Recording spikes … noninvasively?

1. Why to try spikes
2. Neurophysics of hf-EEG
3. The ‚workhorse‘: 600 Hz SEP
4. Technology for 1 kHz and above
5. DIY recipe

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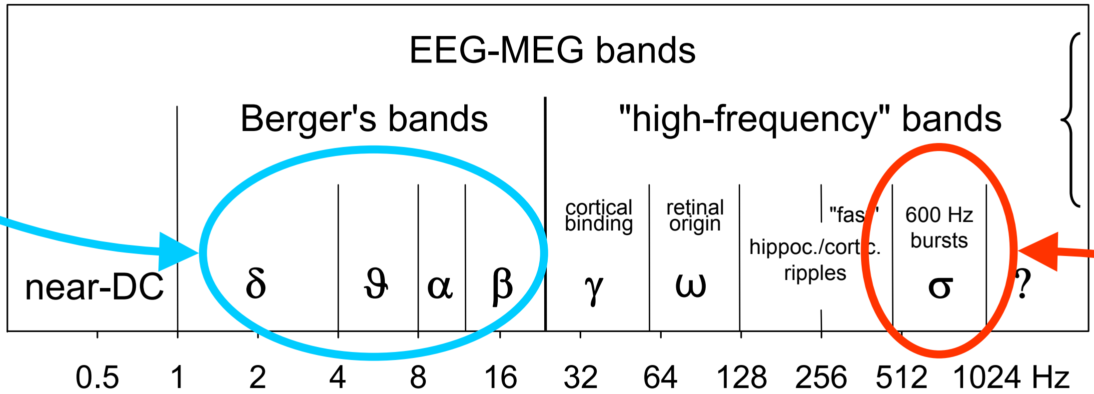
Neurophysics Group
Department of Neurology and Clinical Neurophysiology

CHARITÉ CAMPUS BENJAMIN FRANKLIN

Berger's bands – and beyond

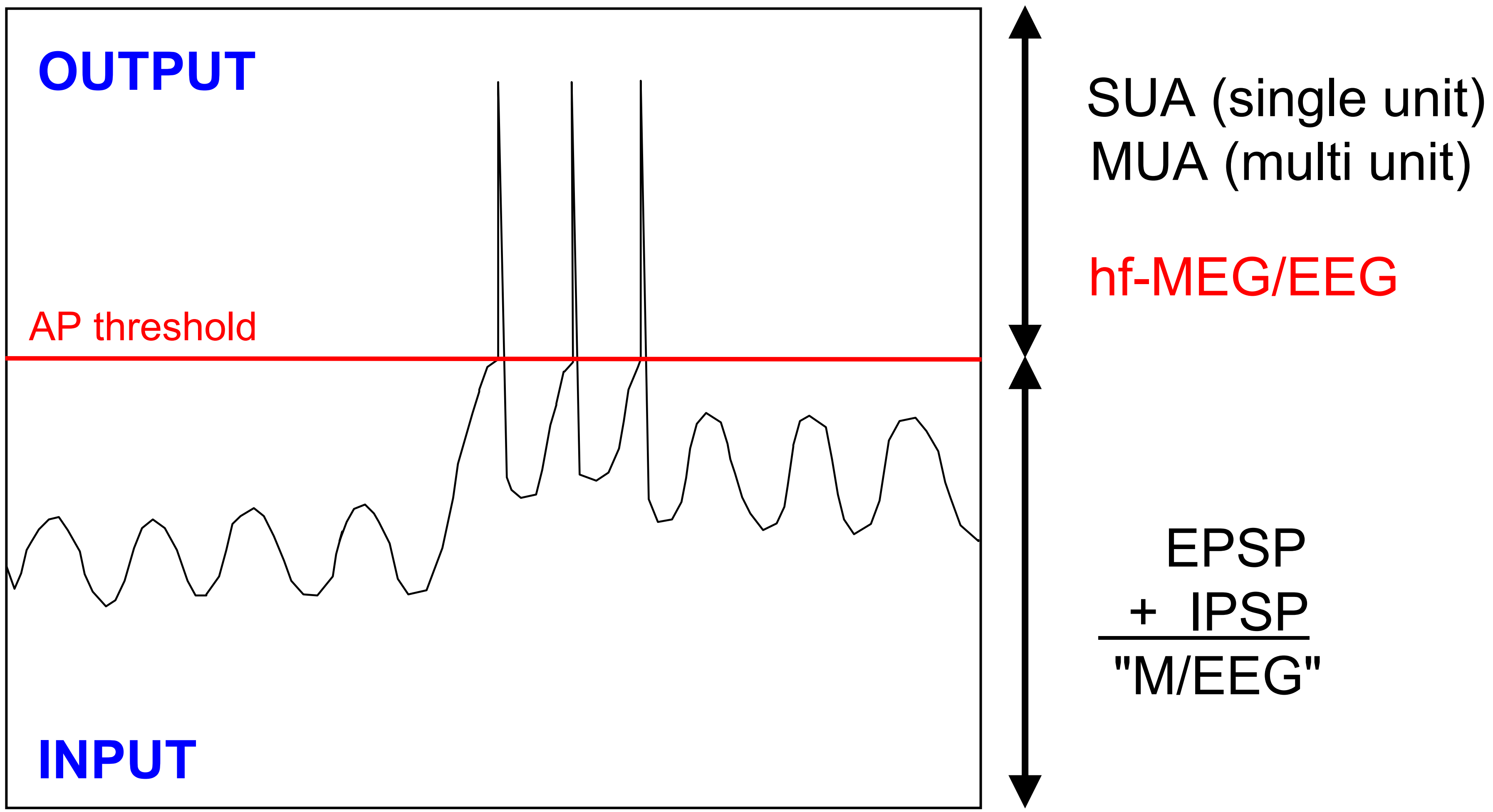
standard low-frequency EEG bands



FO = fast oscillations
VFO = very fast oscillations
HFO = high frequency oscillations
VHF = very high frequency
ultrafast frequencies

non-invasive analysis of
the timing of rapidly repeating population spike bursts
in the human somatosensory system

Standard-MEG/EEG: Σ (EPSP + IPSP)



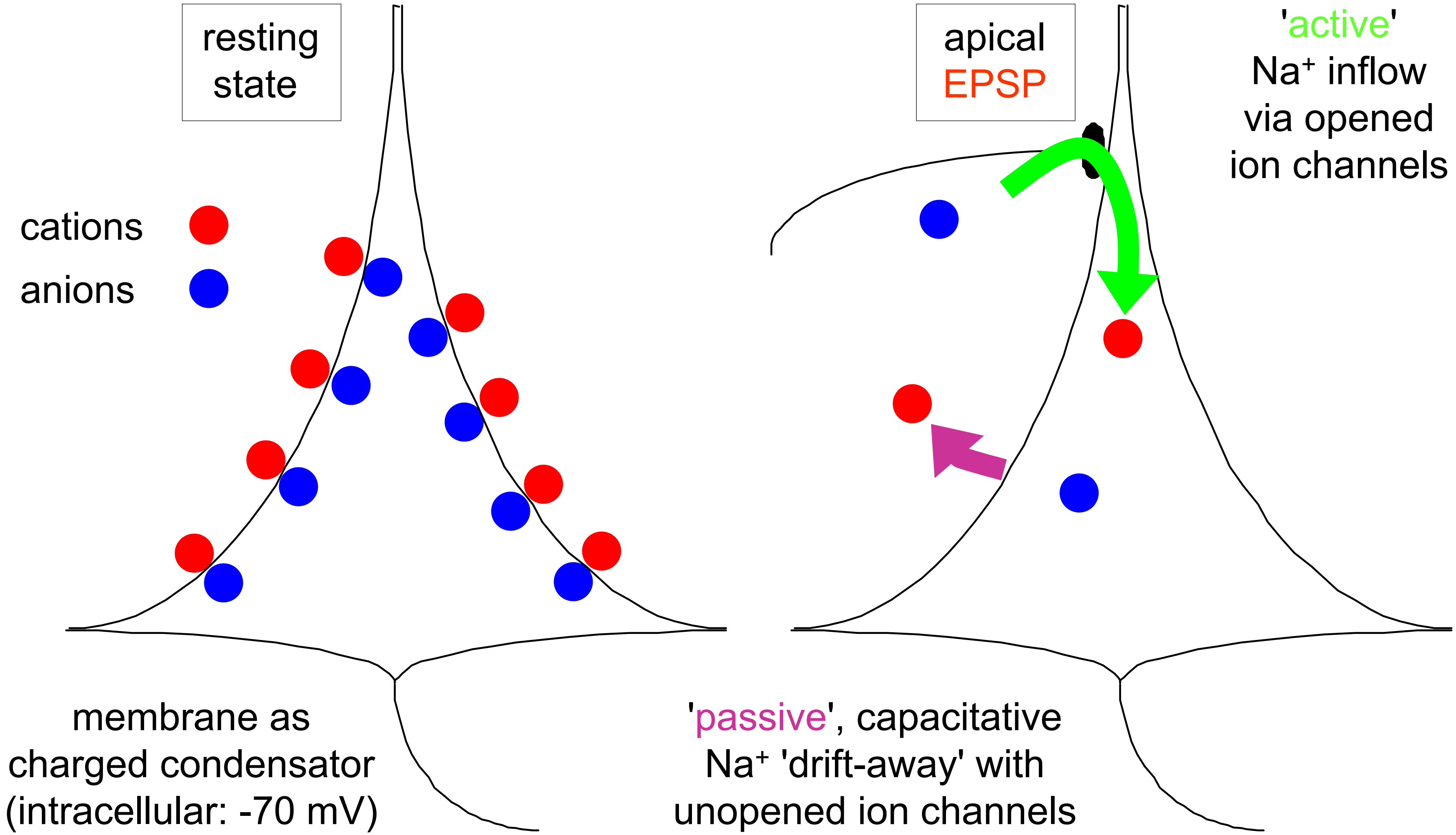
Neurophysics of hf-EEG (… and MEG)

1. Overview:

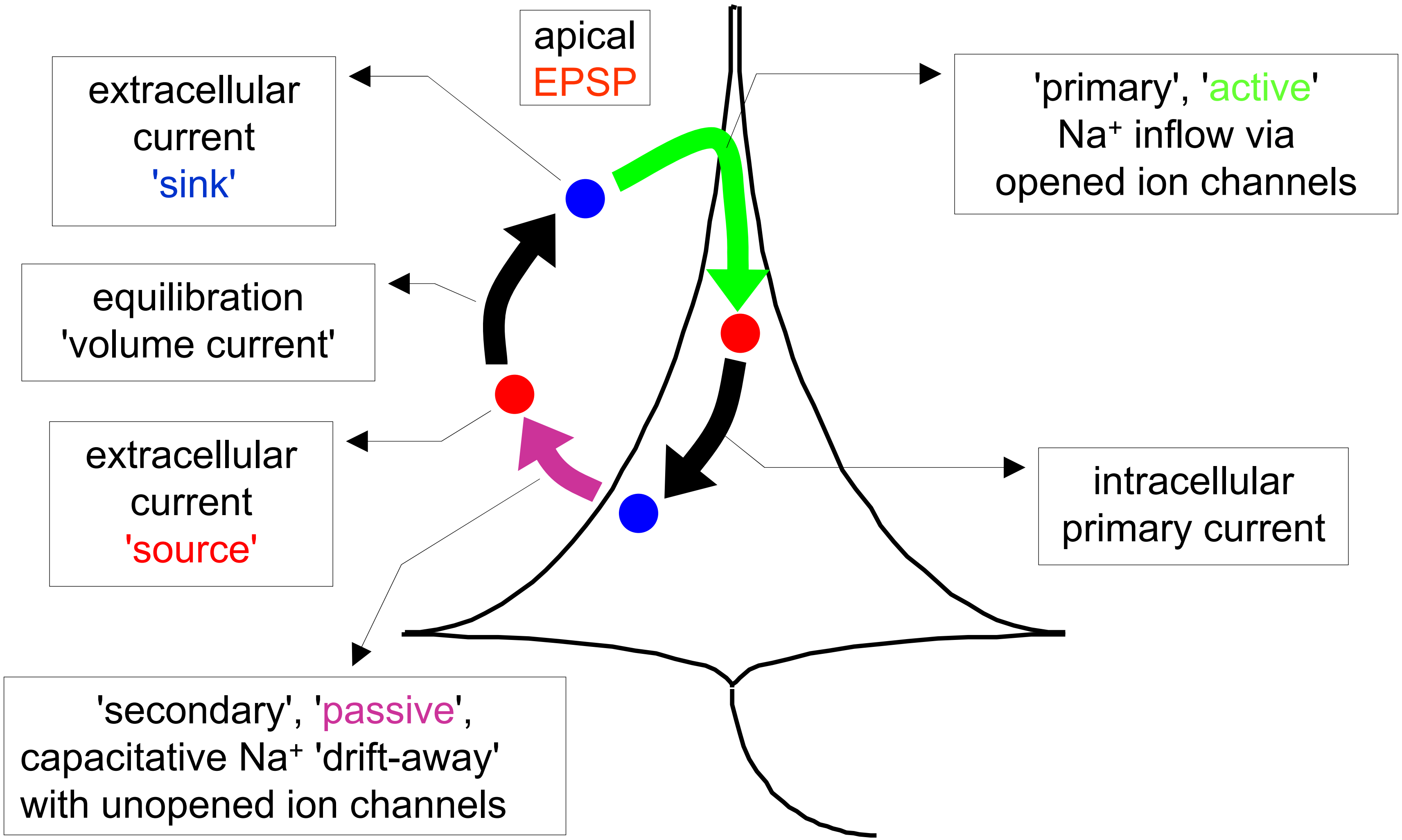
Terms of the Problem

near-fields	far-fields
real dipoles	virtual dipoles
primary sources	secondary sources
traveling peaks	stationary peaks
active current sources	junctional potentials

