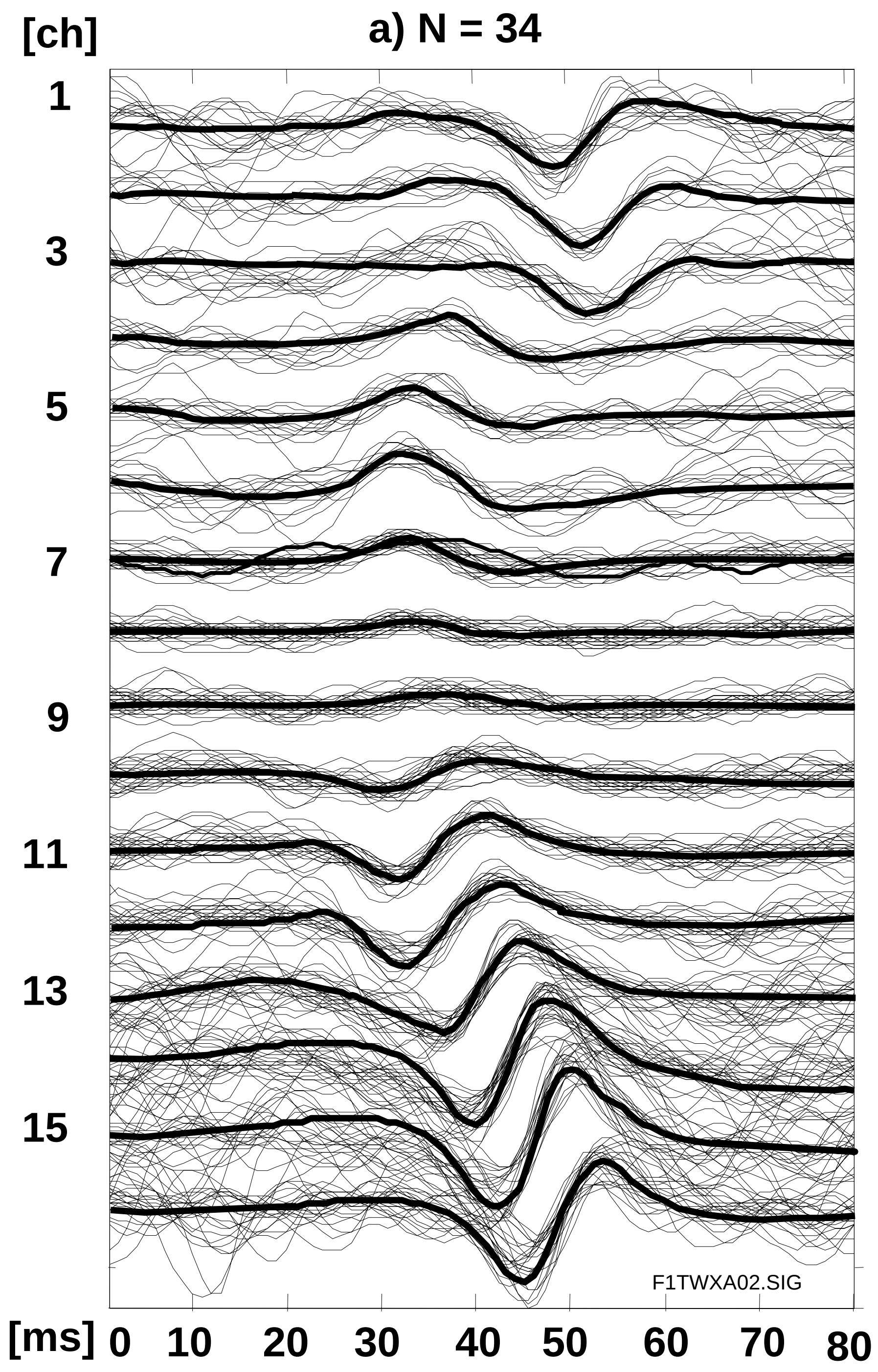

Stick-on array for
puborectalis muscle
(8 electrodes)



Anal Probe, MVC, depth 5cm, Electrodes 1,16 dorsal,
Example of ventral innervation (under electrode pairs 6-8)
16
1
D
L
R
V
Probe view
from outside
16
1
8
16
152 μV
channels
1820
1840
1860
1880
1900
1920
1940
1960
time (ms)

Anal recording, max. voluntary contraction (observe asymmetry)




a) N = 34
b) N = 40
[ch]
1
3
5
7
9
11
13
15
[ms]
0
10
20
30
40
50
60
70
80
F1TWXA02.SIG
F1TQCA04.SIG

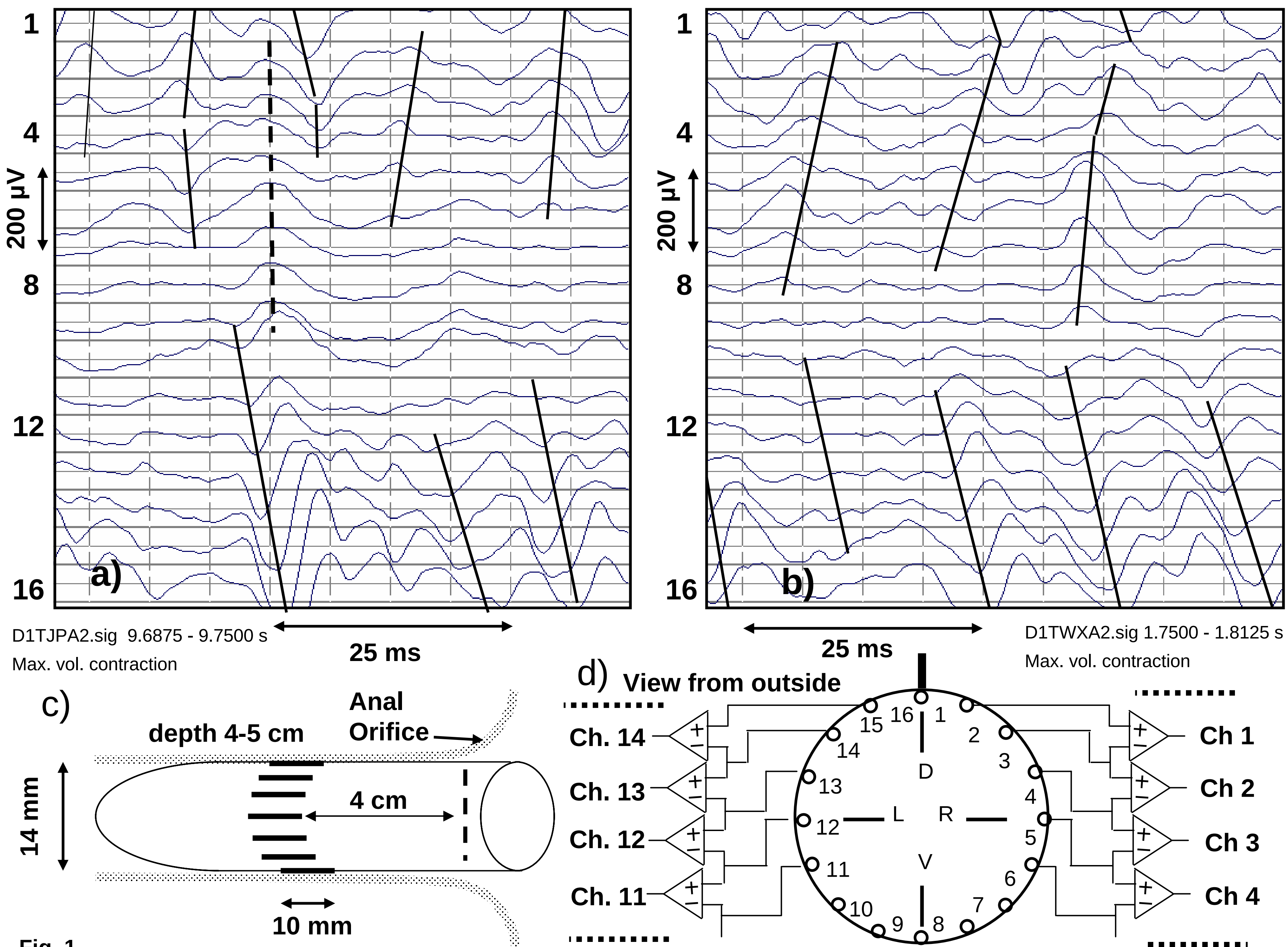

1
4
8
12
16
200 µV
a)
D1TJPA2.sig 9.6875 - 9.7500 s
Max. vol. contraction
25 ms
b)
D1TWXA2.sig 1.7500 - 1.8125 s
Max. vol. contraction
c)
depth 4-5 cm
Anal Orifice
14 mm
4 cm
10 mm
d)
View from outside
Ch. 14
Ch. 13
Ch. 12
Ch. 11
Ch 1
Ch 2
Ch 3
Ch 4
D
L
R
V

Fig. 1

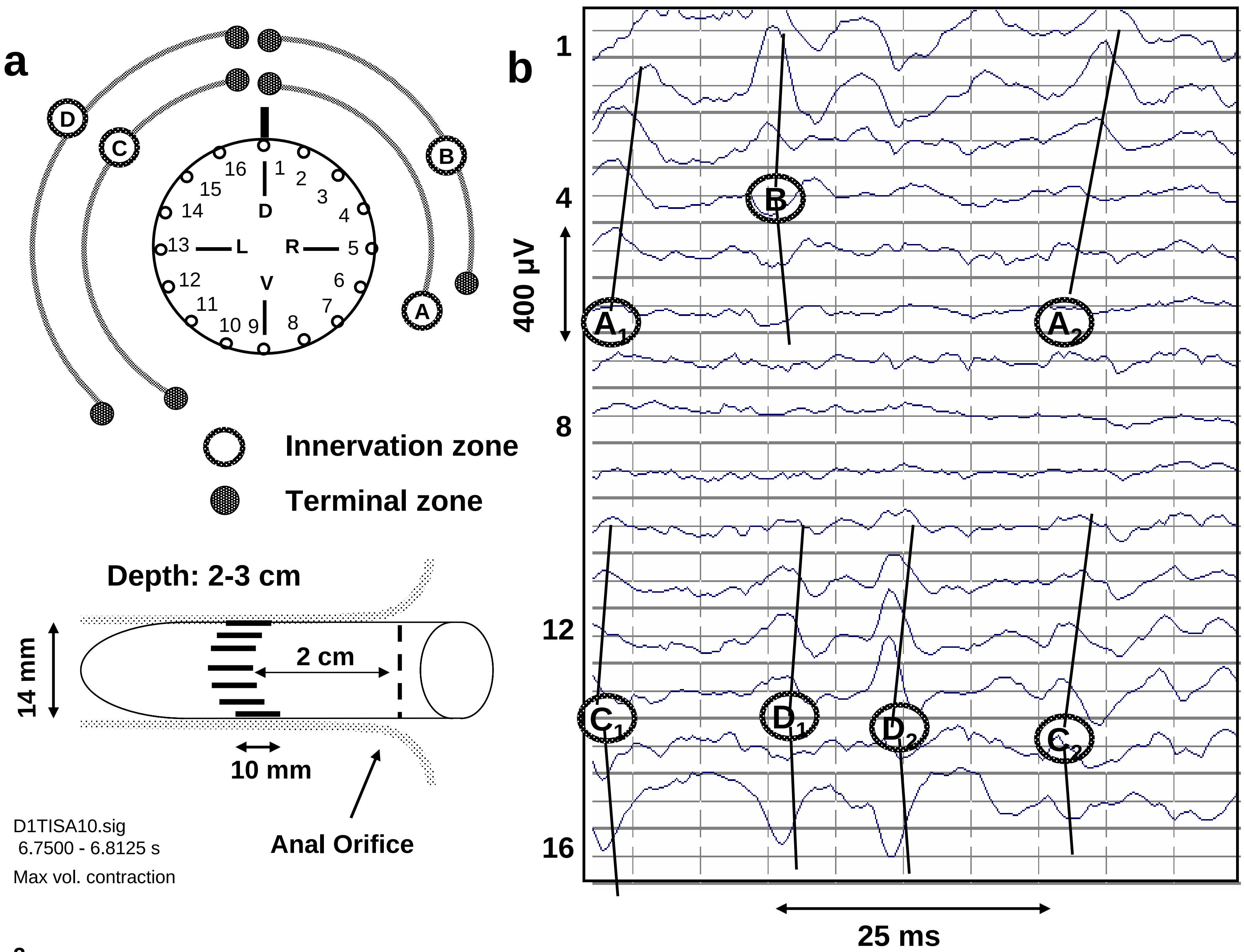
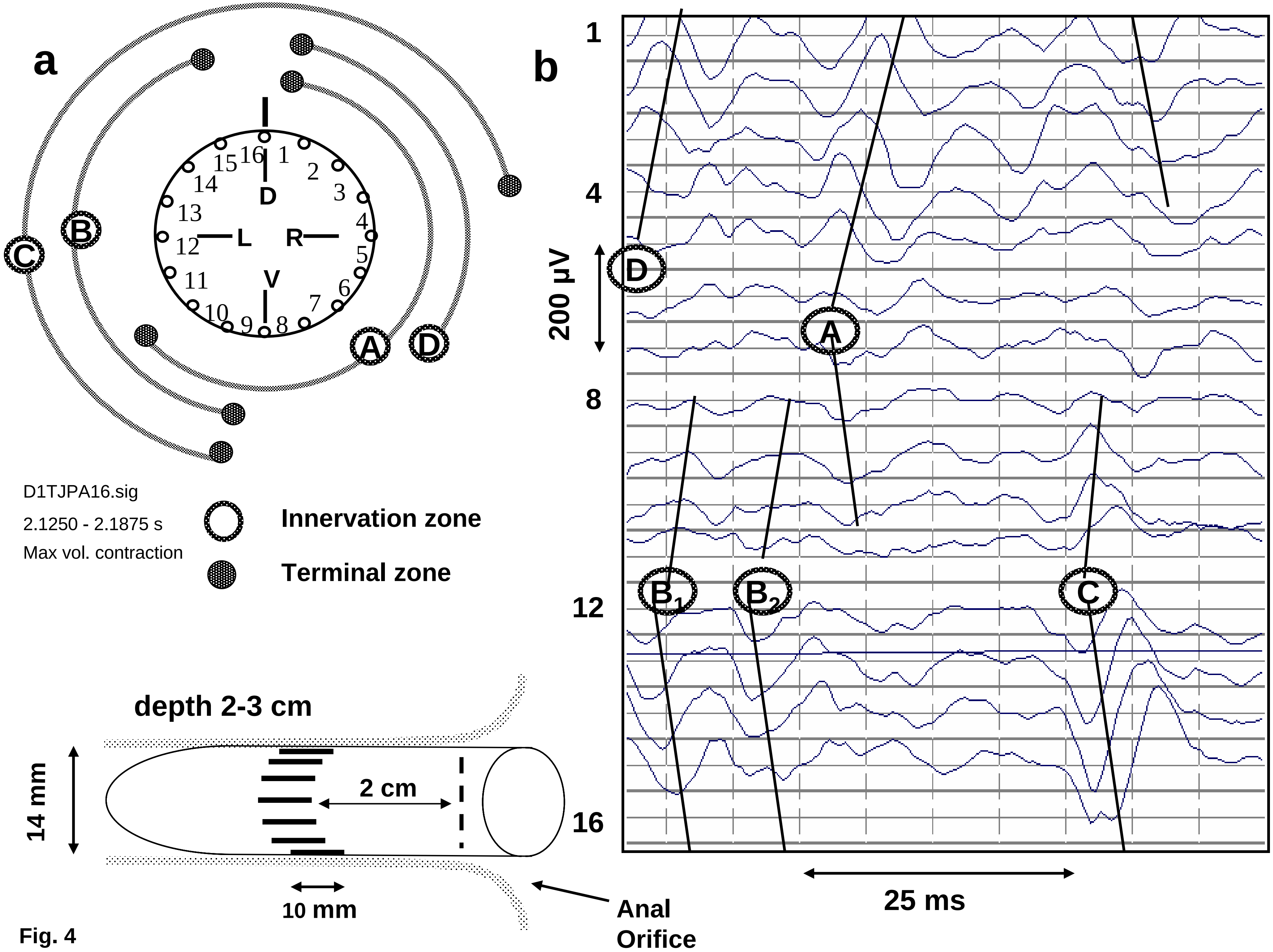

a
b
D
C
B
A
16
1
2
3
4
15
14
13
12
11
10
9
8
7
6
5
D
L
R
V
Innervation zone
Terminal zone
Depth: 2-3 cm
14 mm
2 cm
10 mm
Anal Orifice
D1TISA10.sig
6.7500 - 6.8125 s
Max vol. contraction
400 μV
25 ms
A1
A2
B
C1
C2
D1
D2

Fig. 3



a
16
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
D
L
R
V
A
B
C
D
D1TJPA16.sig
2.1250 - 2.1875 s
Max vol. contraction
Innervation zone
Terminal zone
depth 2-3 cm
14 mm
2 cm
10 mm
Anal Orifice
b
1
4
8
12
16
200 µV
D
A
B1
B2
C
25 ms

Fig. 4

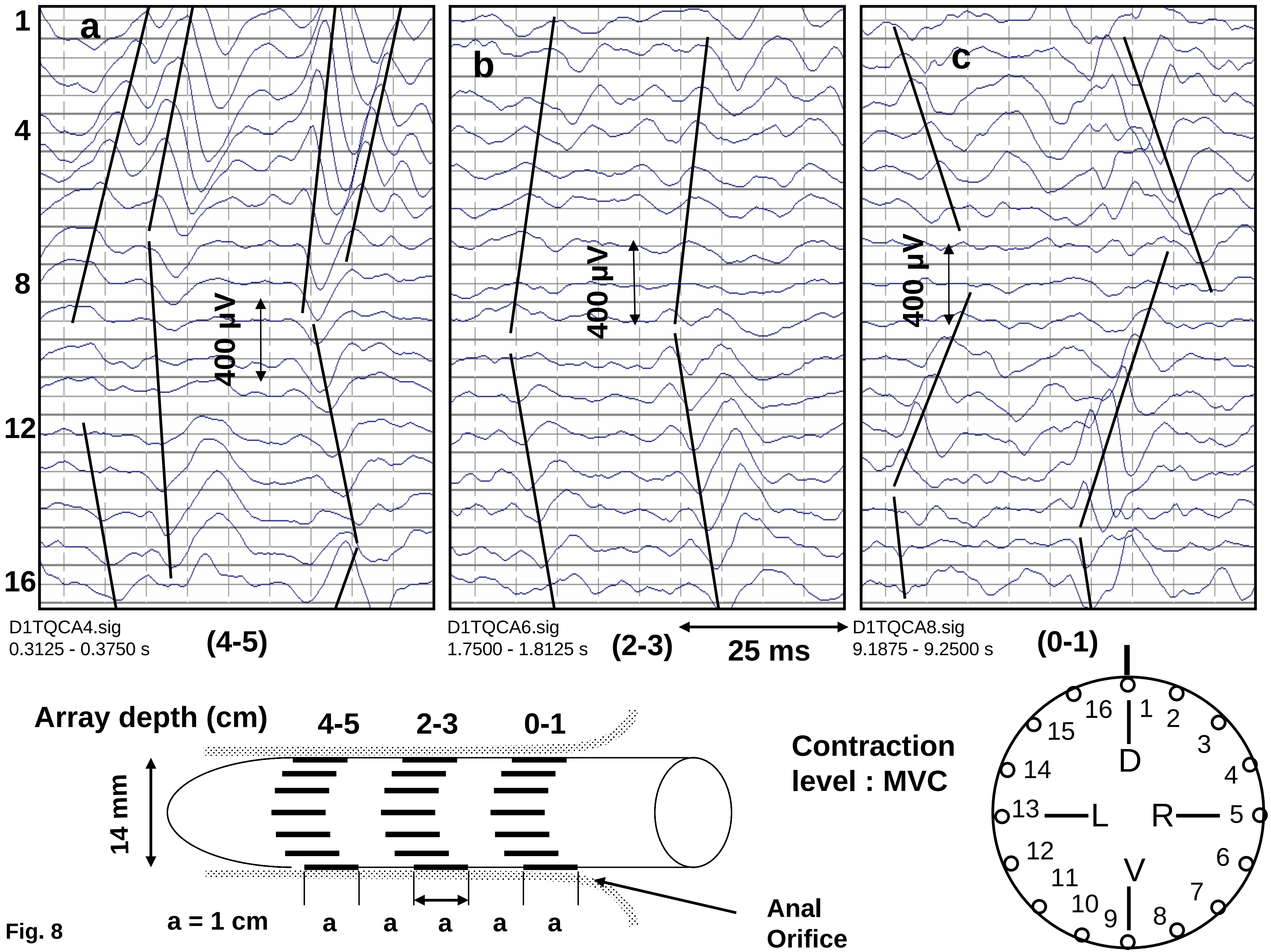

1
4
8
12
16
a
b
c
400 µV
400 µV
400 µV
D1TQCA4.sig
0.3125 - 0.3750 s
(4-5)
D1TQCA6.sig
1.7500 - 1.8125 s
(2-3)
25 ms
D1TQCA8.sig
9.1875 - 9.2500 s
(0-1)
Array depth (cm)
4-5
2-3
0-1
14 mm
a = 1 cm
a a a a a
Contraction level : MVC
Anal Orifice
D
L
R
V
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Fig. 8