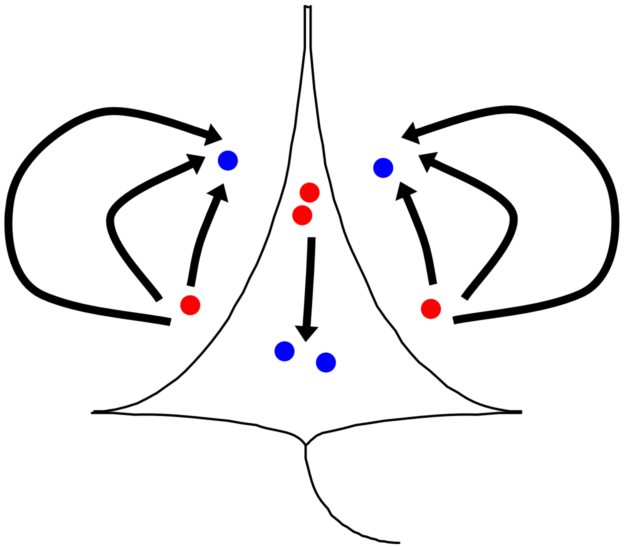
2. Ion currents and membrane potential

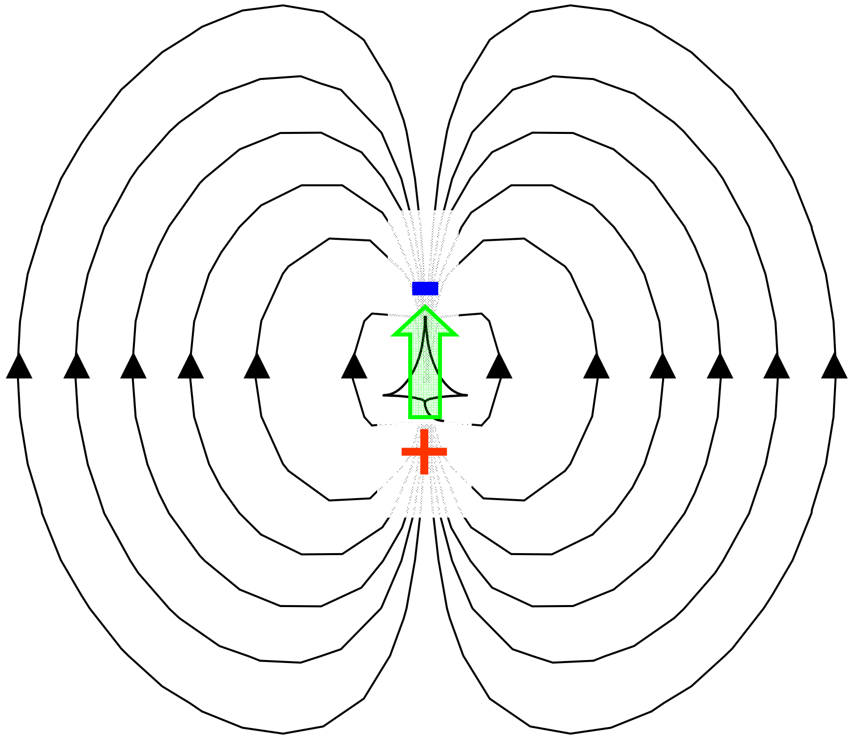


3. Closing the current loop



4. Equivalent Current Dipole (ECD)

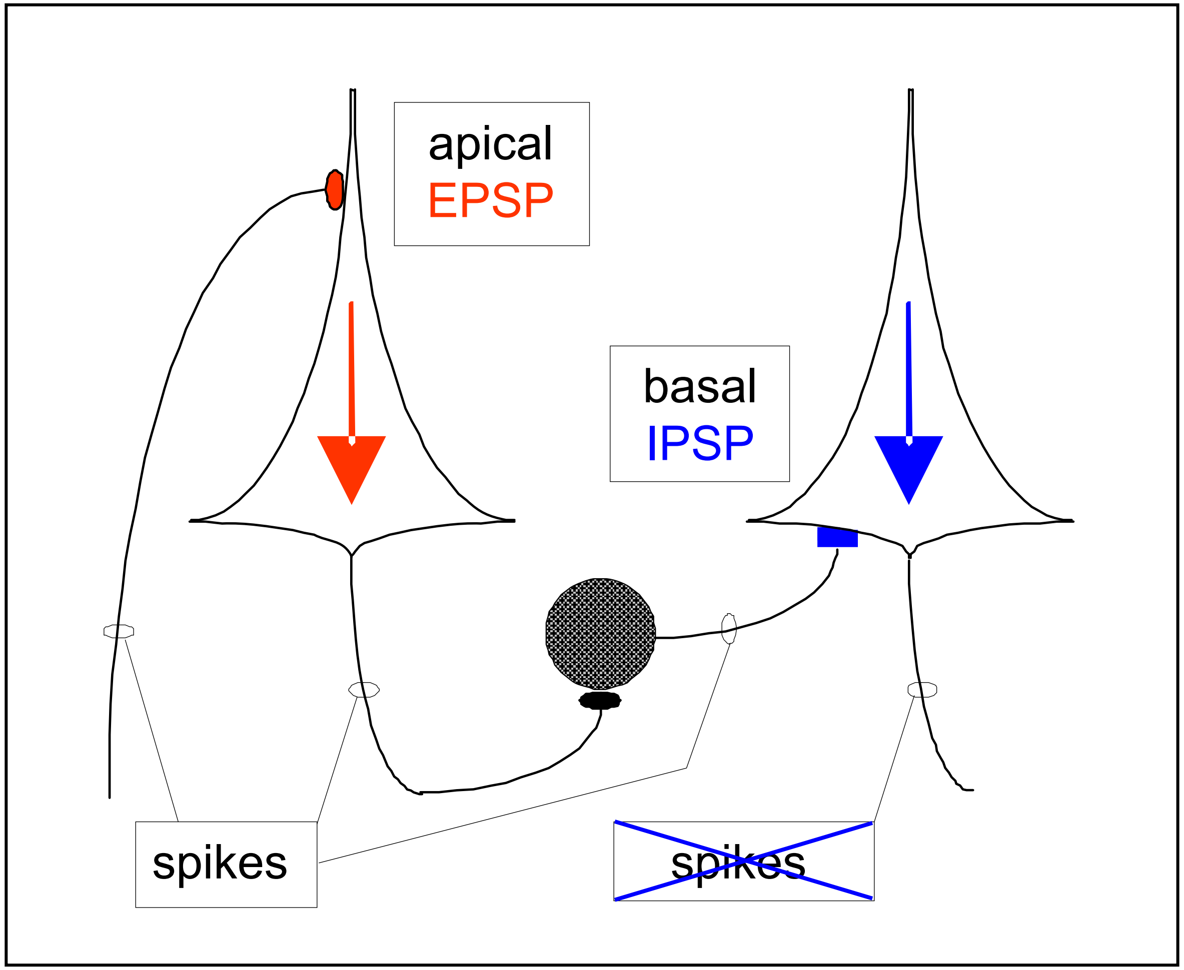




intra- and extracellular:
current sources → current sinks

EEG: extracellular volume currents

5. Synaptic events: EPSP and IPSP

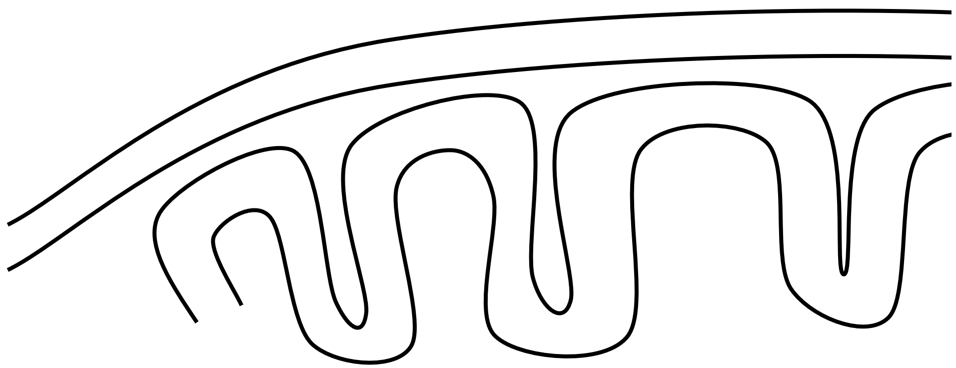


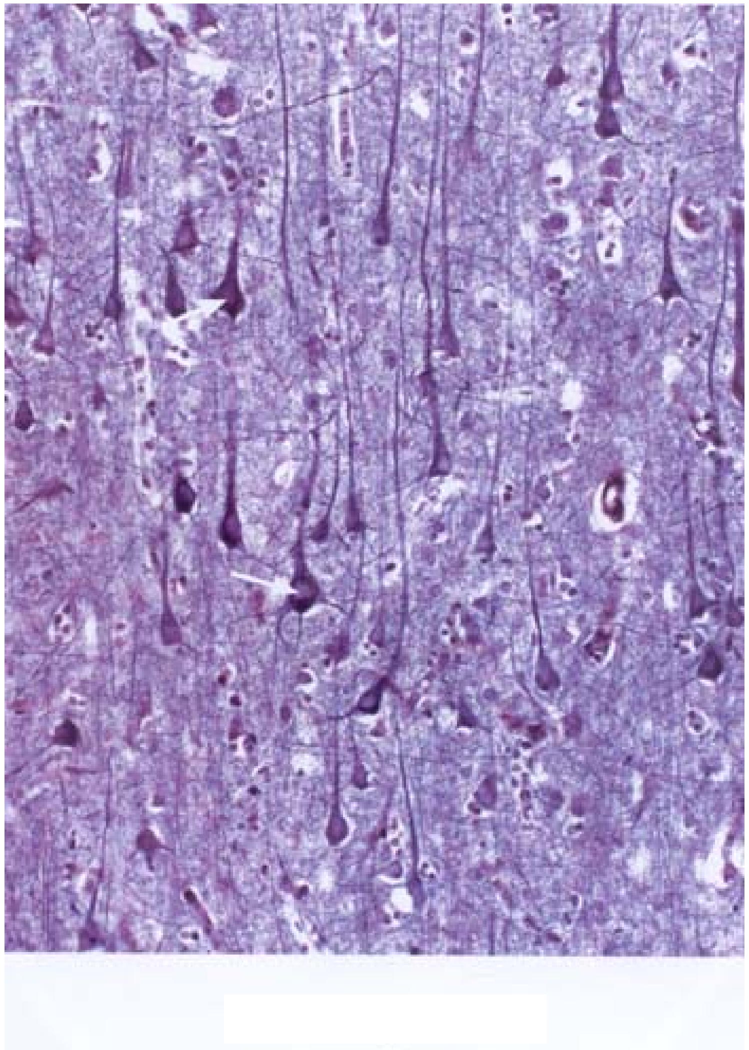
net current flow: apical EPSP = basal IPSP

EPSP = excitatory postsynaptic potential (glutamate: Na^{+}_{in})

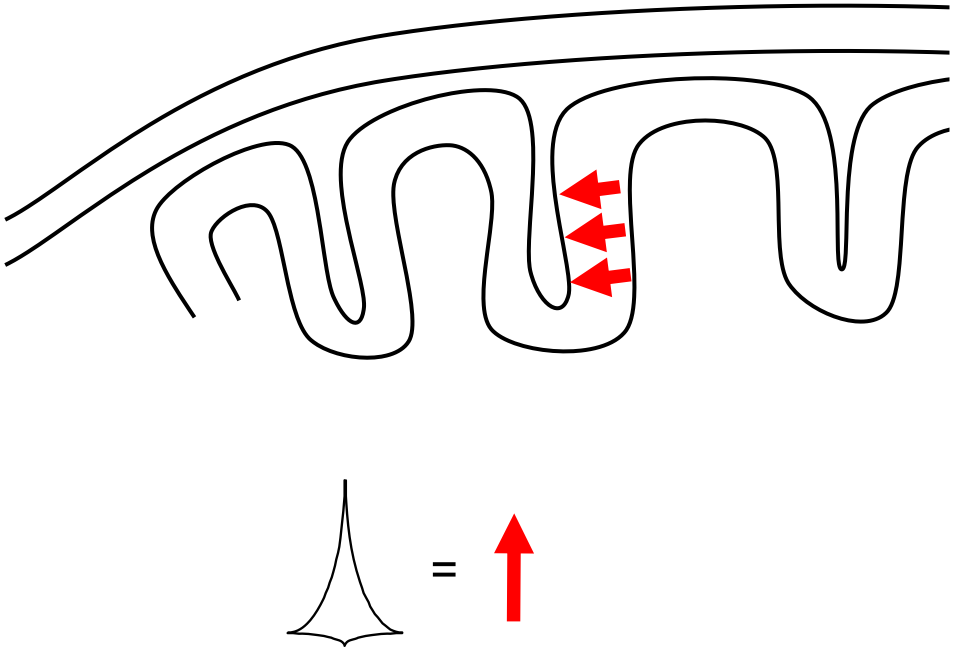
IPSP = inhibitory postsynaptic potential ($GABA_A$: Cl^{-}_{in})

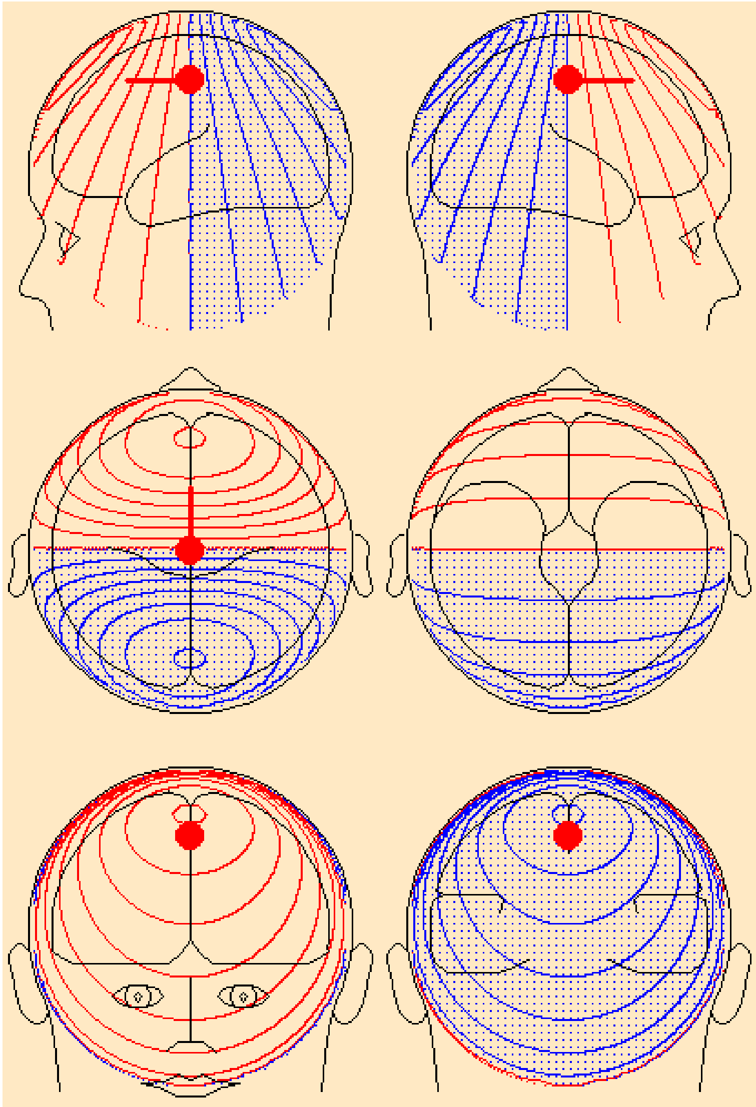
6. Far fields: tangential cortical dipoles





6. Far fields: tangential cortical dipoles

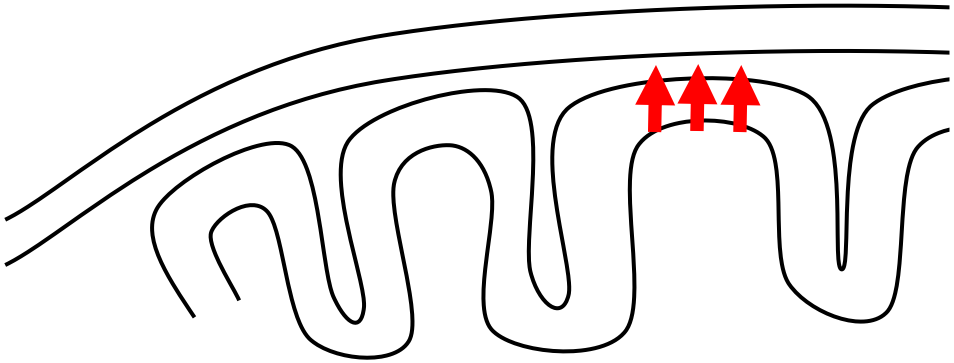


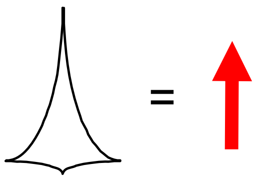


DipoleSimulator © P. Berg (2002)

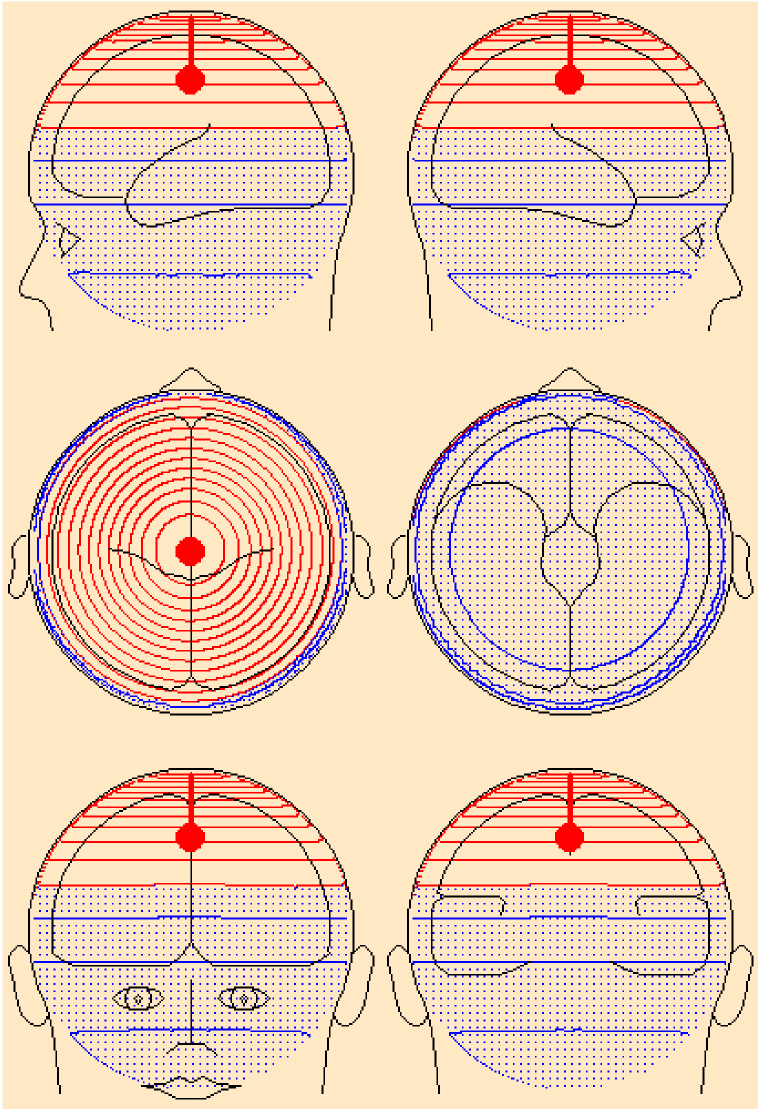
'open field' from pyramidal cells:
- elongated structure = apical dendrite
- parallel structure = summation due to 'palisade' arrangement

7. Far fields: radial cortical dipoles



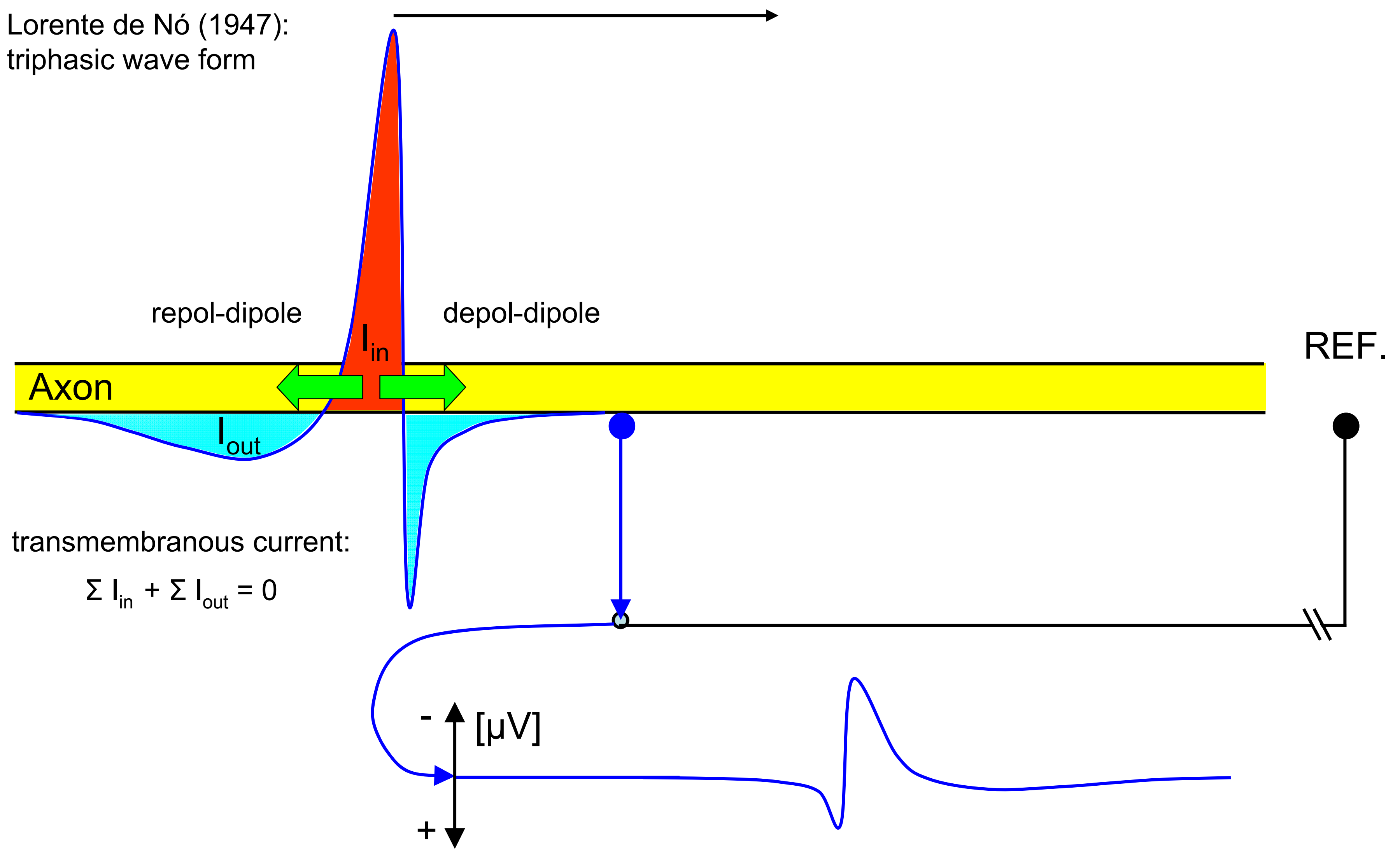


'open field' from pyramidal cells:
- elongated structure = apical dendrite
- parallel structure = summation due to 'palisade' arrangement



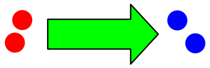
DipoleSimulator © P. Berg (2002)

8. Propagating action potential

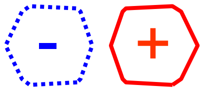


9. Infinite vs. finite volume conductor

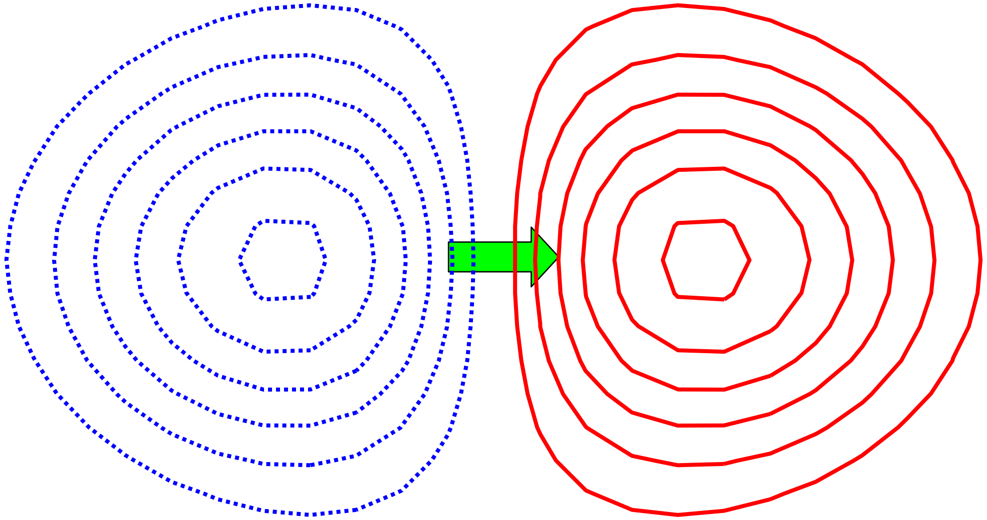
current dipole in
infinite volume conductor



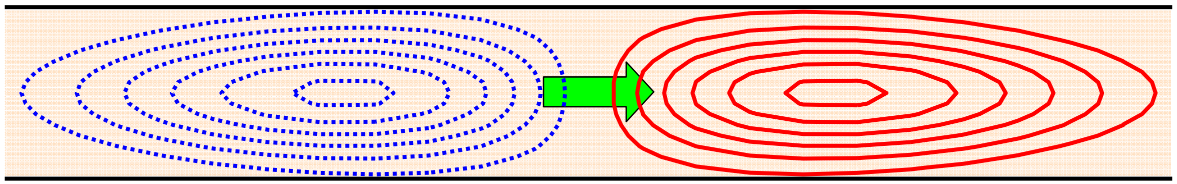
intracellular
current dipole



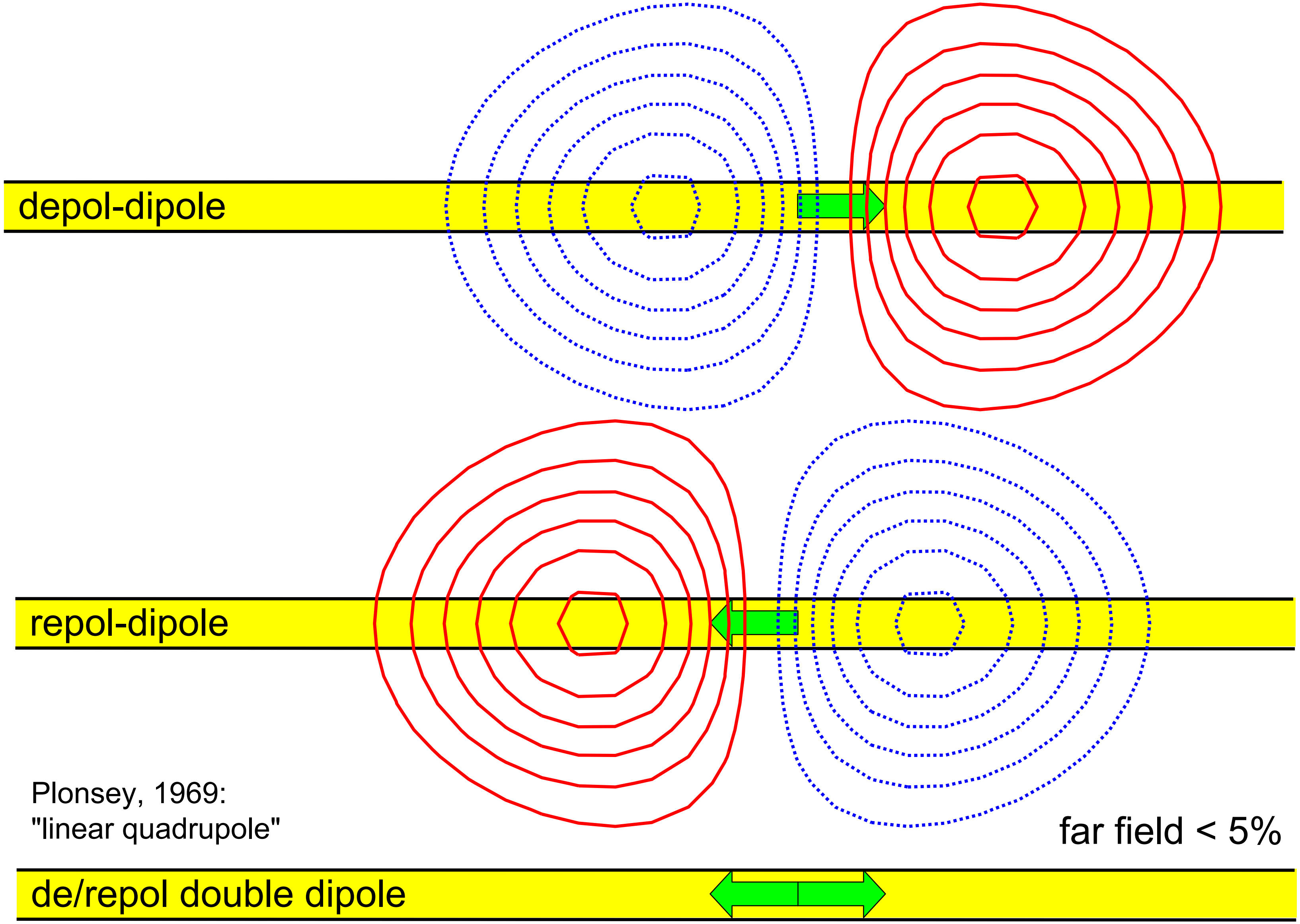
extracellular
potential distribution



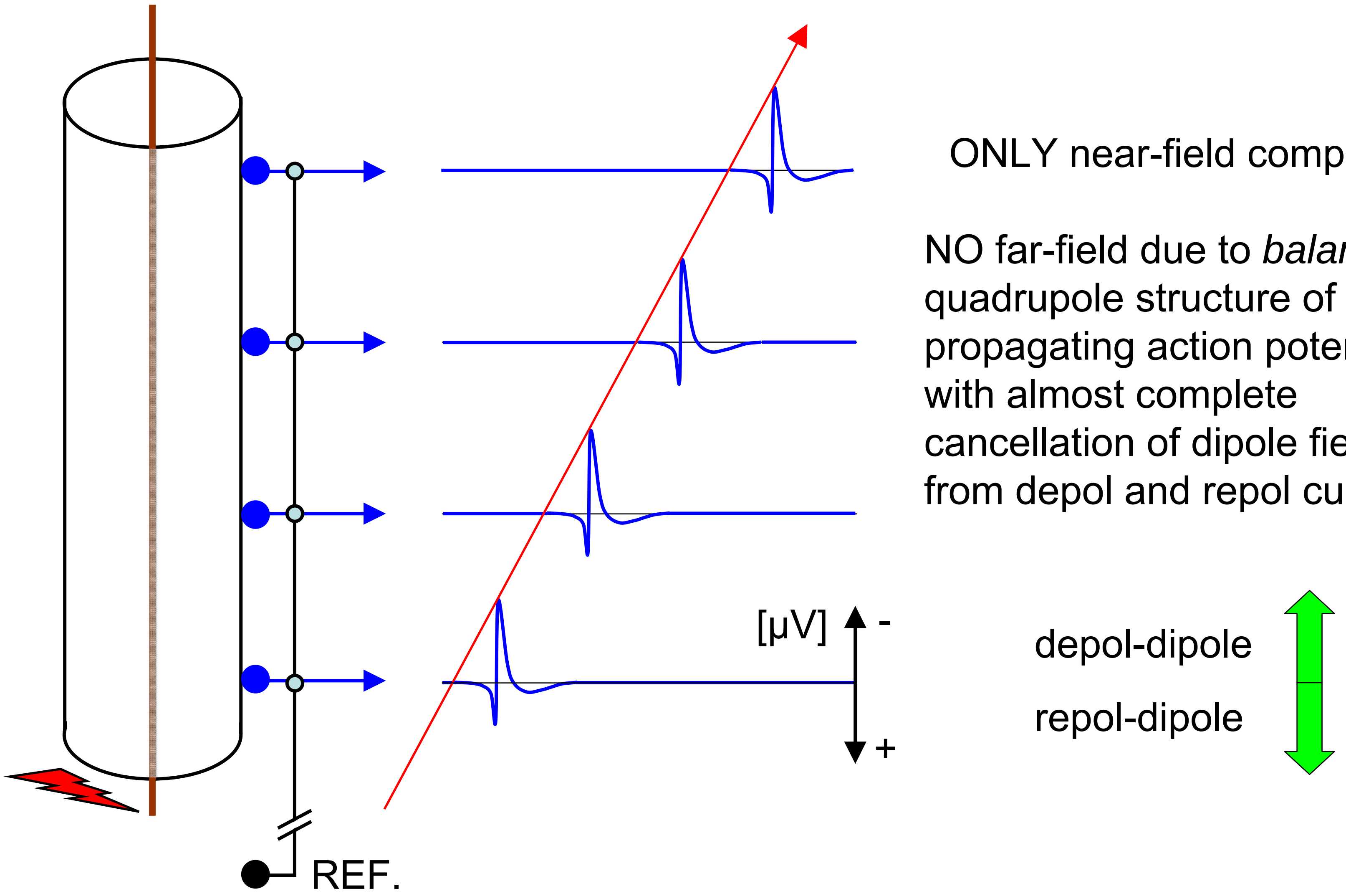
current dipole in
cylindrical volume conductor



10. Action potential: quadrupole



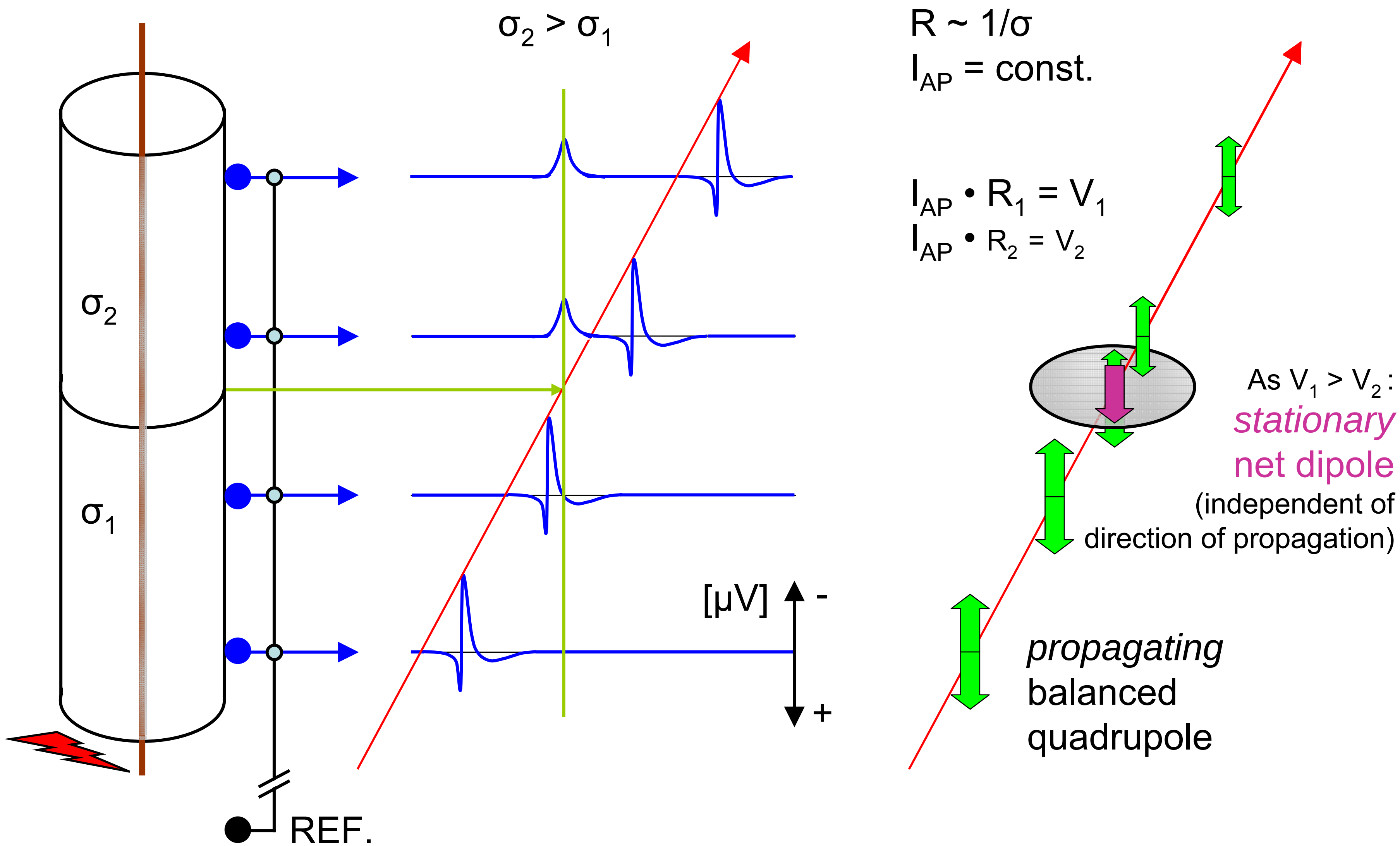
11. Homogenous volume conductor



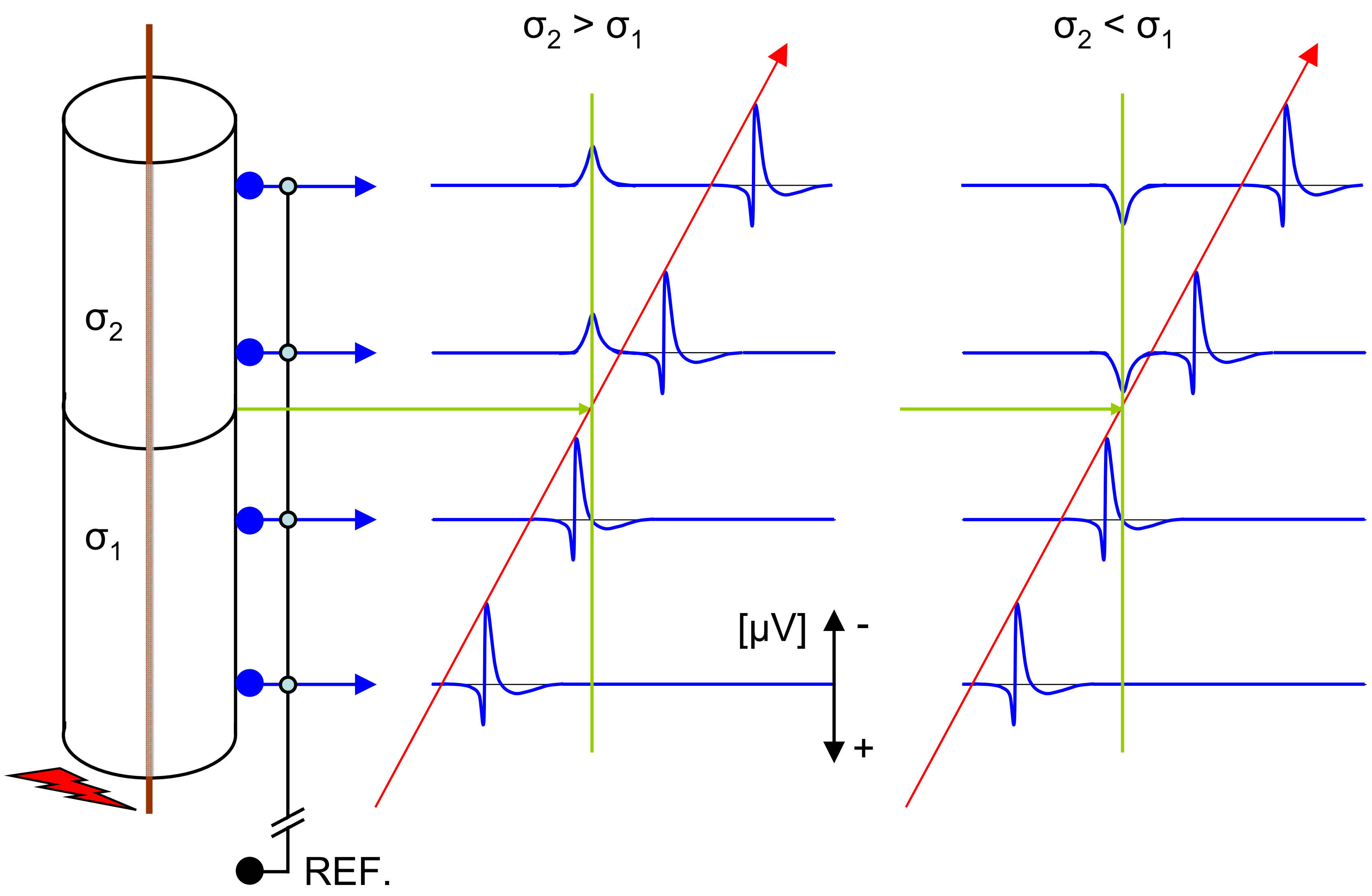
ONLY near-field components

NO far-field due to *balanced* quadrupole structure of the propagating action potential with almost complete cancellation of dipole fields from depol and repol currents