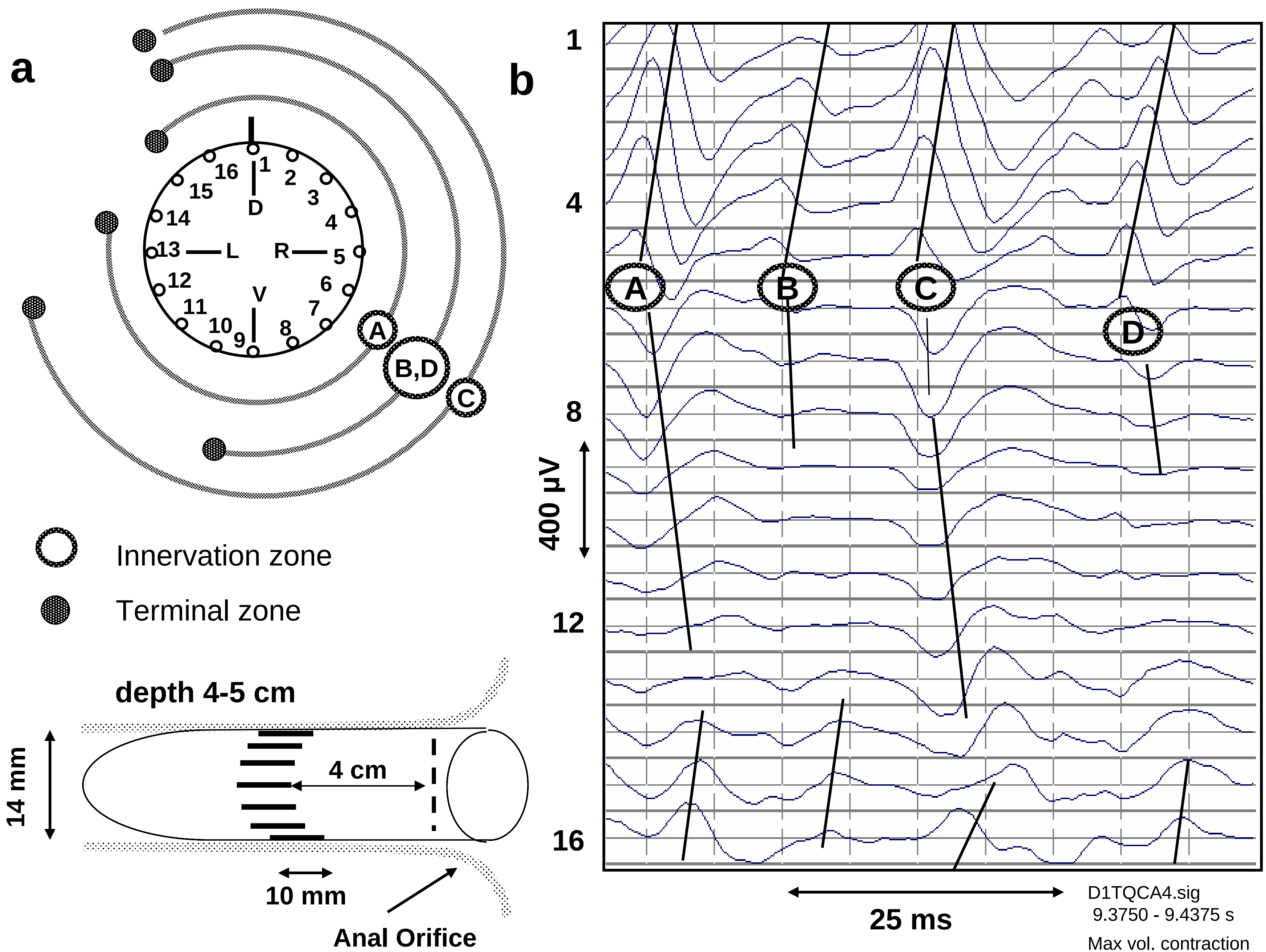
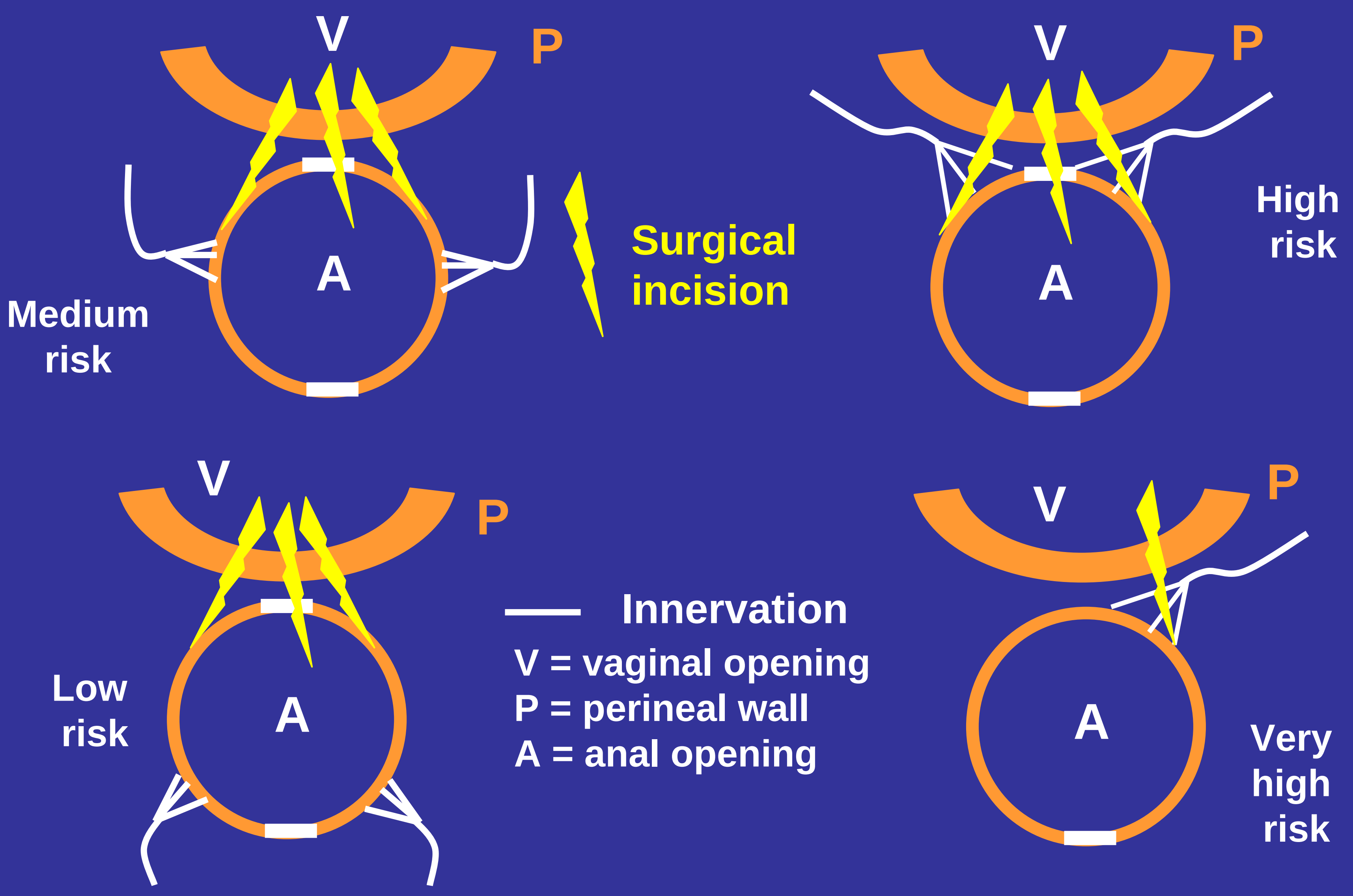

a
b
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
D
L
R
V
A
B,D
C
Innervation zone
Terminal zone
depth 4-5 cm
14 mm
4 cm
10 mm
Anal Orifice
400 µV
25 ms
D1TQCA4.sig
9.3750 - 9.4375 s
Max vol. contraction

Fig. 5

OASIS: possible sphincter damage due to episiotomy



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Editors

Urinary and Fecal Incontinence

An Interdisciplinary Approach

Chapter 34

Functional Asymmetry of Pelvic Floor Innervation and Its Potential Role in the Pathogenesis of Fecal and Urinary Incontinence – Report from the EU-sponsored Research Project OASIS (On Asymmetry In Sphincters) 34

Paul Enck, Fernando Azpiroz, Roberto Merletti

Contents

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2006 ISEK Congress Keynote Lecture

Electromyography of pelvic floor muscles

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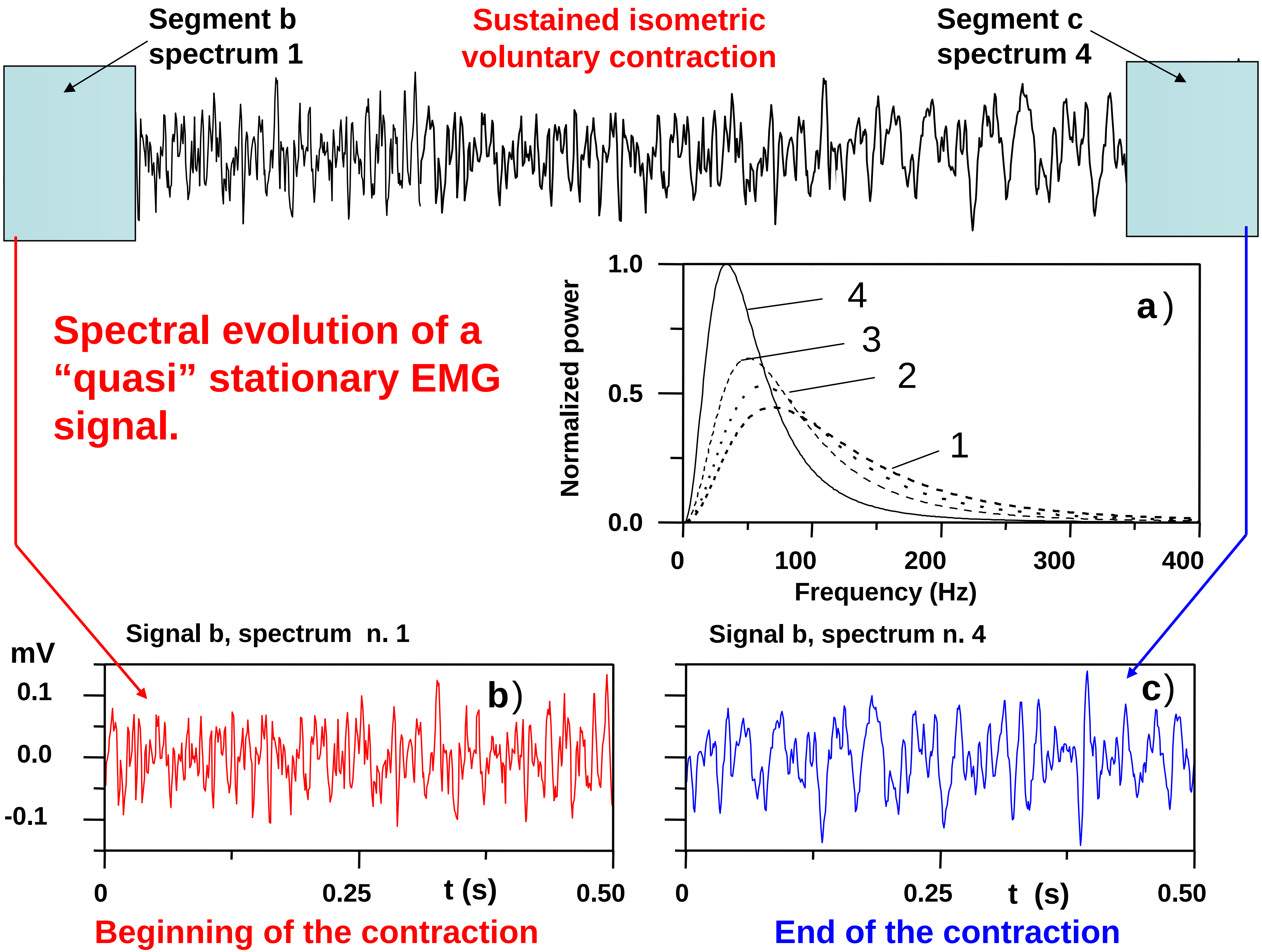
Abstract