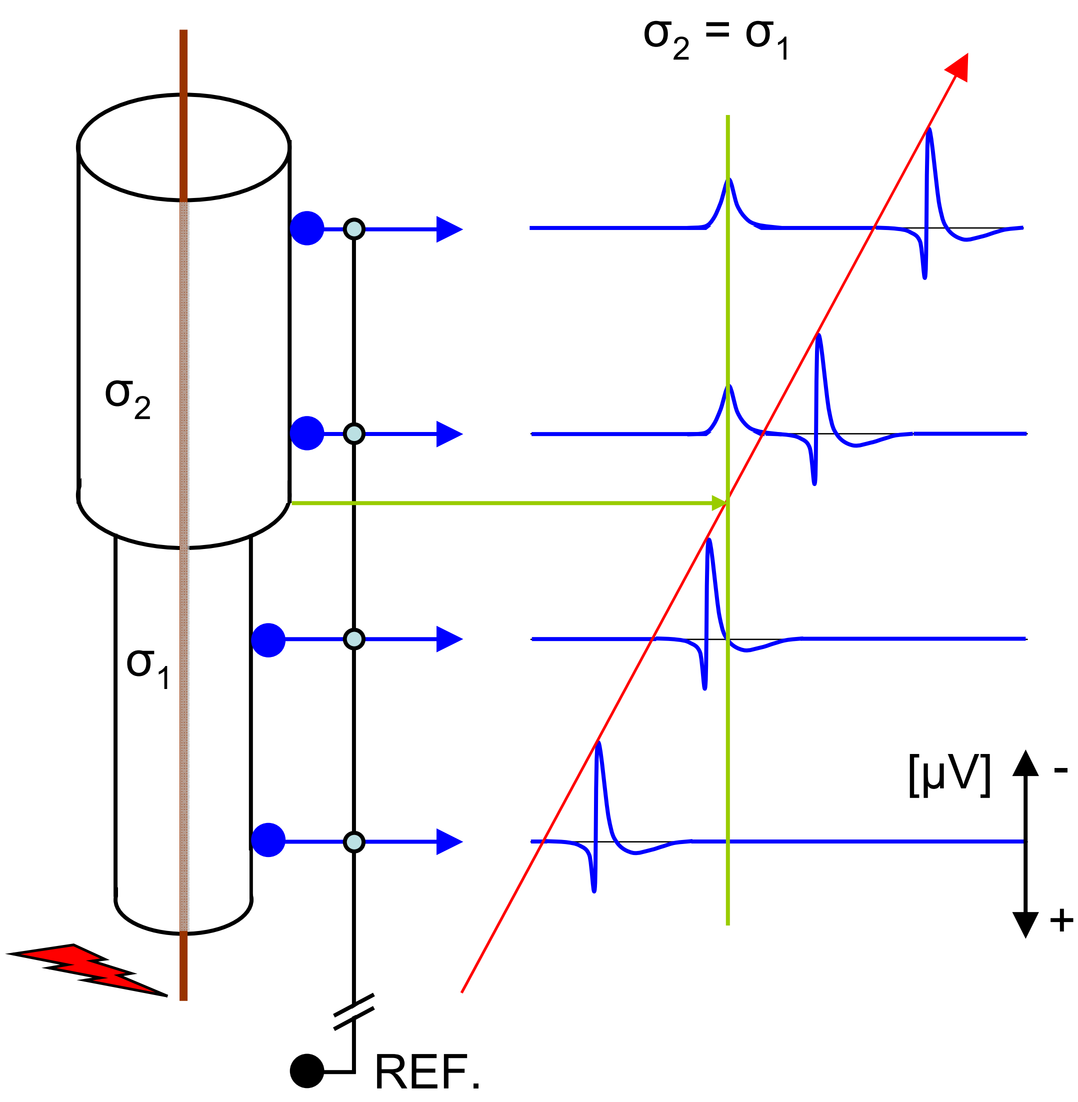
12. Conductivity Change: Ohm's Law



13. Conductivity Change: Polarity Switch



14. Geometry of volume conductor

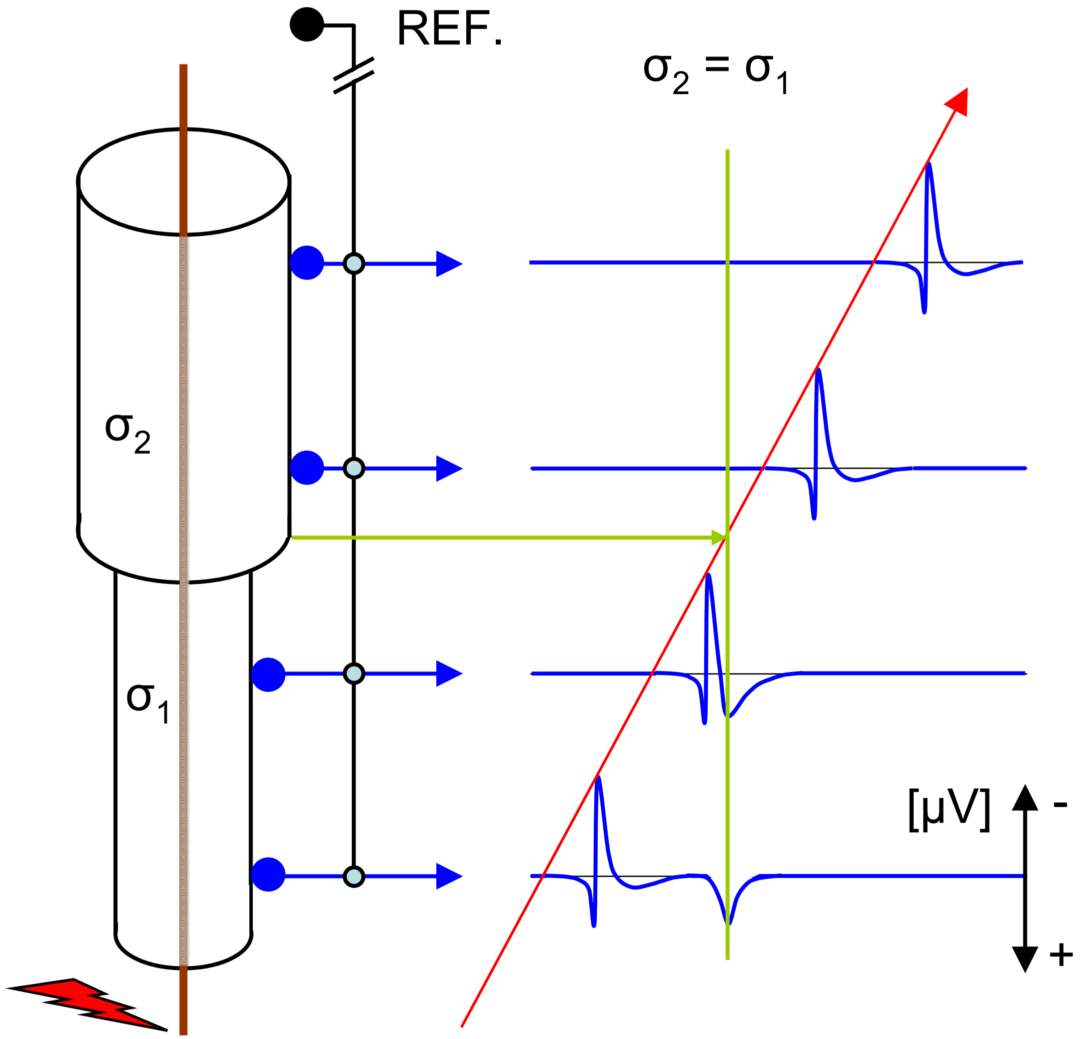


Comparable far field components due to step-like decrease of extracellular resistance through:

1) increase of conductivity

2) widening of conductor diameter

15. Localisation of reference electrode

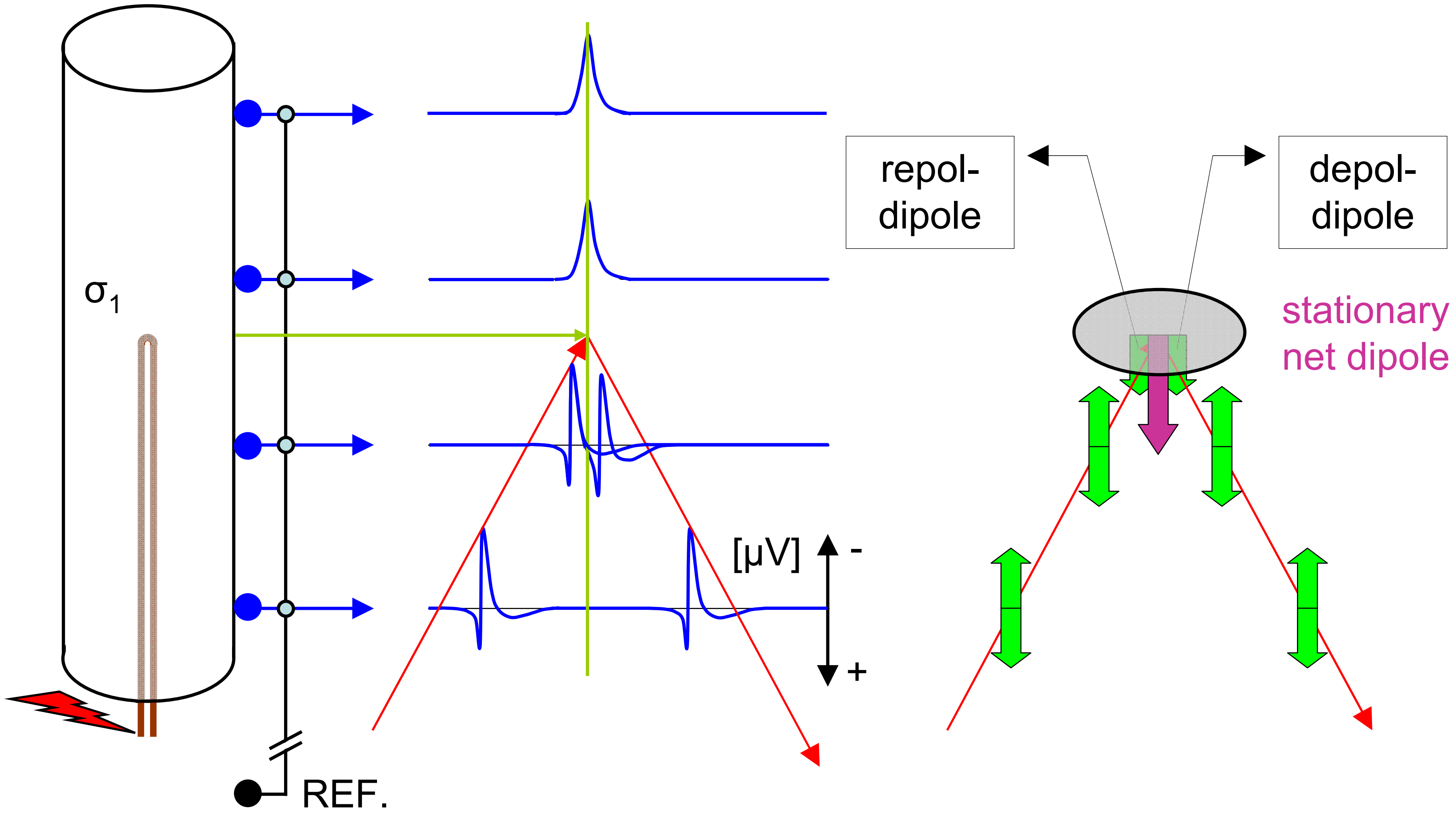


Polarity and site of a monophasic far field component depend on the placement of the reference electrode:

1) Far fields do NOT occur in the compartment of the reference electrode.

2) The monophasic far field is POSITIVE if the reference electrode is placed on the volume conductor part with LOWER resistance.

16. Changing direction of propagation



17. Subcortical far field 'generators'

0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
latency
[ms]

- distal n. acusticus
- meatus acusticus internus
- n. cochlearis
- corpus trapezoideum
- n. olivaris superior
- lemniscus lateralis
- colliculus inferior

BAEP
(brainstem auditory
evoked potentials)

- transition arm – trunk
- plexus brachialis
- dorsal horn
- transition trunk – neck
- dorsal column
- transition neck – head (foramen magnum)
- n. cuneatus
- lemniscus medialis
- n. ventroposterolateralis thalami
- radiatio thalamocorticalis

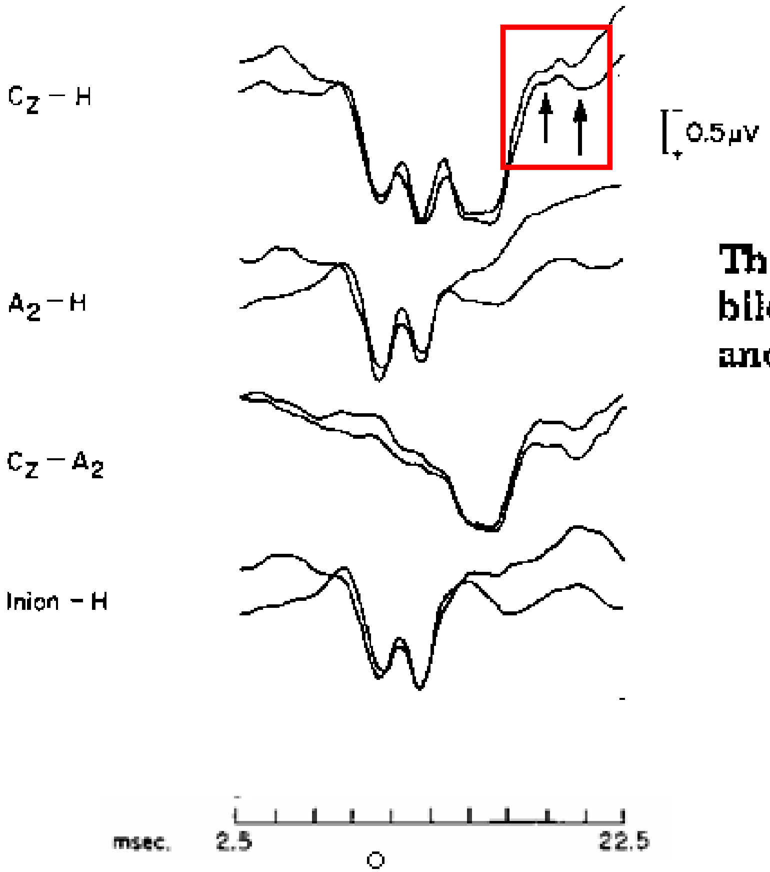
SEP (N. medianus)
(somatosensory
evoked potentials)

Electroencephalography and Clinical Neurophysiology, 1976, 41: 460—466

SOMATOSENSORY EVOKED POTENTIAL IN MAN: FAR FIELD POTENTIALS *

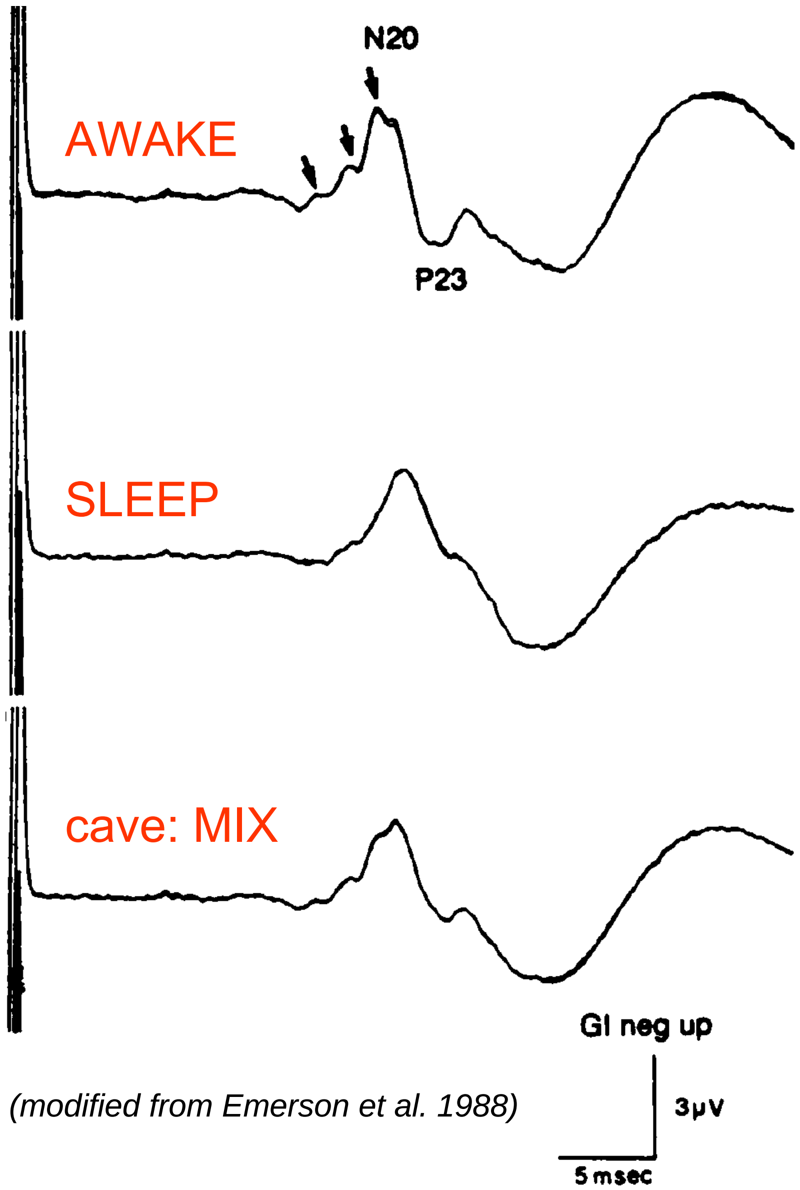
ROGER Q. CRACCO and JOAN B. CRACCO

Department of Neurology, State University of New York, Downstate Medical Center, Brooklyn, N.Y. 11203 (U.S.A.)



These potentials are followed by a poorly defined bilobed positive component with peaks at about 18.5 and 20 msec (arrows).

Early EEG studies (1976-1988)



(modified from Emerson et al. 1988)

generator hypotheses:

Cracco and Cracco (1976):
brainstem and diencephalic structures

Abbruzzese et al. (1978):
N14–P15: *n. cuneatus, medial lemniscus*
N16: *thalamus*
N17: *thalamocortical radiation*

Stöhr and Riffel (1982):
P16-P18: 1.4 ms = 714 Hz; *volley ascending in thalamocortical afferents*

Maccabee et al. (1983, 1986):
N16 *caudal* thalamocortical radiation
N18 *rostral* thalamocortical radiation

functional dissociation:

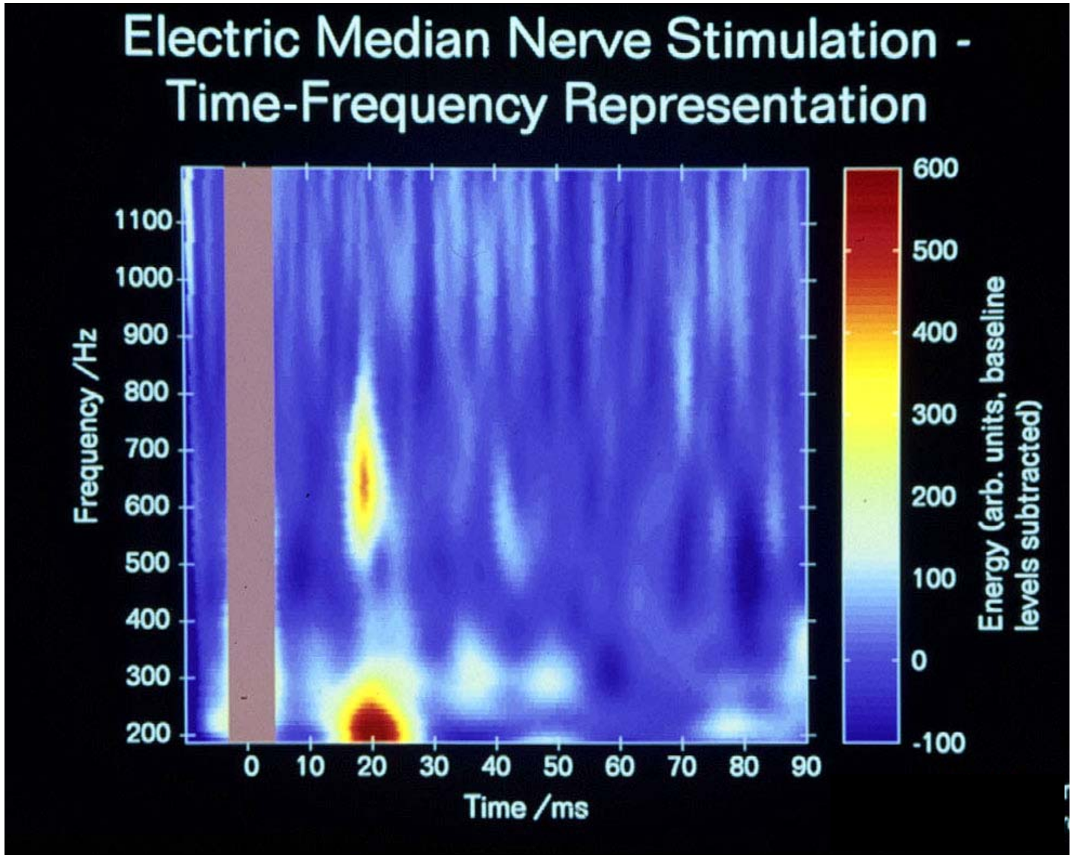
Emerson et al. (1988), Yamada et al. (1988):
during sleep: hf-oscillation ⇓ vs. N20 ⇔

MEG: Cortical burst generator

Electroencephalography and clinical Neurophysiology, 91 (1994) 483–487

Localization of evoked neuromagnetic 600 Hz activity in the cerebral somatosensory system

Gabriel Curio [a,*], Bruno-Marcel Mackert [a], Martin Burghoff [b], Roman Koetitz [b], Klaus Abraham-Fuchs [c] and Wolfgang Härer [c]



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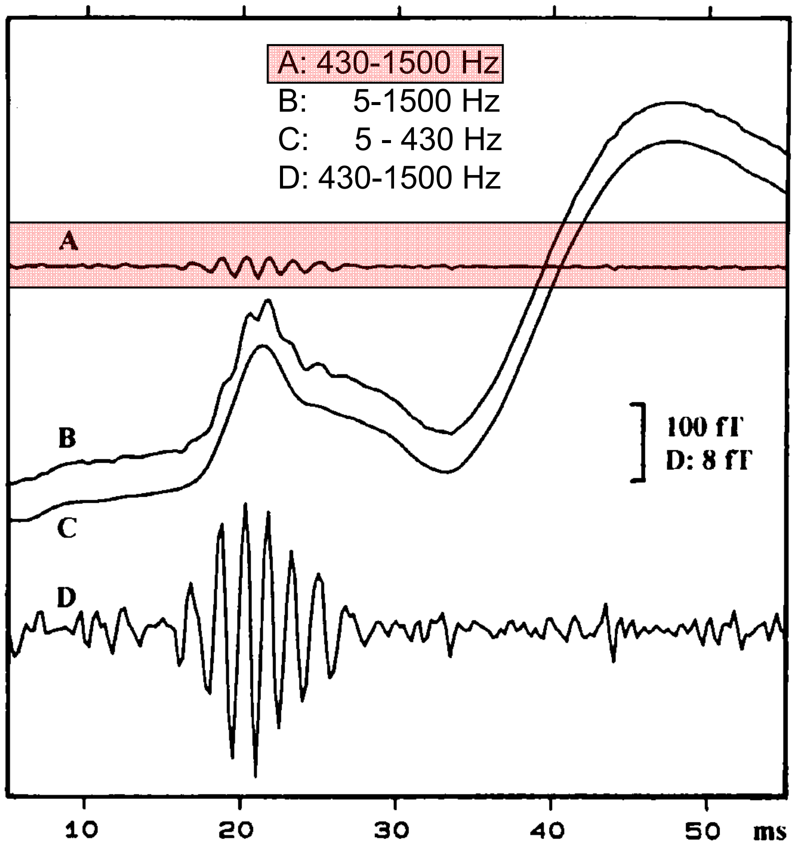
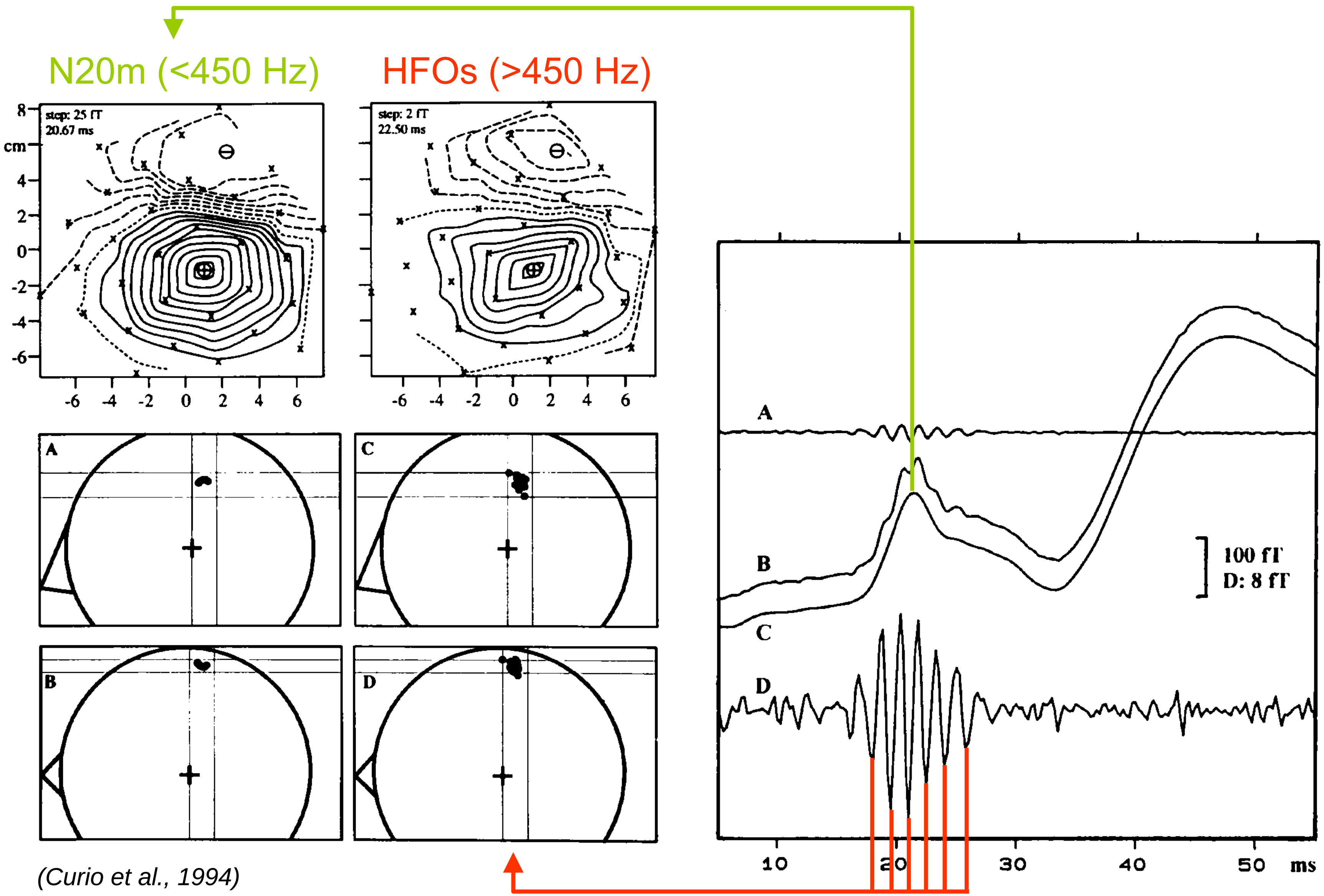


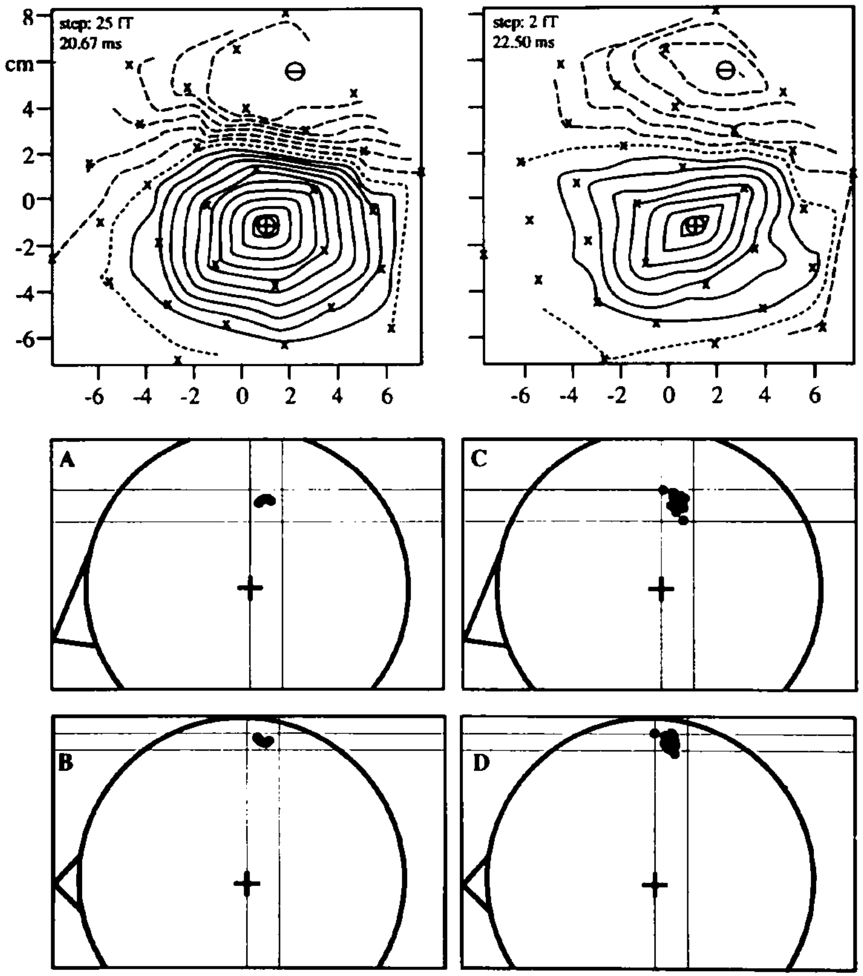
Co-localisation of N20m and 600 Hz burst



(Curio et al., 1994)

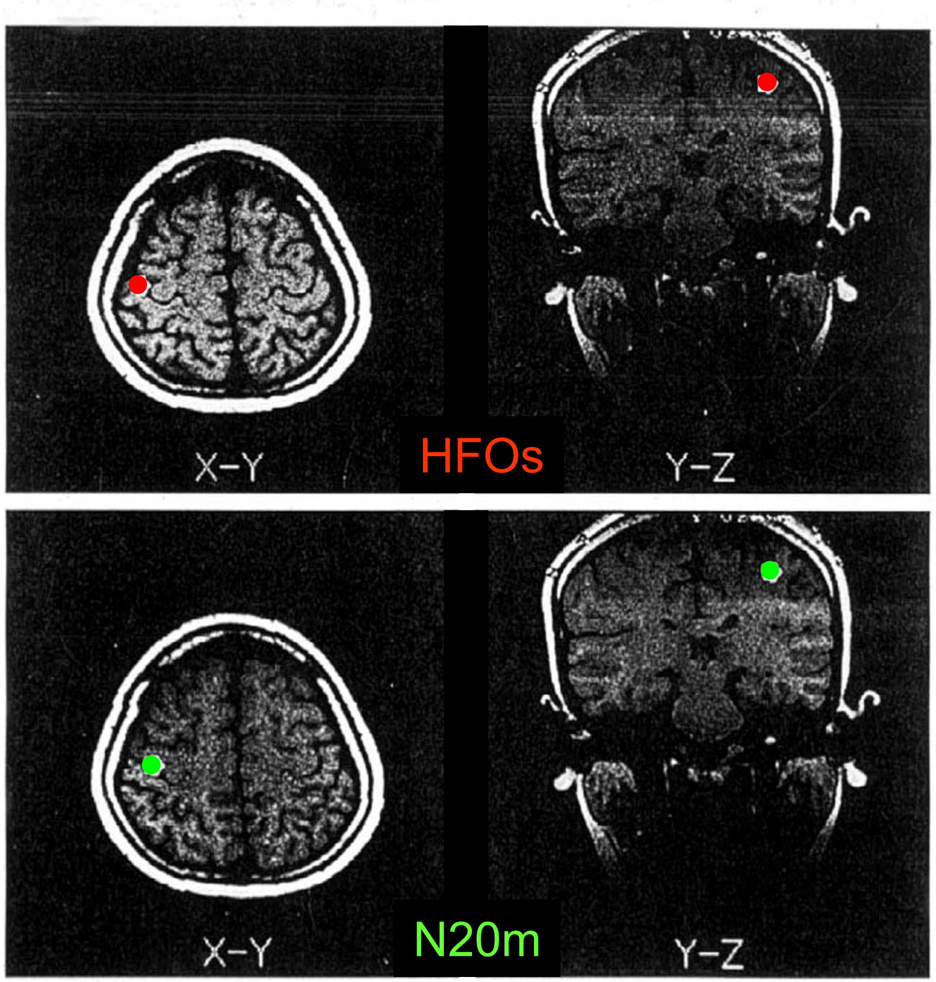
Co-localisation of N20m and 600 Hz burst

N20m (<450 Hz) HFOs (>450 Hz)

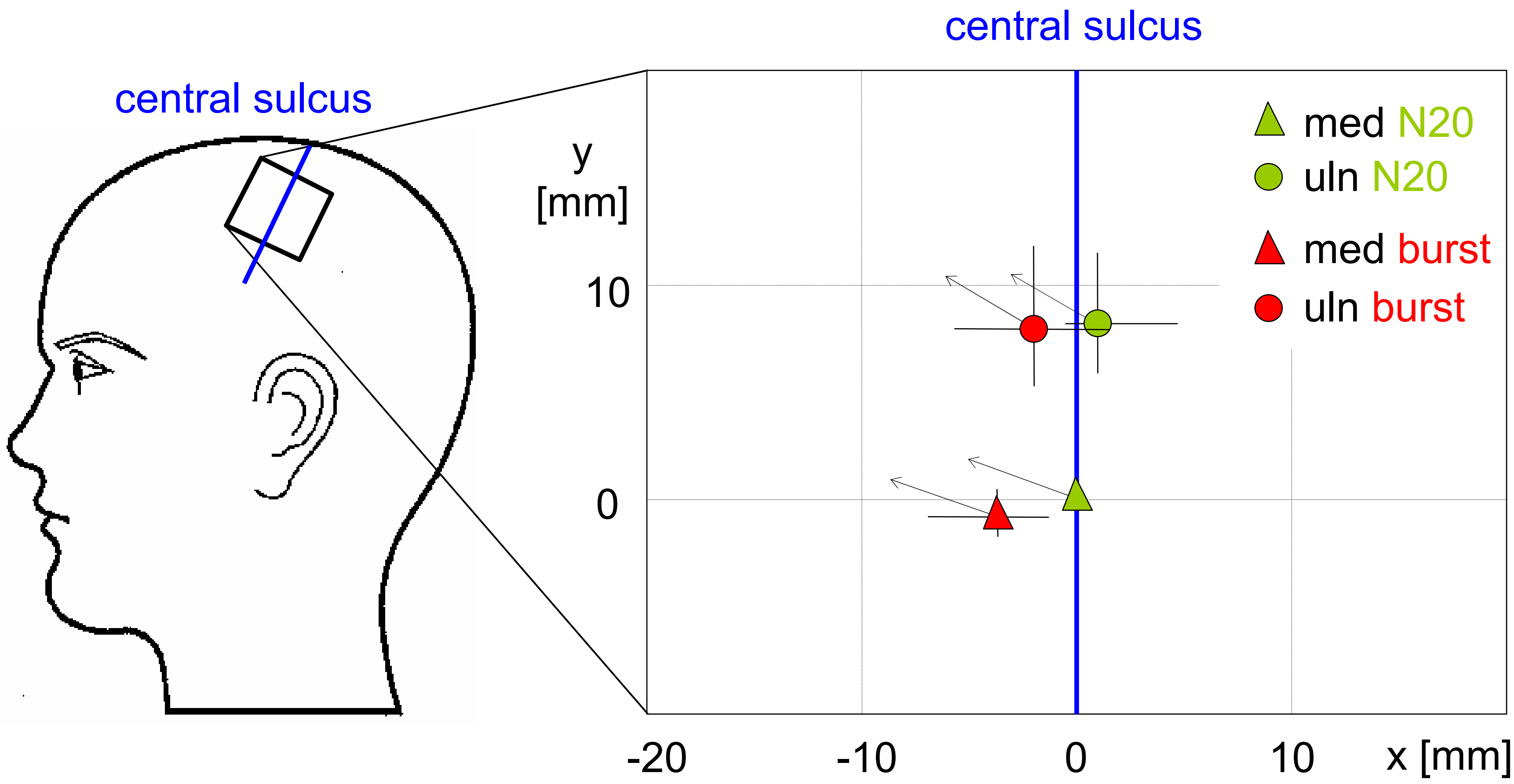


(Curio et al., 1994)