Pelvic floor muscles (PFM) are intimately involved in function of lower urinary tract, the anorectum and sexual functions, therefore their neural control transcends the primarily important somatic innervation of striated muscle, as they are directly involved in "visceral activity". Neural control of pelvic organs is affected by a unique co-ordination of somatic and autonomic motor nervous systems. Visceral and somatic sensory fibres supply sensory information from pelvic organs; their input influences through central integrative mechanisms also pelvic floor muscle activity. Anatomically, somatic afferent and efferent nerves of the sacral cord segments, reflexly integrated at the spinal cord and brainstem level, conduct neural control of PFM. The inputs from several higher centres influence the complex reflex control and are decisive for voluntary control, and for socially adapted behaviour related to excretory functions.

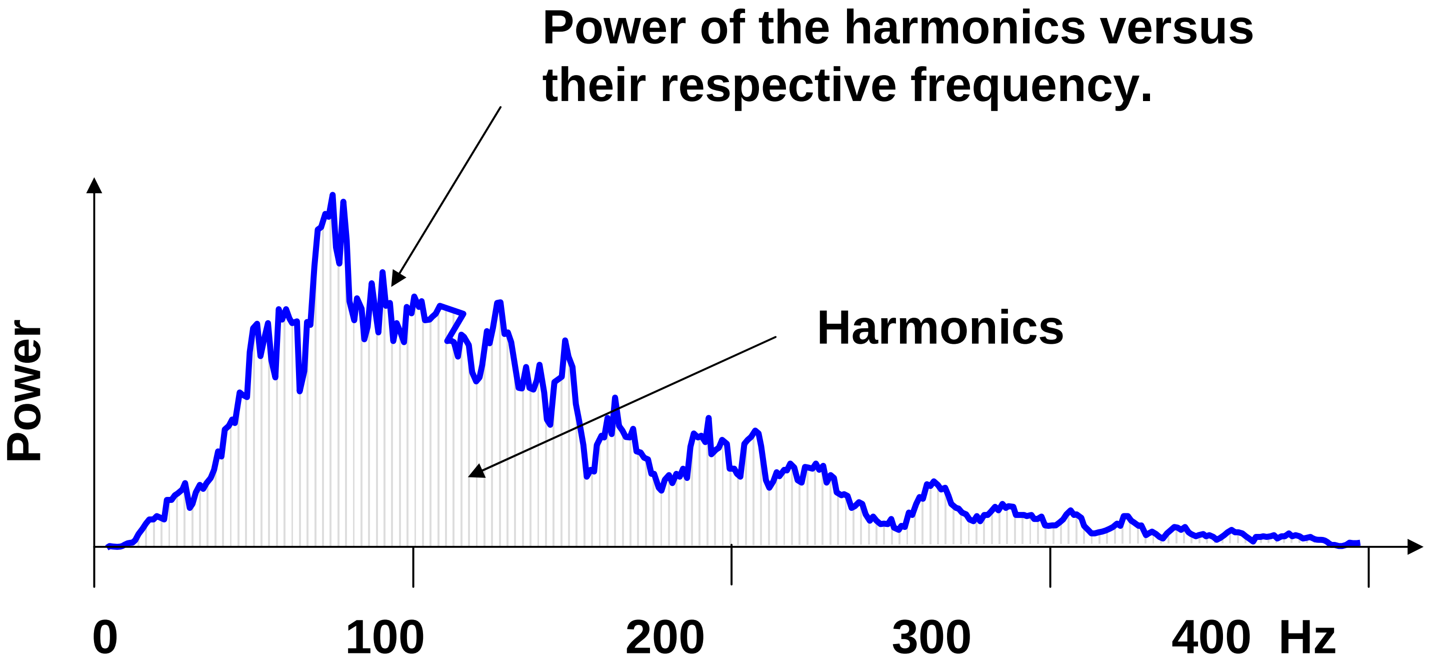
Myoelectric manifestations of muscle fatigue



Segment b
spectrum 1
Sustained isometric
voluntary contraction
Segment c
spectrum 4
Spectral evolution of a
"quasi" stationary EMG
signal.
Normalized power
1.0
0.5
0.0
4
3
2
1
a)
0
100
200
300
400
Frequency (Hz)
Signal b, spectrum n. 1
Signal b, spectrum n. 4
mV
0.1
0.0
-0.1
b)
c)
0
0.25
t (s)
0.50
Beginning of the contraction
End of the contraction

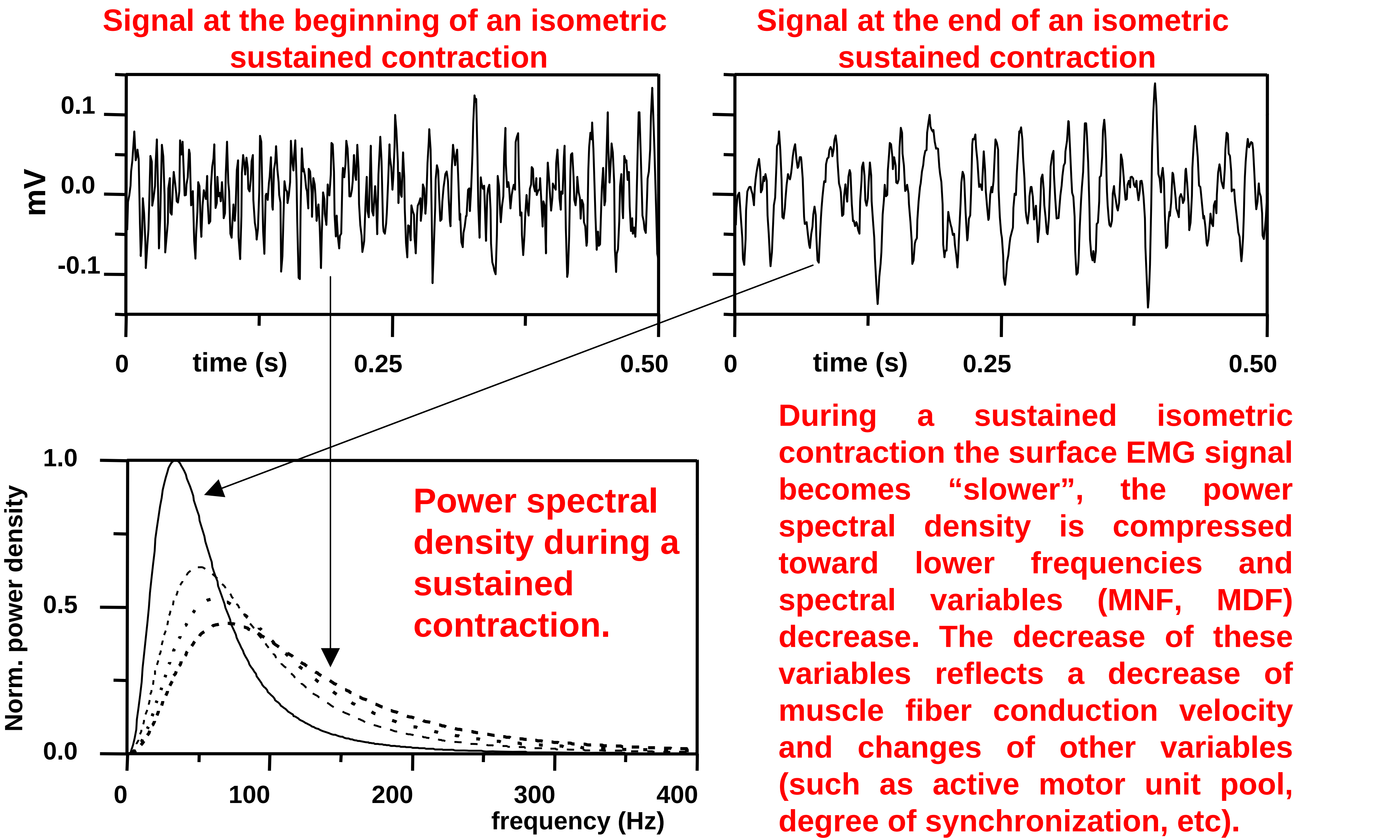
EMG power spectrum

The power of the EMG signal is distributed in the frequency range 10-400 Hz



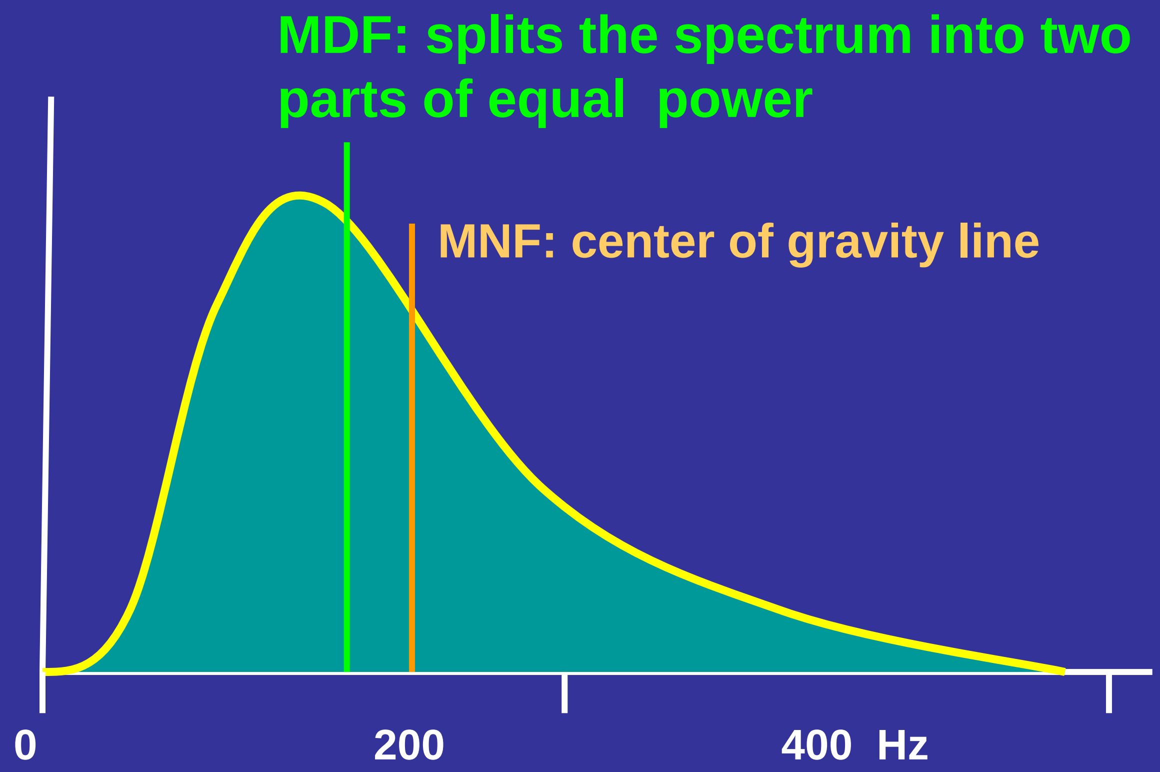
The spectrum of the EMG signal changes as a function of time during an isometric constant force sustained contraction , because muscle fiber conbduction velocity and motor unit action potential shape change in time. These parameters recover quickly and there change may be small during intermittent contractions.

Myoelectric manifestations of muscle fatigue



During a sustained isometric contraction the surface EMG signal becomes “slower”, the power spectral density is compressed toward lower frequencies and spectral variables (MNF, MDF) decrease. The decrease of these variables reflects a decrease of muscle fiber conduction velocity and changes of other variables (such as active motor unit pool, degree of synchronization, etc).

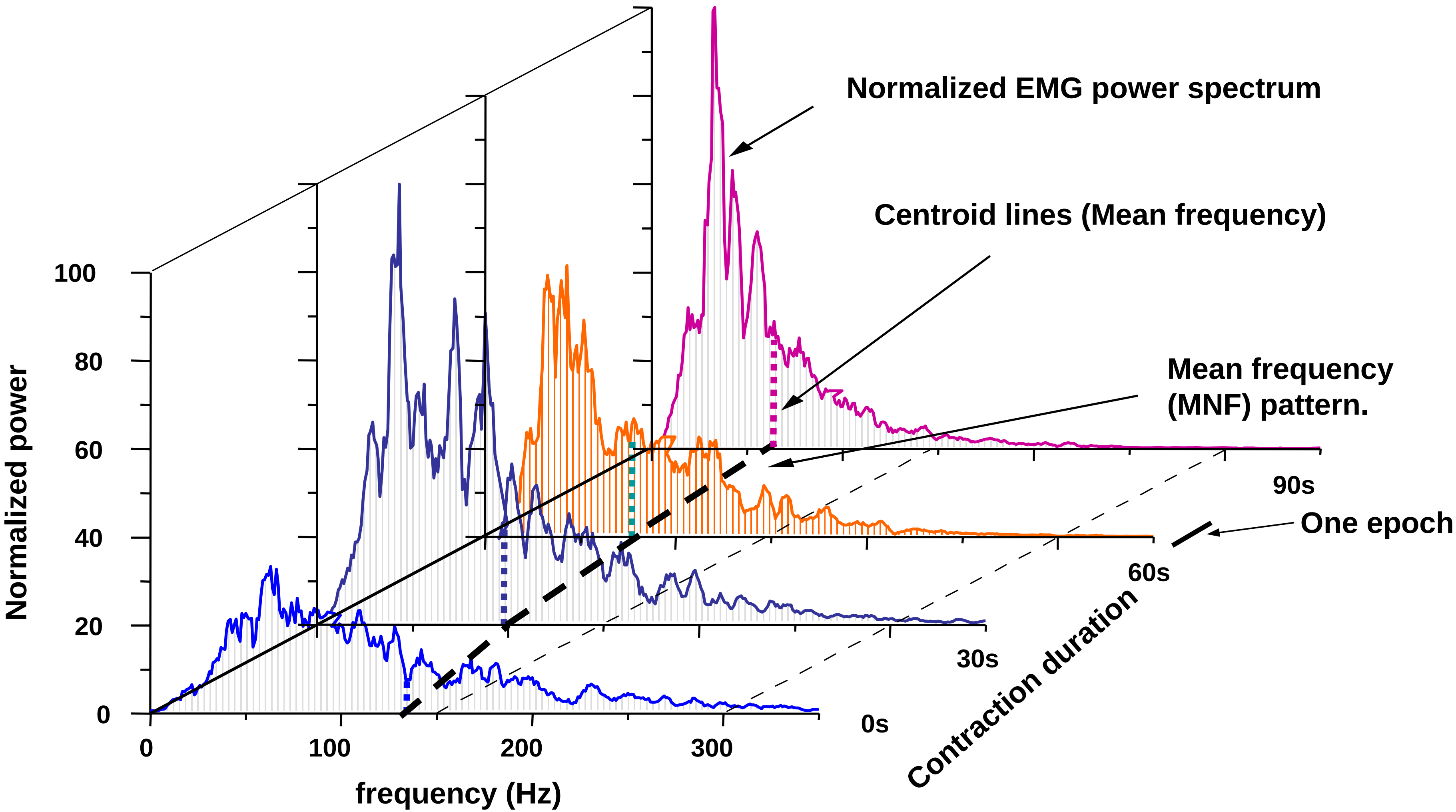
Mean and median spectral frequenclies of the EMG signal (MNF and MDF)



$$f_m = \int_0^{\infty} f\,P(f)df \Big/ \int_0^{\infty} P(f)d$$

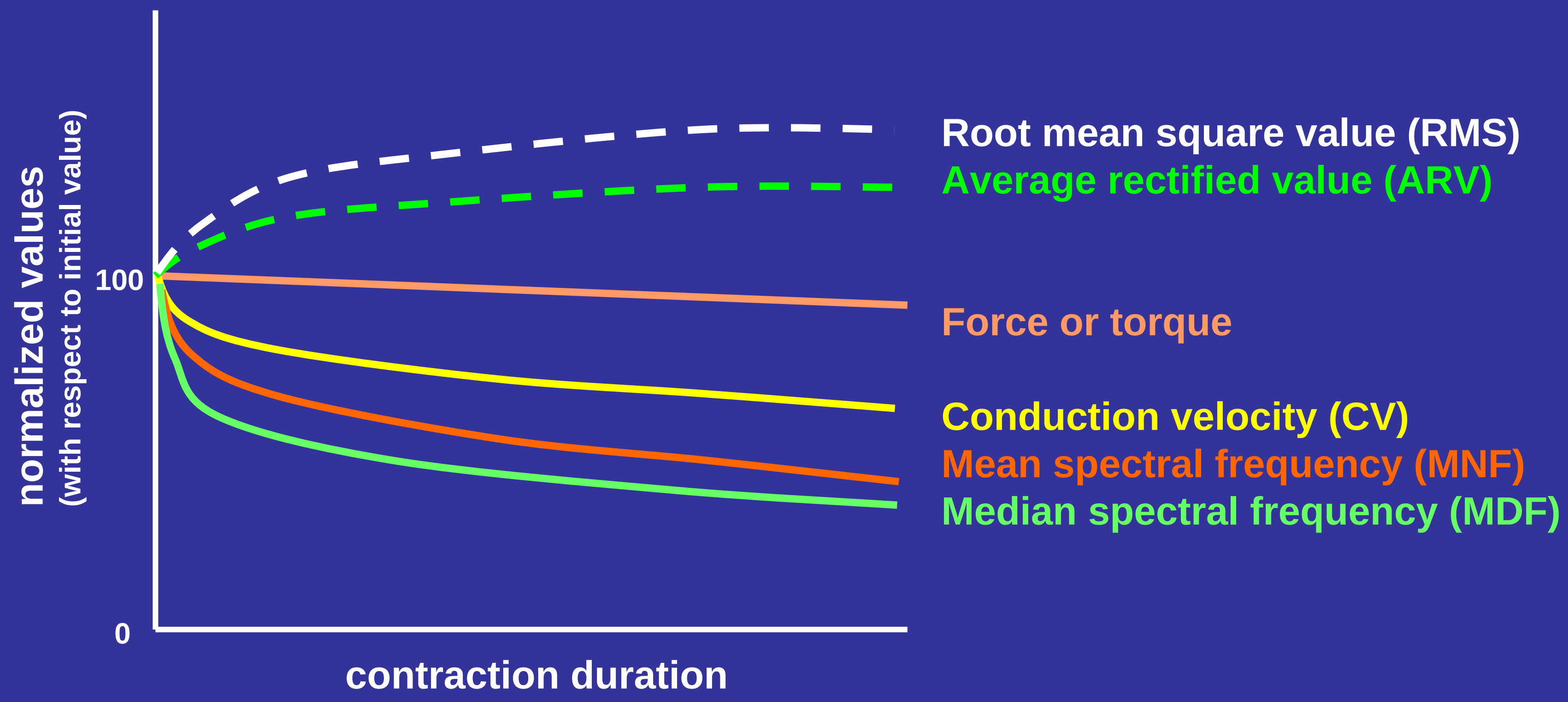
$$\int_0^{f_{med}} P(f)df = \int_{f_{med}}^{\infty} P(f)df = \frac{1}{2}\int_0^{\infty} P(f)df$$