(modified from Hashimoto et al. 1996)



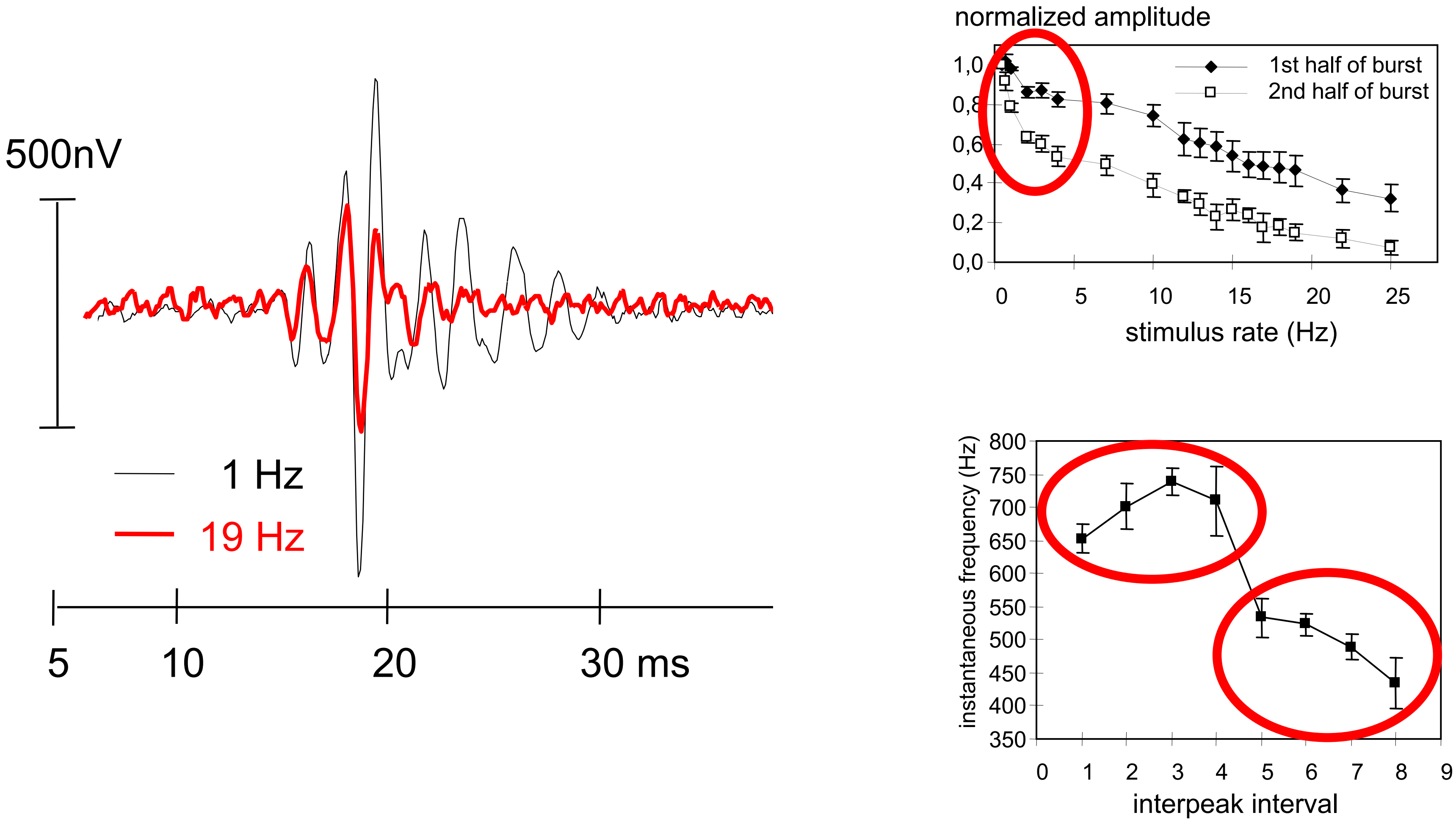
Somatotopy



High-resolution (7 mm) somatotopy of burst generators in S-1

(Curio et al., 1997)

Burst components: stimulation rate



(modified from Klostermann, Nolte and Curio; 1999)

Burst components: simultanous MEG + EEG

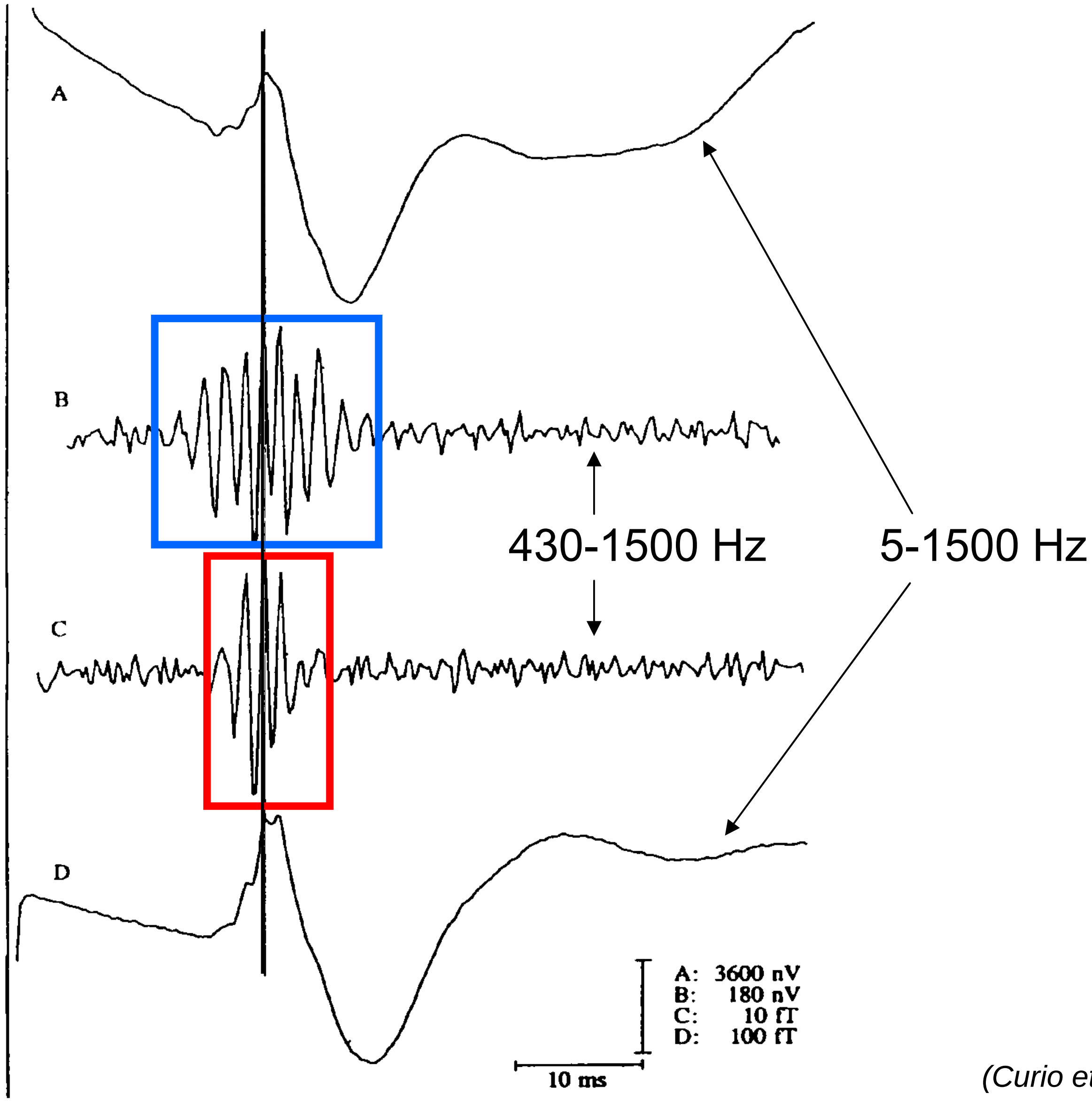
A, B: EEG

early radial: TC aff.

late radial: area 1

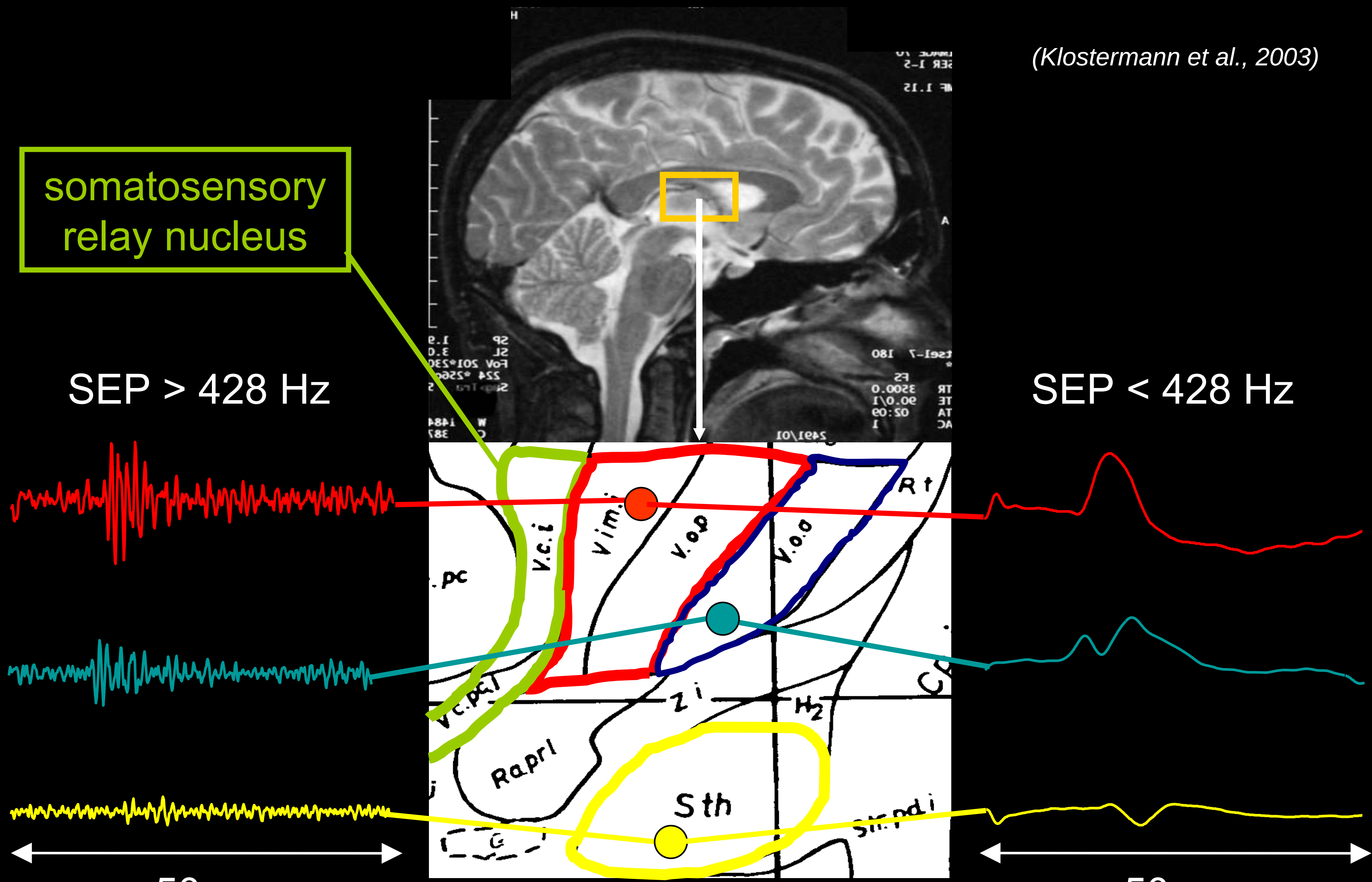
C, D: MEG

tangential: area 3b



(Curio et al., 1994)

Thalamic SEP: Deep Brain Stimulation (DBS)



Physiology in LGN: Intensity

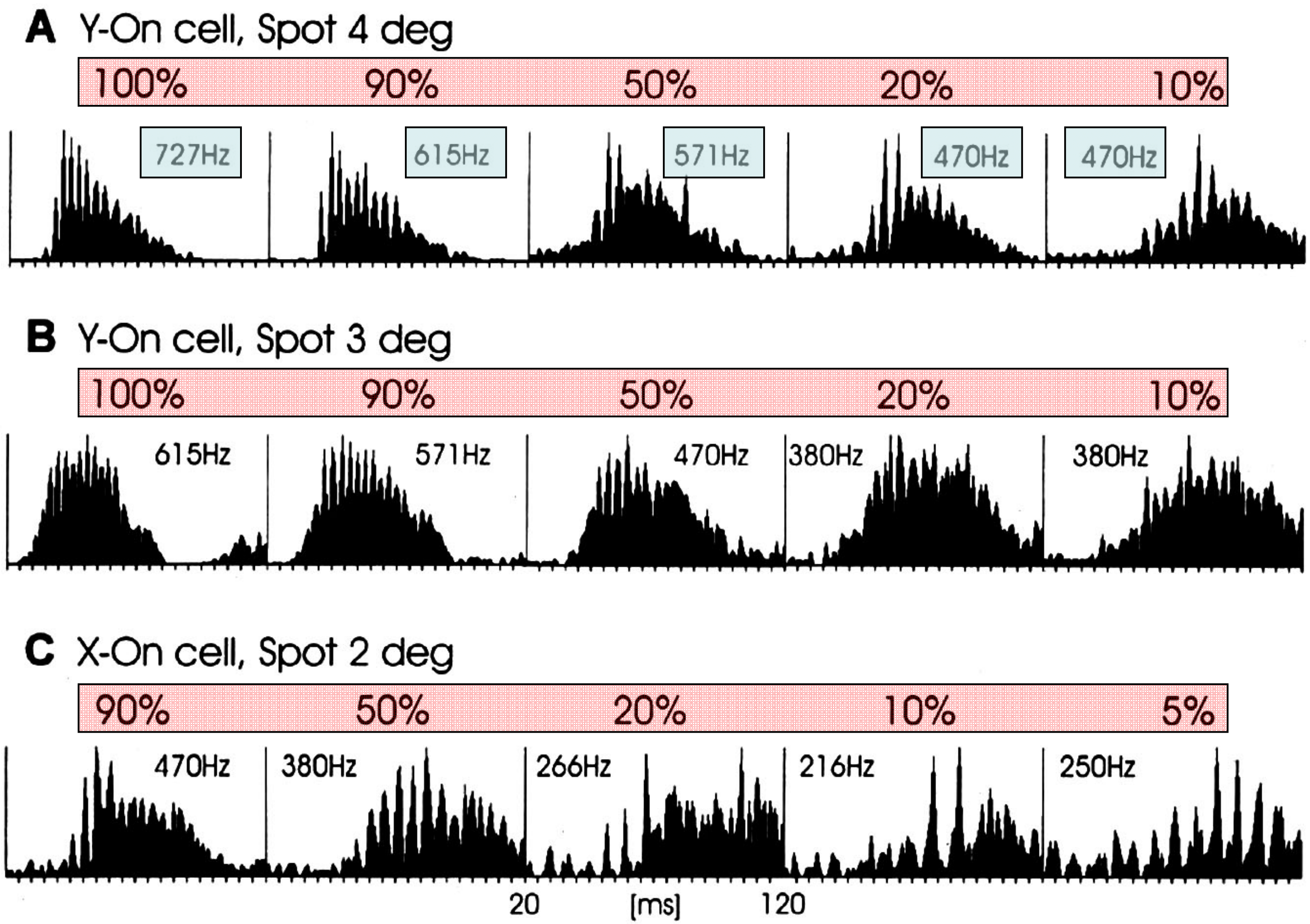
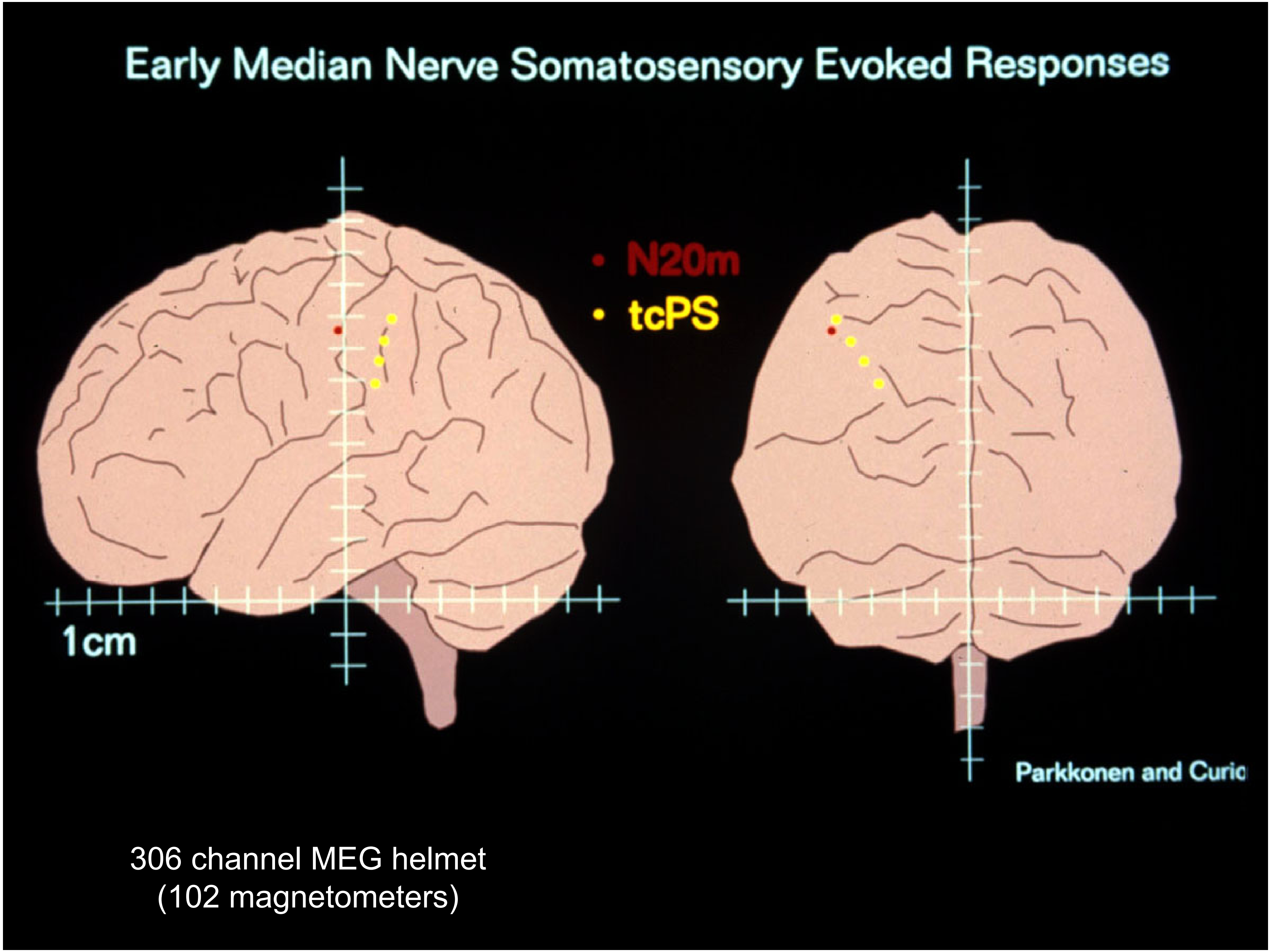
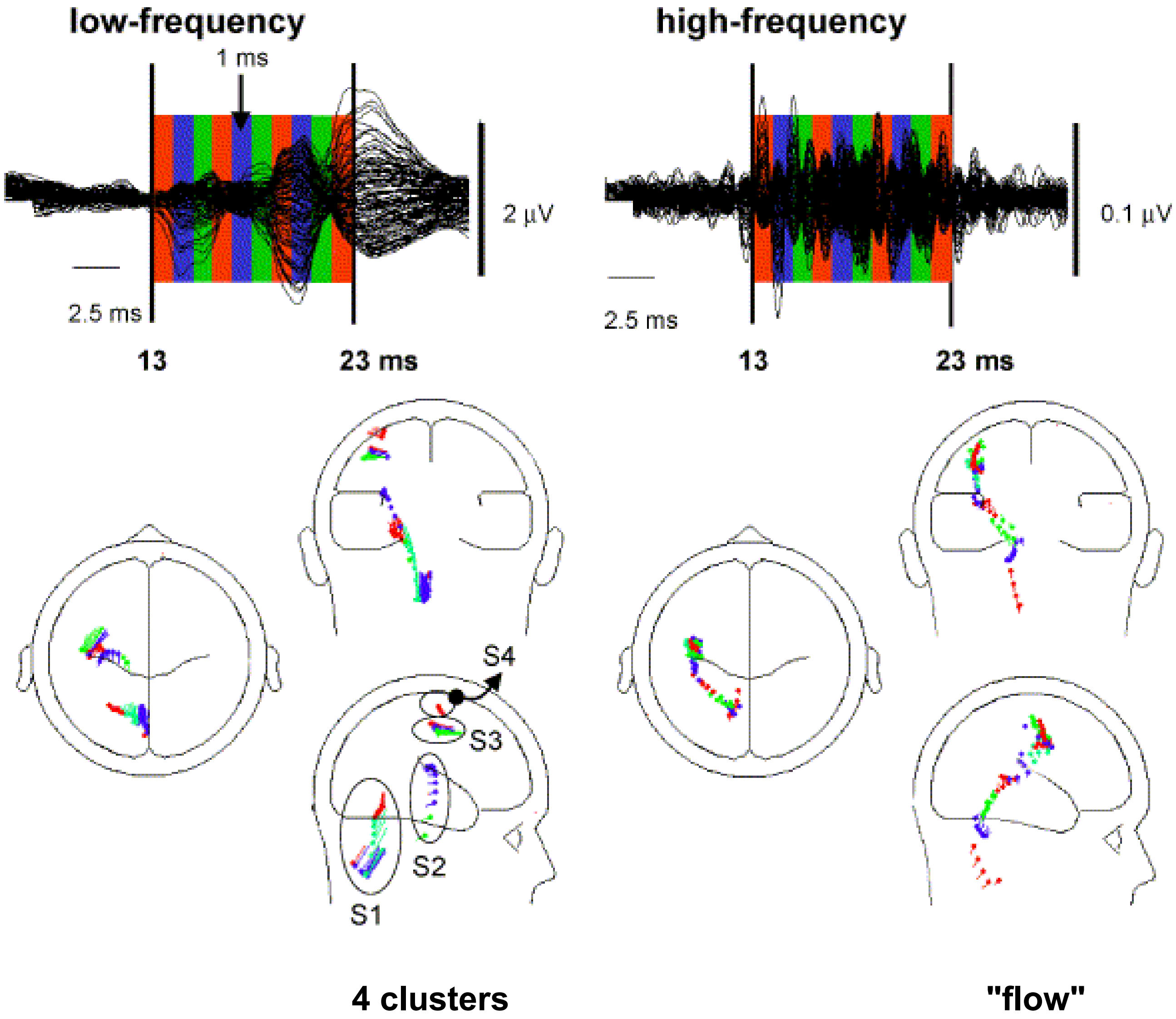


Figure 4. Initial light responses of two Y-cells (**A**, **B**) and one X-cell (**C**) elicited by light spots of constant size but varied intensity, resulting in 100, 90, 50, 20, 10 and 5% contrast to background. Frequency of the oscillation declines with decreasing stimulus contrast.

(modified from Funke and Kerscher, 2000)

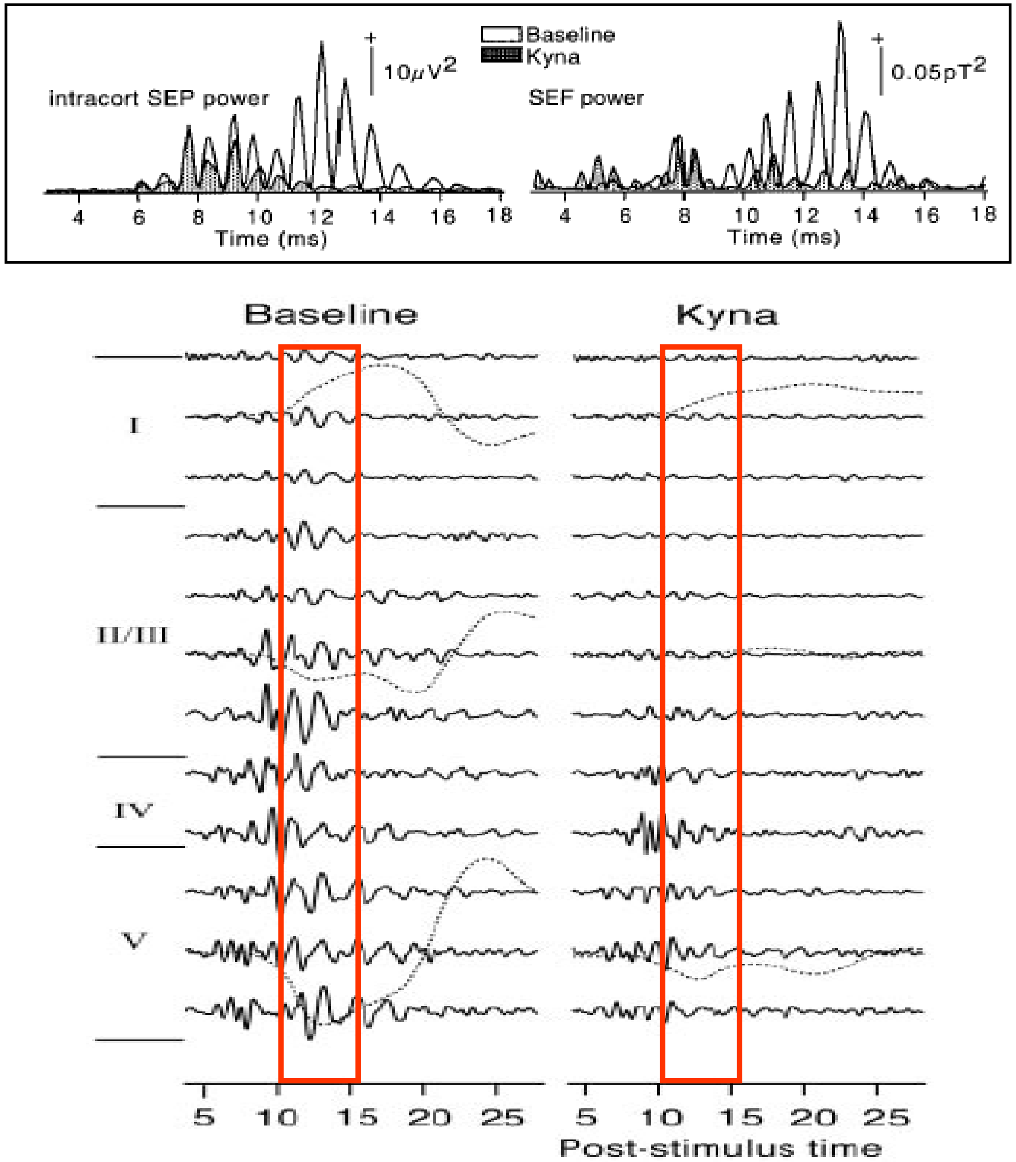

Early Median Nerve Somatosensory Evoked Responses
N20m
tcPS
1cm
Parkkonen and Curio
306 channel MEG helmet
(102 magnetometers)

EEG source analysis



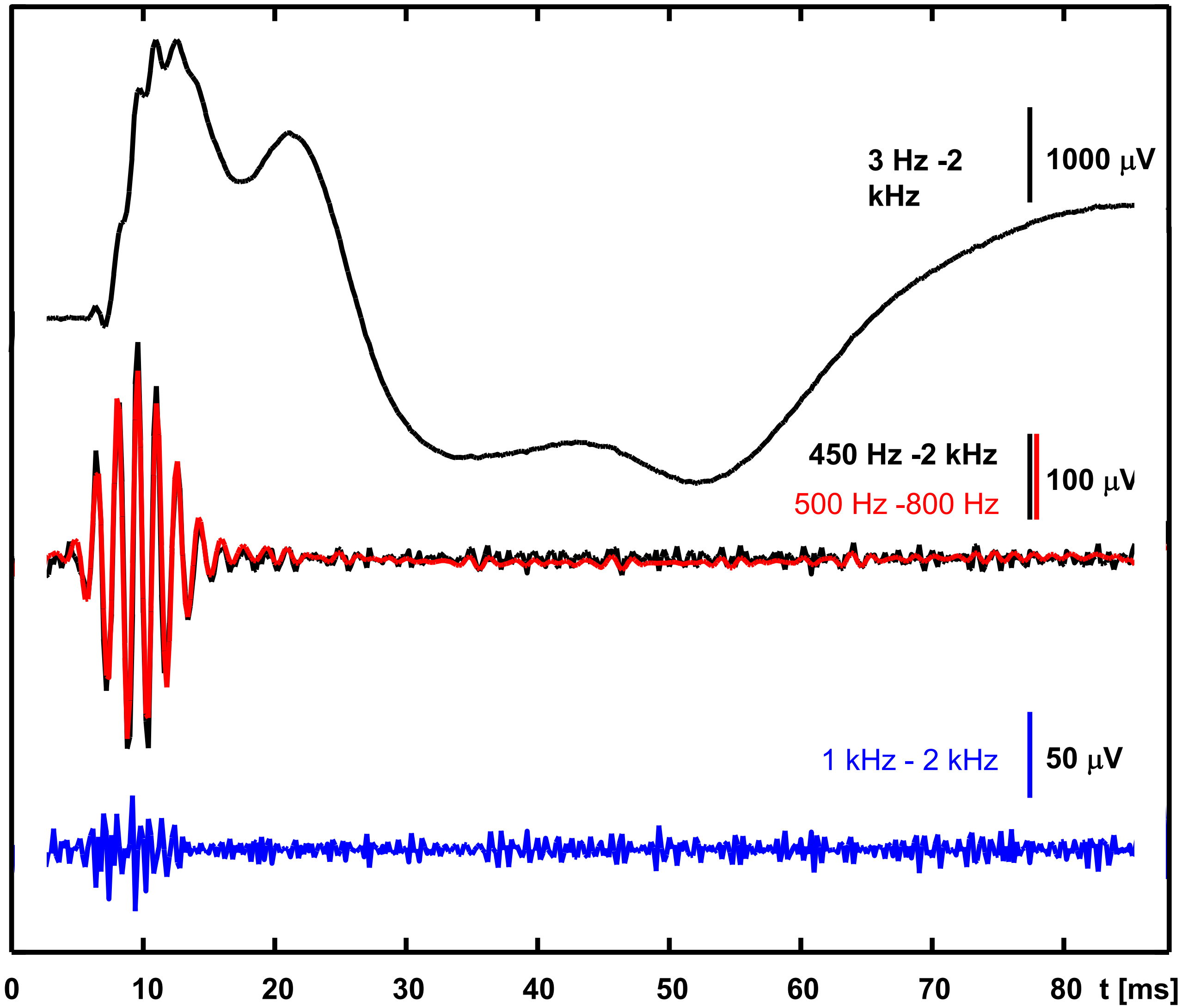
(Gobbelé et al., 2004)

Early burst survives cortical glutamate antagonisation



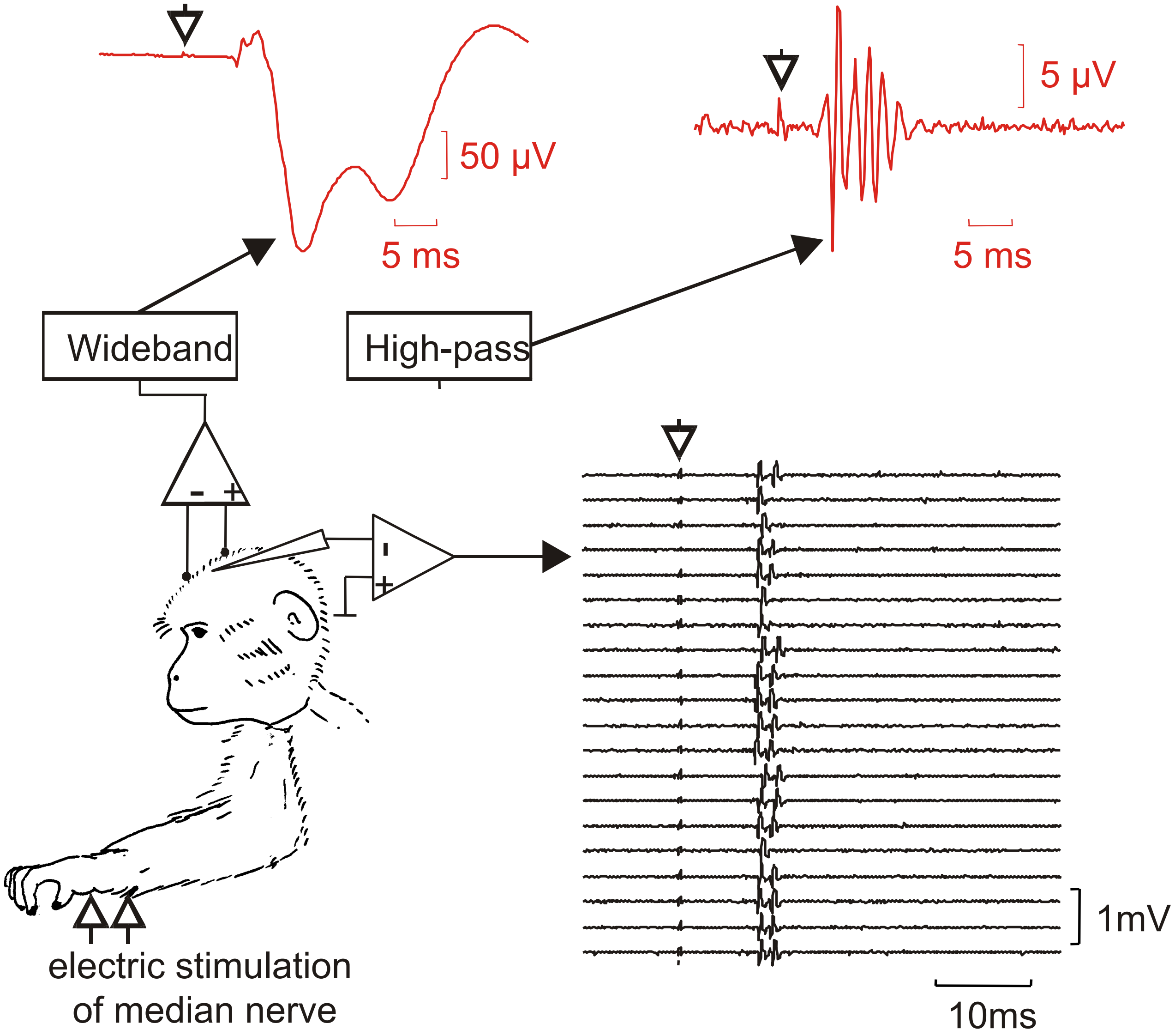
(Ikeda et al, 2002)

Epidural SEP from monkey S-1



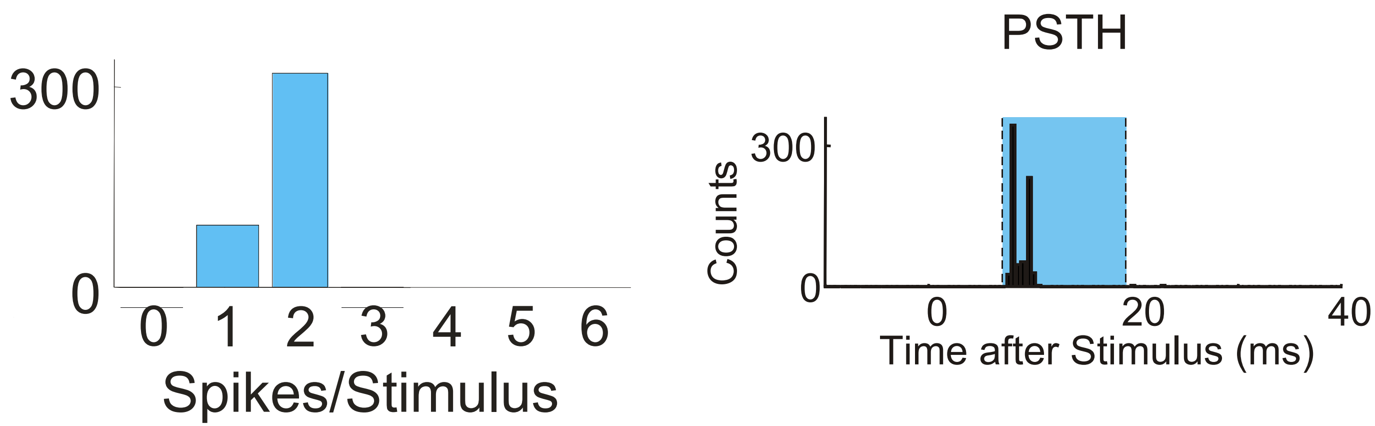
(Baker, Curio, Lemon, J Physiol., 2003)