Myoelectric manifestations of muscle fatigue



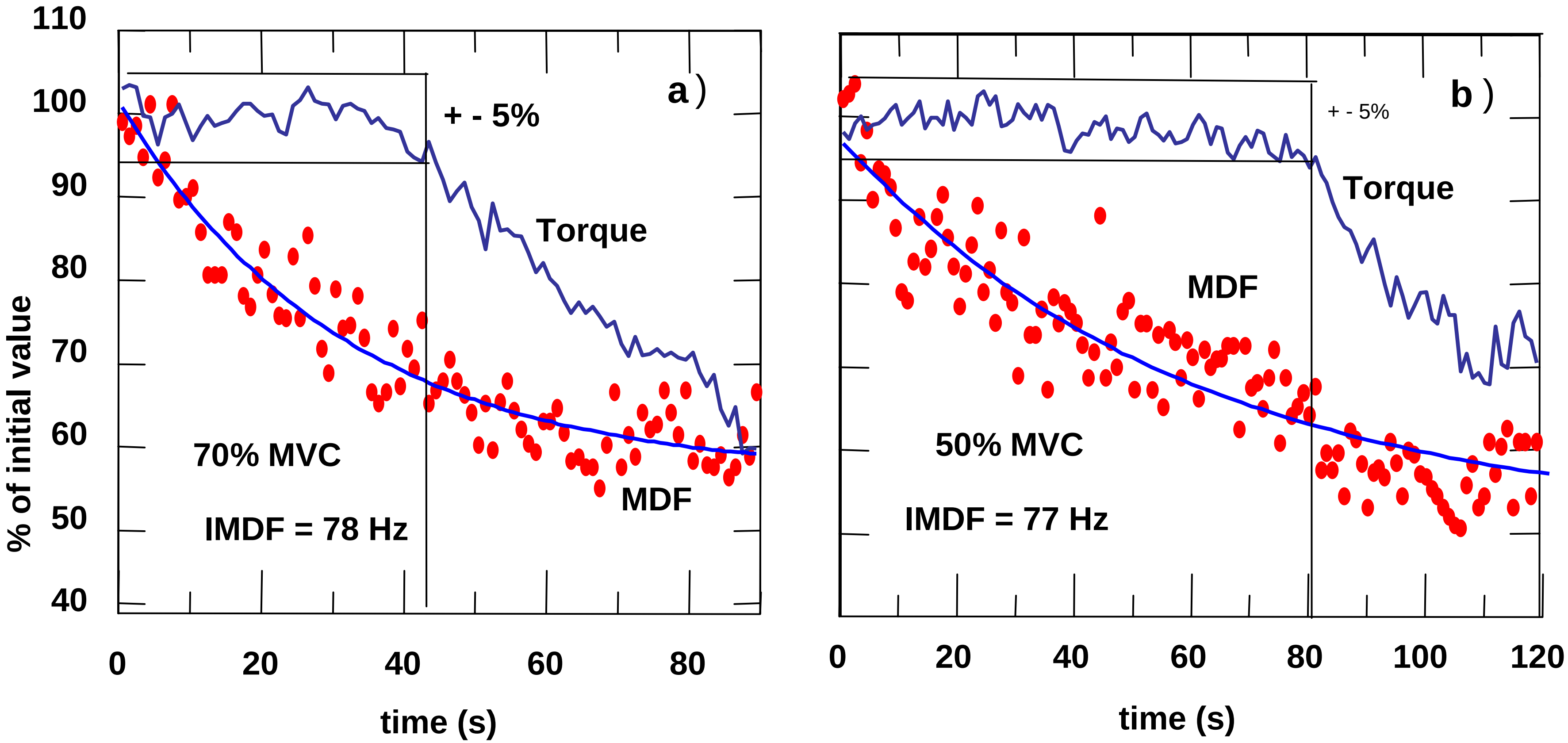
Example of power spectrum of the EMG of the biceps brachii during a sustained isometric contraction at 60% MVC. The centroid value (MNF) progressively moves towards the lower frequency values demonstrating myoelectric manifestations of muscle fatigue. The rate of change can be taken as an index of fatigue.

The Fatigue Plot



**The fatigue plot depicts the time course of some EMG signal variables normalized with respect to their individual initial values.
It allows comparison of the patterns and rates of change of these variables which reflect muscle properties.**

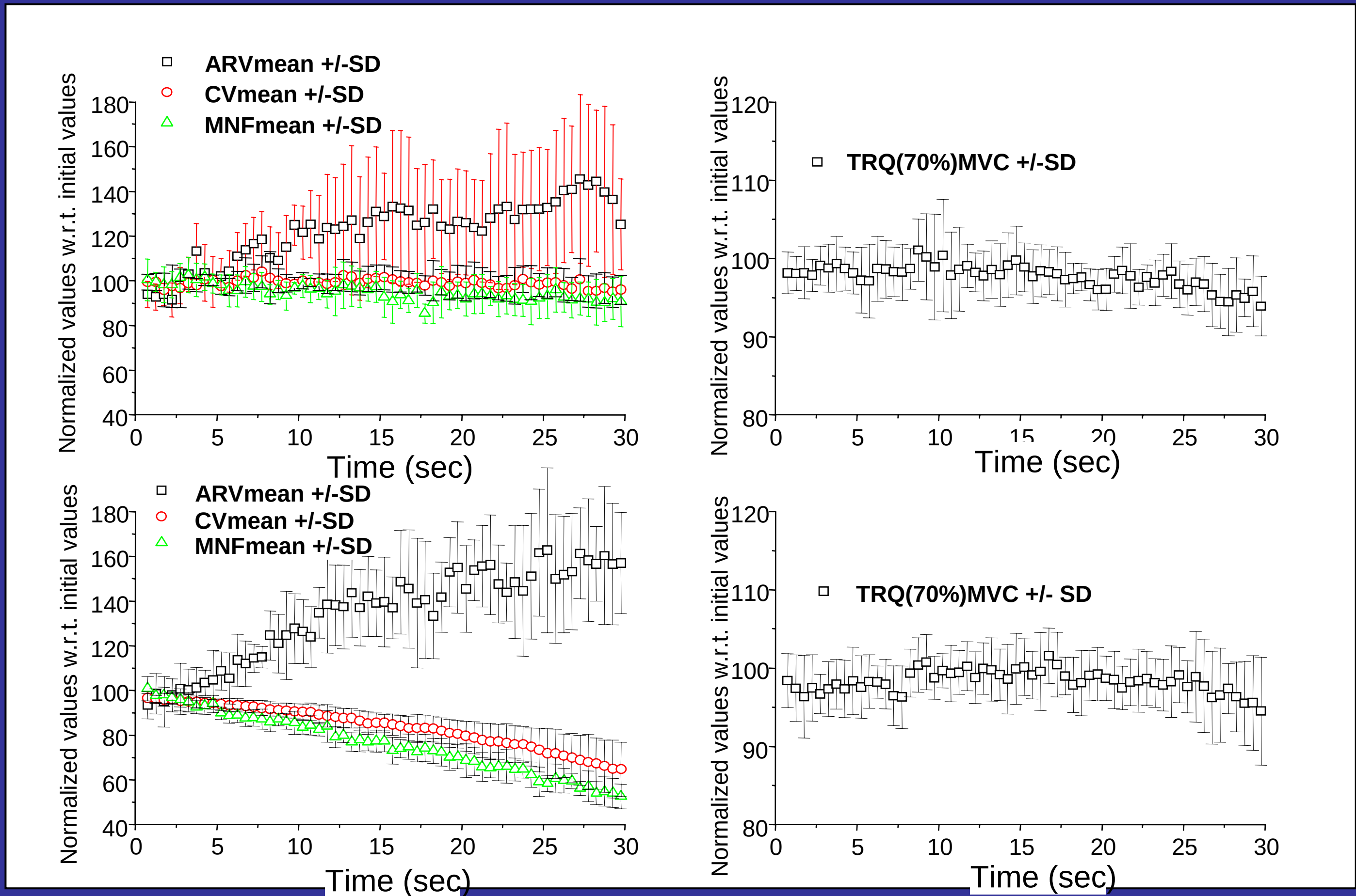
Myoelectric and mechanical manifestations of muscle fatigue during voluntary sustained isometric contractions



During strong contractions the pattern of MDF or MNF may be exponential. Initial slope or time constant can be used as indexes of myoelectric manifestations of muscle fatigue. These manifestations begin at the beginning of the contraction and precede and predict mechanical fatigue.

The Fatigue Plot during voluntary contractions

The Fatigue Plot is the graph of the time course of the EMG variables, normalized with respect to their initial value, during a sustained voluntary or electrically evoked contraction. It describes percent variations of different variables with respect to their initial value. The graphs below show differences observable between two healthy subjects during isometric 70% MVC contractions of the biceps brachii sustained for 30 s.

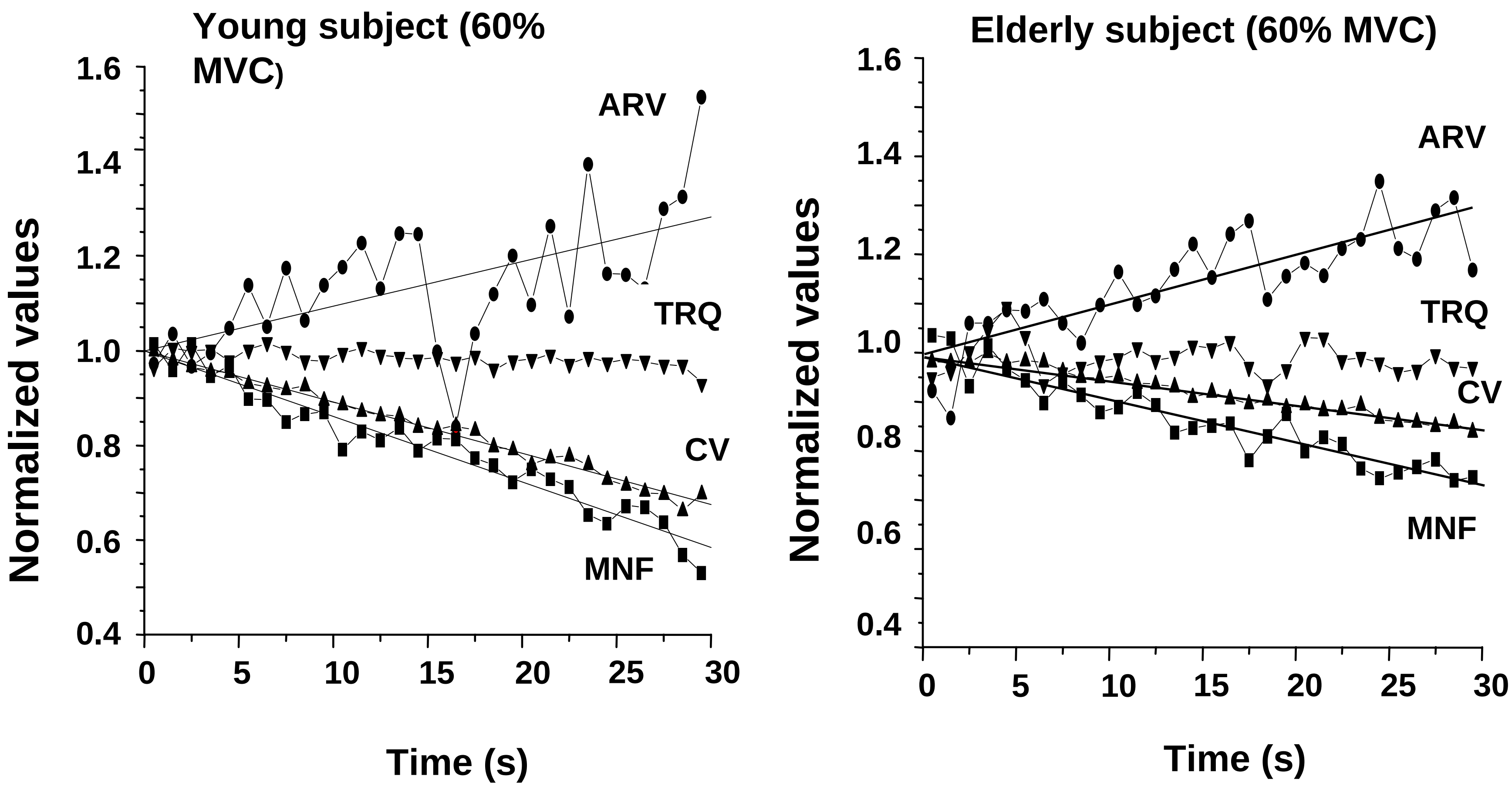


Subject 1
Mean ± std. dev. of 9 repetitions. Small myoelectric manifestations of muscle fatigue.

Subject 8
Mean ± std. dev. of 9 repetitions. Large myoelectric manifestations of muscle fatigue.

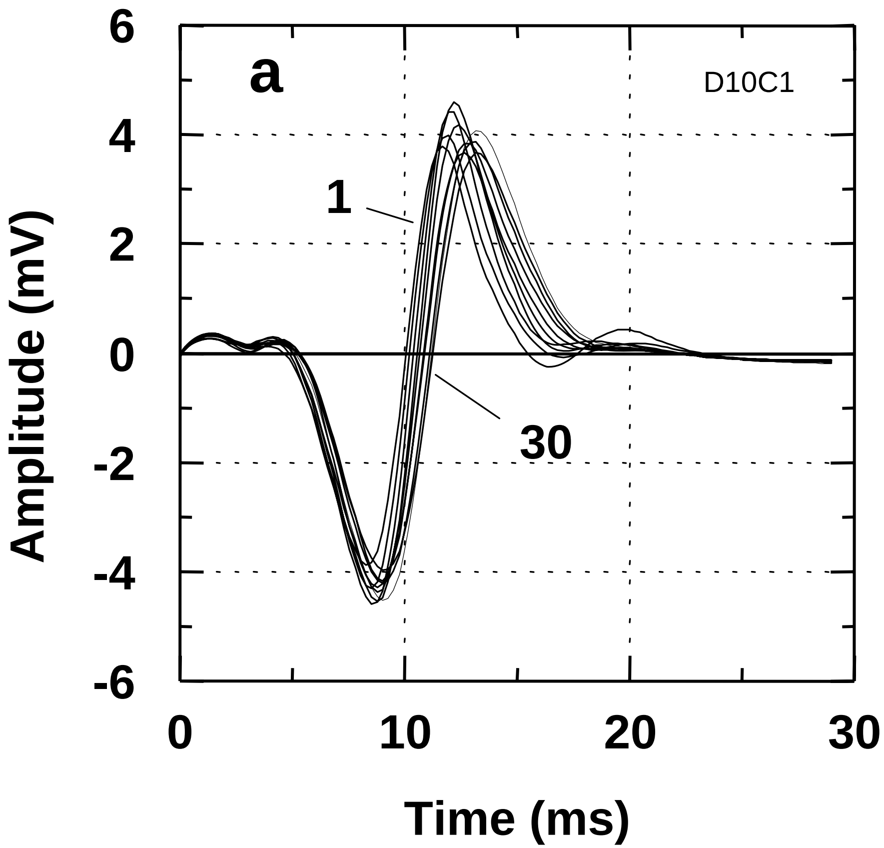
Rainoldi A., Galardi G., Maderna L., Comi G., Lo Conte L., Merletti R., Repeatability of surface EMG variables during voluntary isometric contractions of the biceps brachii, *J. Electrom Kinesiol.,* 9, 105-119, 1999.

The Fatigue Plot during voluntary contractions

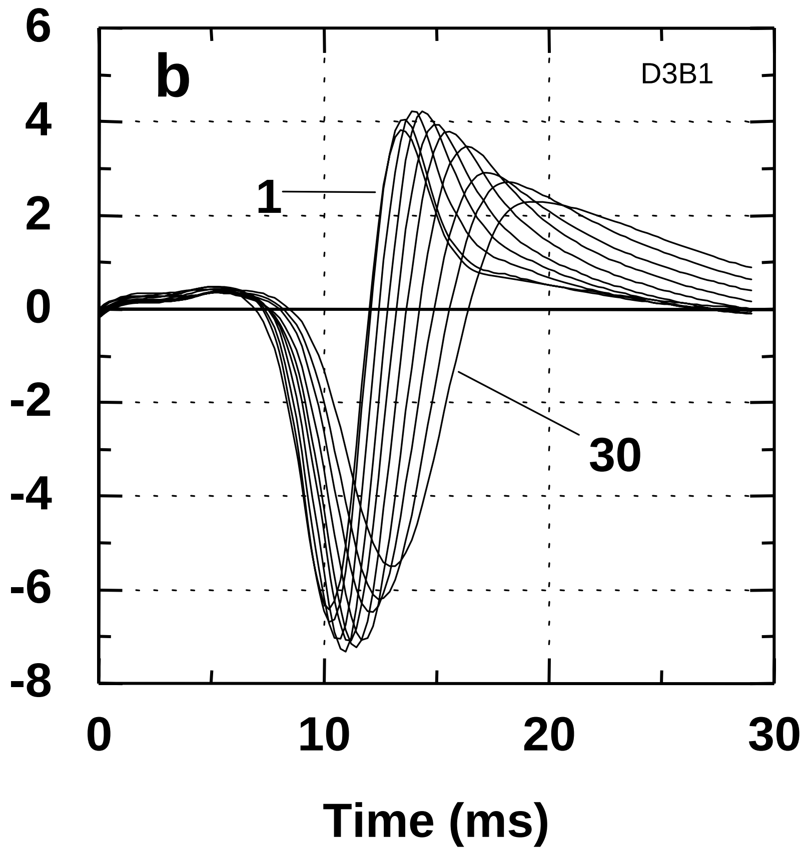


The number of type II (larger) muscle fibers decreases with age. This is reflected by reduced MVC and myoelectric manifestations of muscle ftigue.

M-wave changes during electrical stimulation of the tibialis anterior muscle of two individuals for 30 s at 30 pps



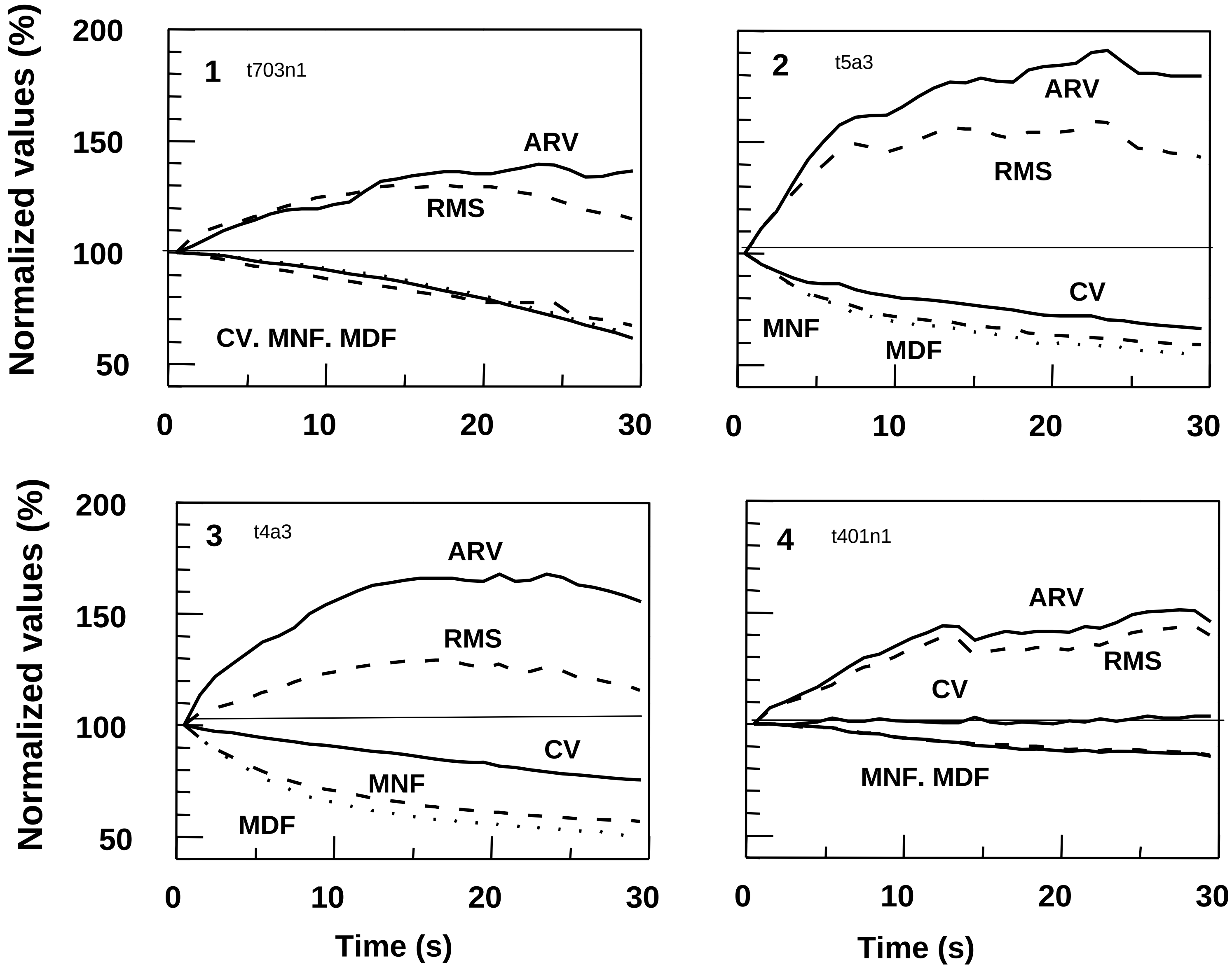
Subject a: limited myoelectric manifestations of muscle fatigue



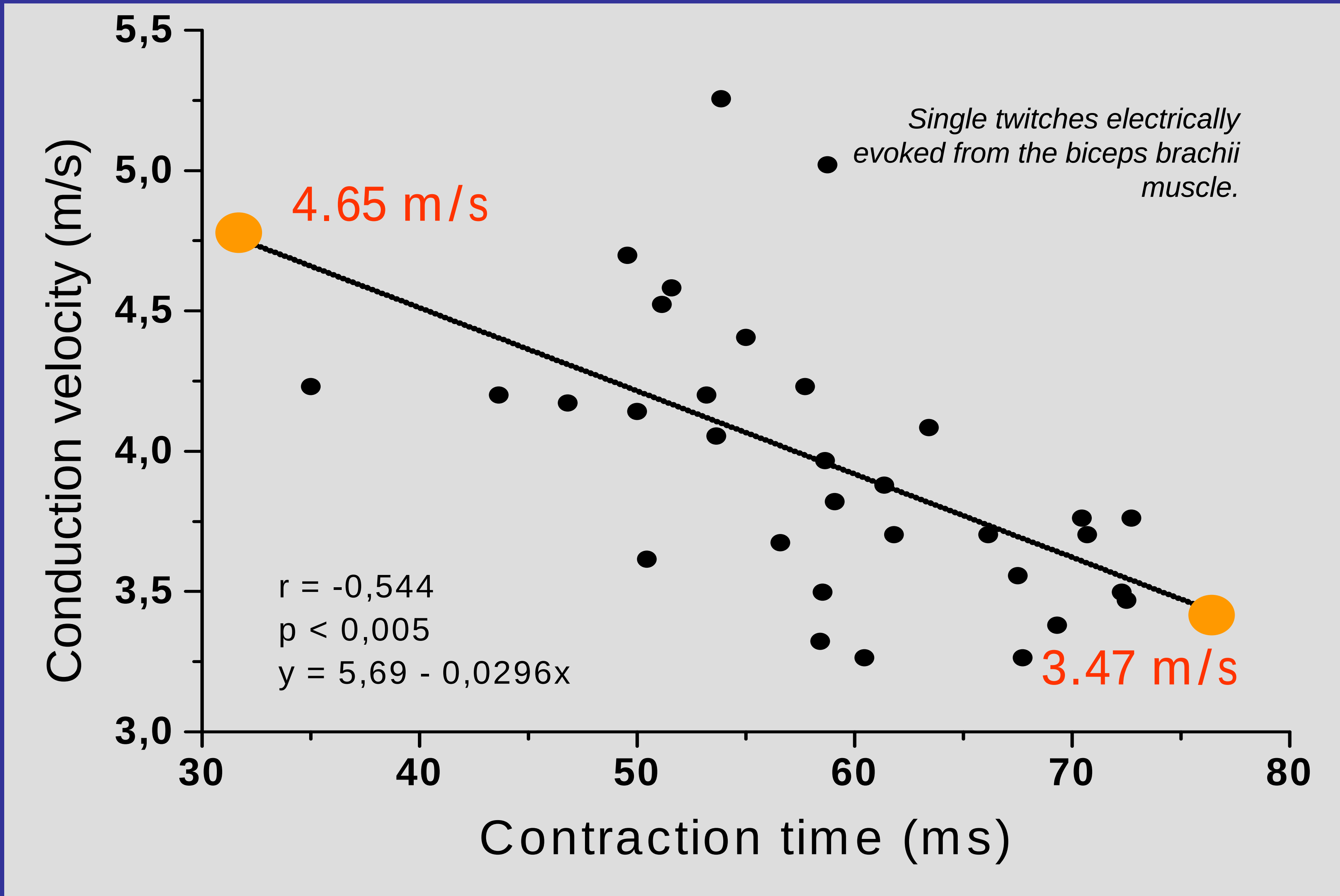
Subject a: marked myoelectric manifestations of muscle fatigue

Fatigue plots obtained during electrical stimulation of the tibialis anterior of 4 individuals for 30 s at 30 pps

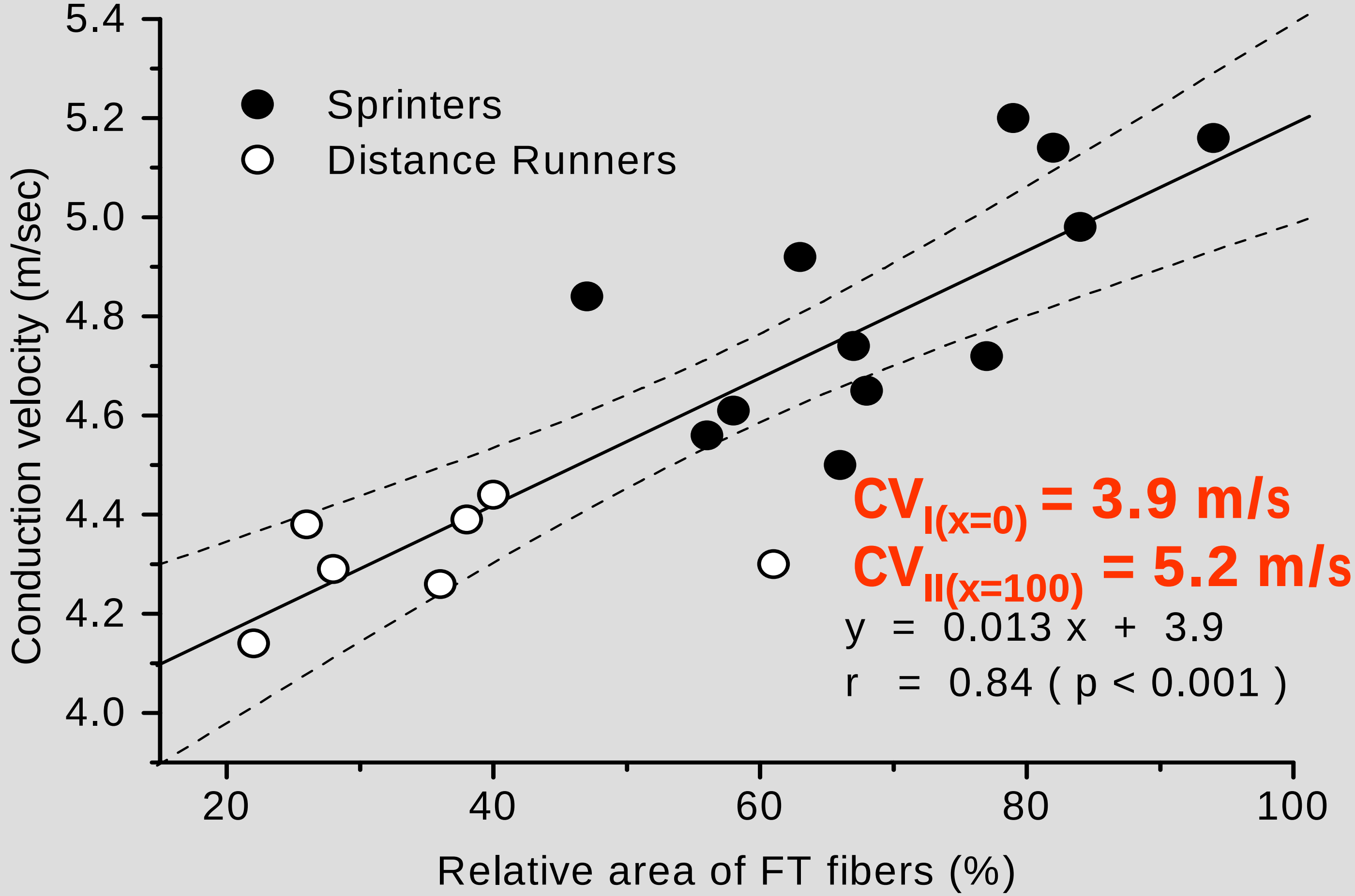
(individual differences are evident)



Hopf, R.L.Herbort, M. Gnass, H. Günther, K. Lowitzsch, "Fast and slow contraction times associated with fast and slow spike conduction of skeletal muscle fibers in normal subject and in spastic hemiparesis", *Z. Neurol*, **vol. 206,pp. 193-202,1974.**

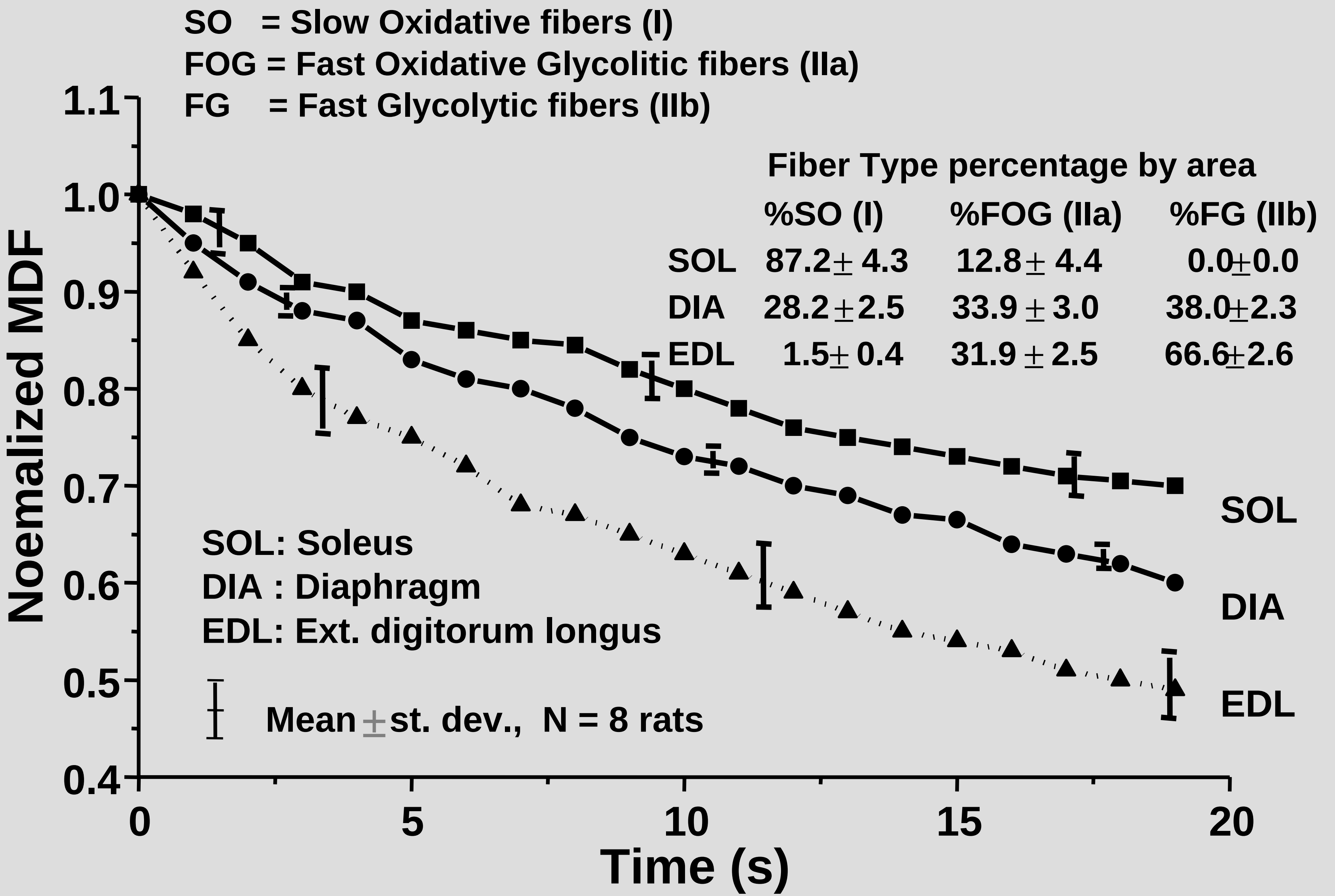


Sadoyama T., T. Masuda, H. Miyata, and S. Katsuta , "Fiber conduction velocity and fiber composition in human vastus lateralis", Eur. J. Appl. Physiol. 57, 767-771, 1988.



Komi P.V. and Tesch P., *EMG frequency spectrum, muscle structure, and fatigue during dynamic contractions in man.* **Eur J Appl Physiol Occup Physiol, 1979, 42(1):41-50.**

Kupa, S.H. Roy, S.C. Kandarian, C.J. De Luca, "Effects of muscle fiber type and size on EMG median frequency and conduction velocity", *J Appl Physiol*, vol. 79(1), pp.23-32, 1995.



Hvala Lepa !

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