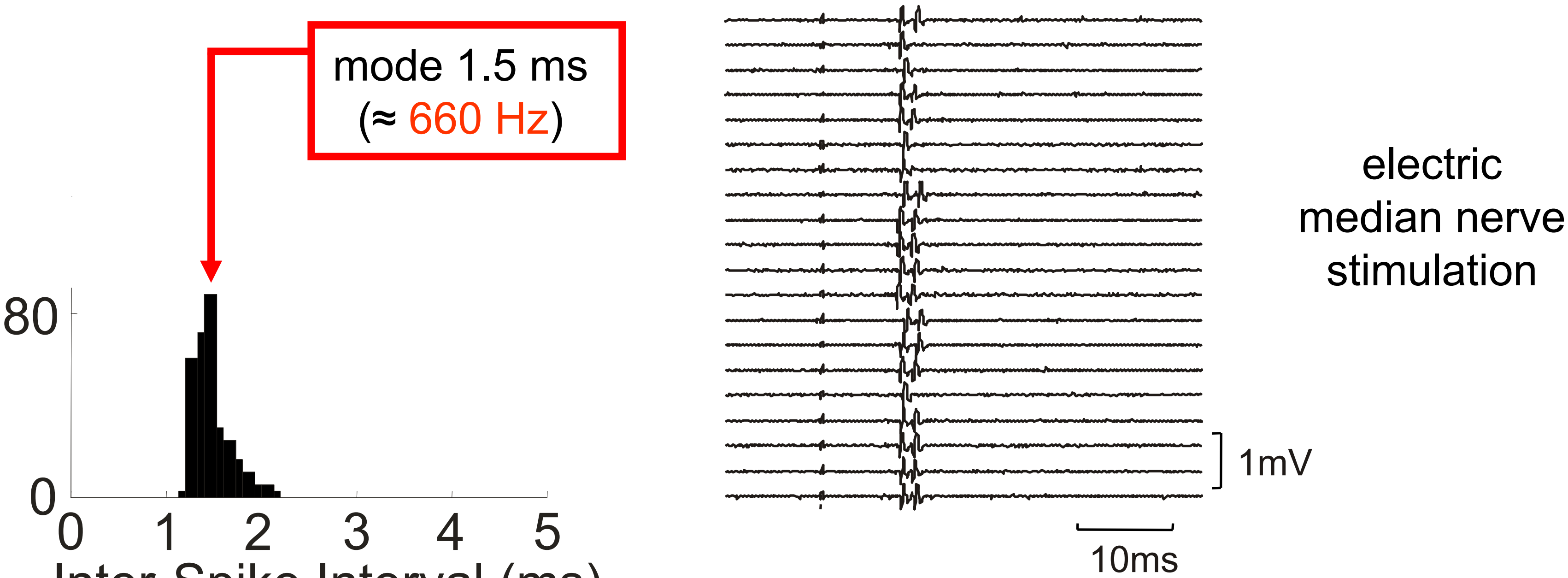
Physiology in monkey S-1: burst neurons



(Baker, Curio, Lemon, J Physiol., 2003)

Physiology in monkey S-1: burst neurons





(Baker, Curio, Lemon, J Physiol., 2003)

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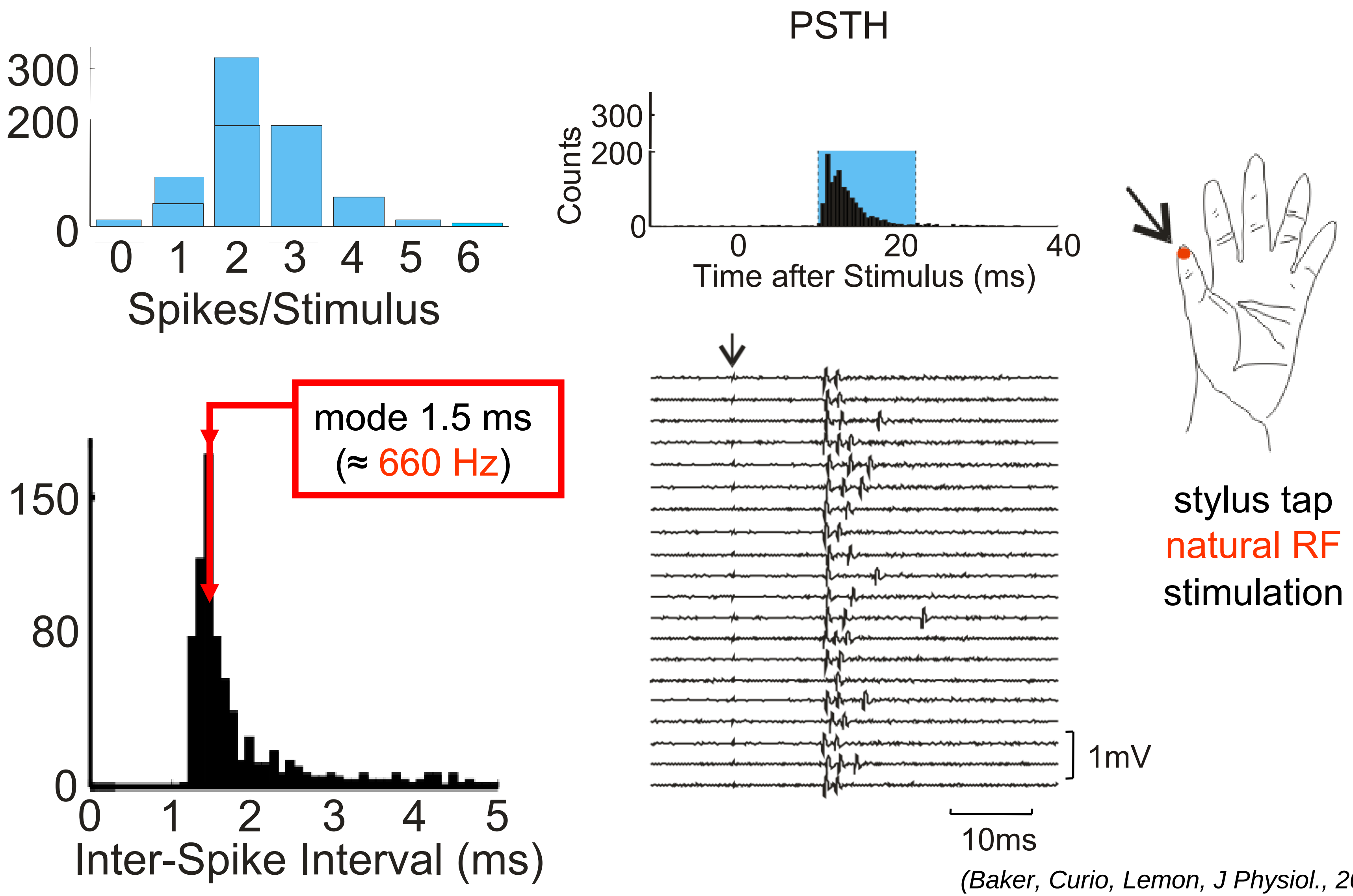
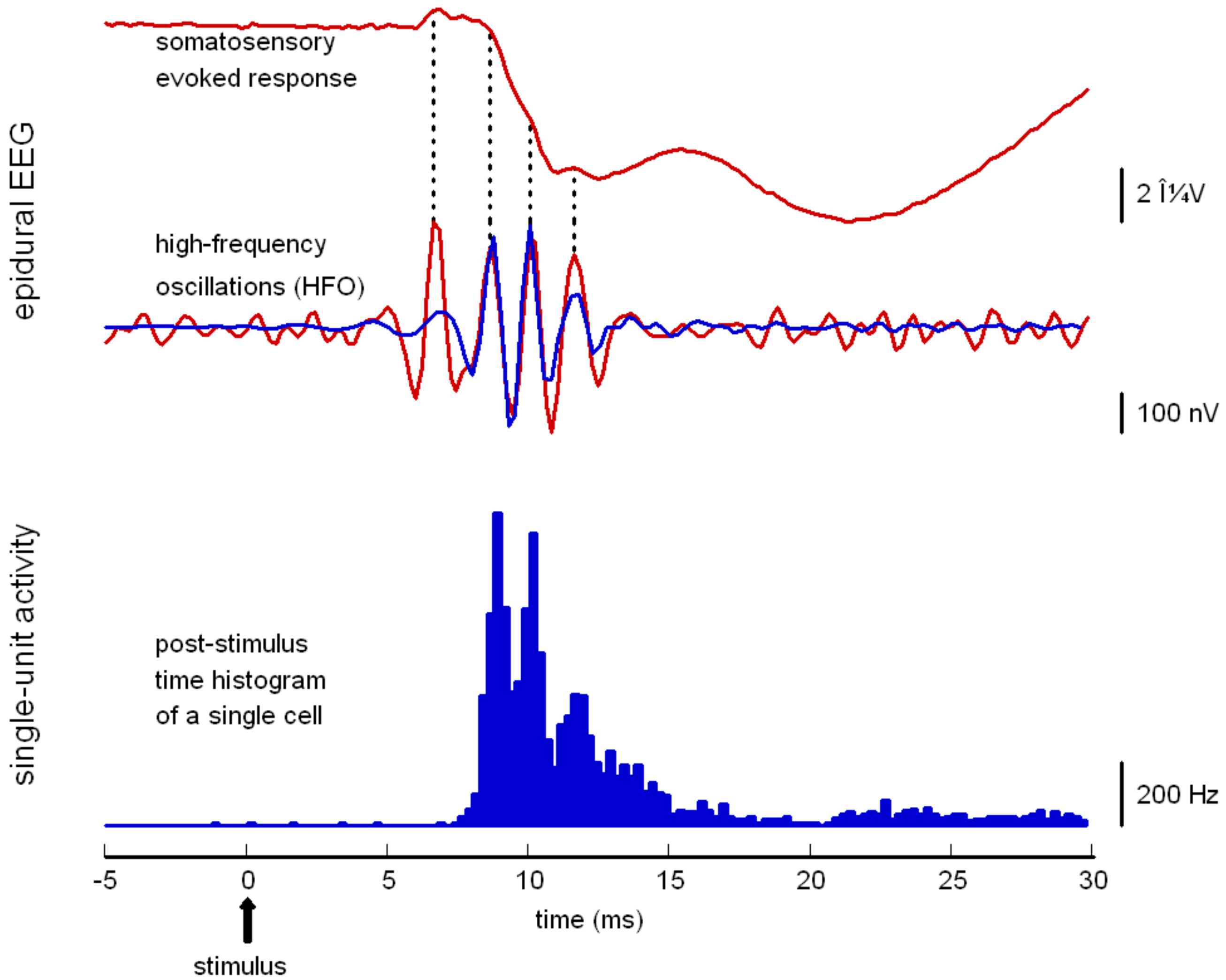
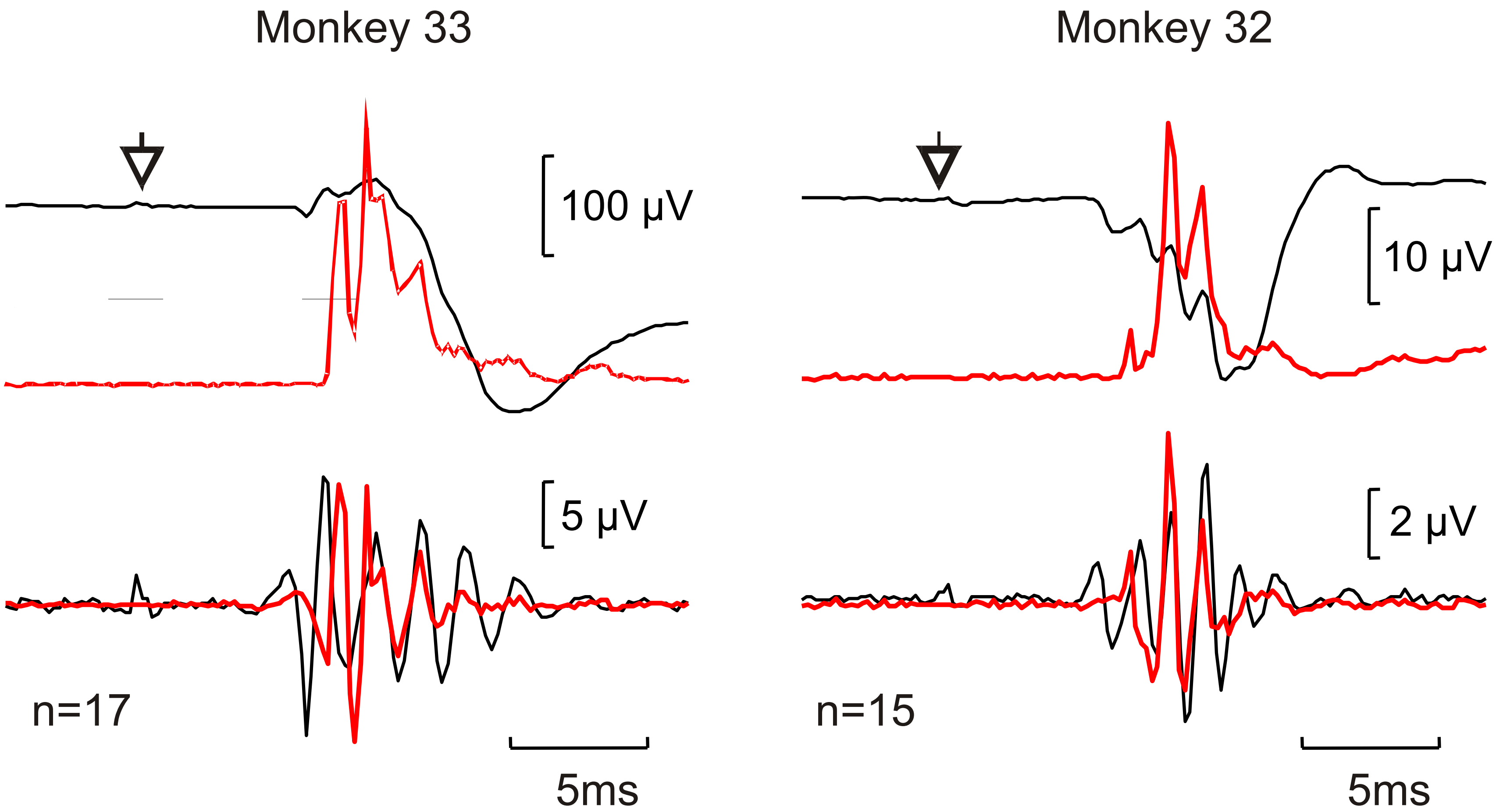


(Baker, Curio, Lemon, J Physiol., 2003)

Physiology in monkey S-1: burst neurons



Physiology in monkey S-1: burst neurons

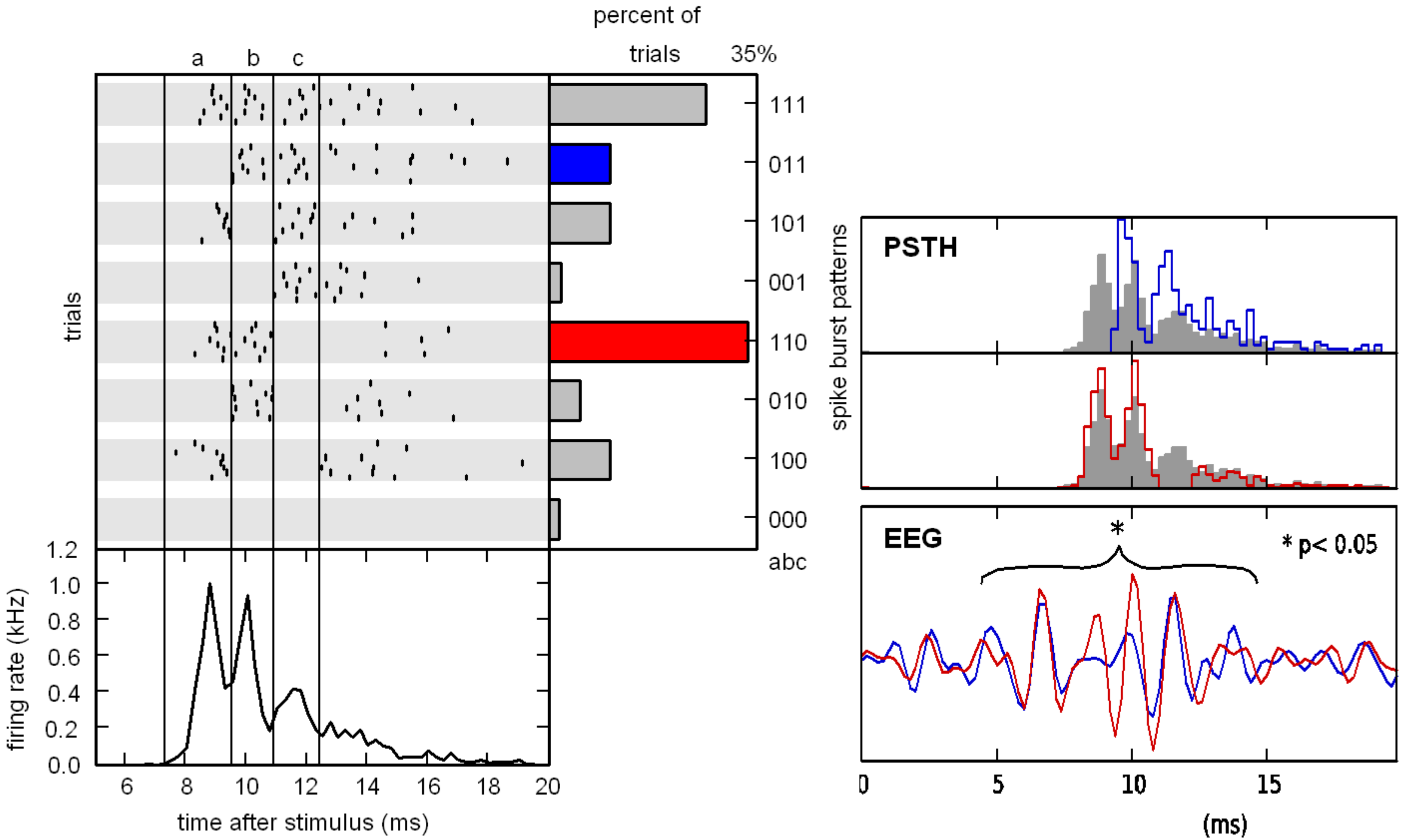


epidural EEG

summed single unit PSTHs

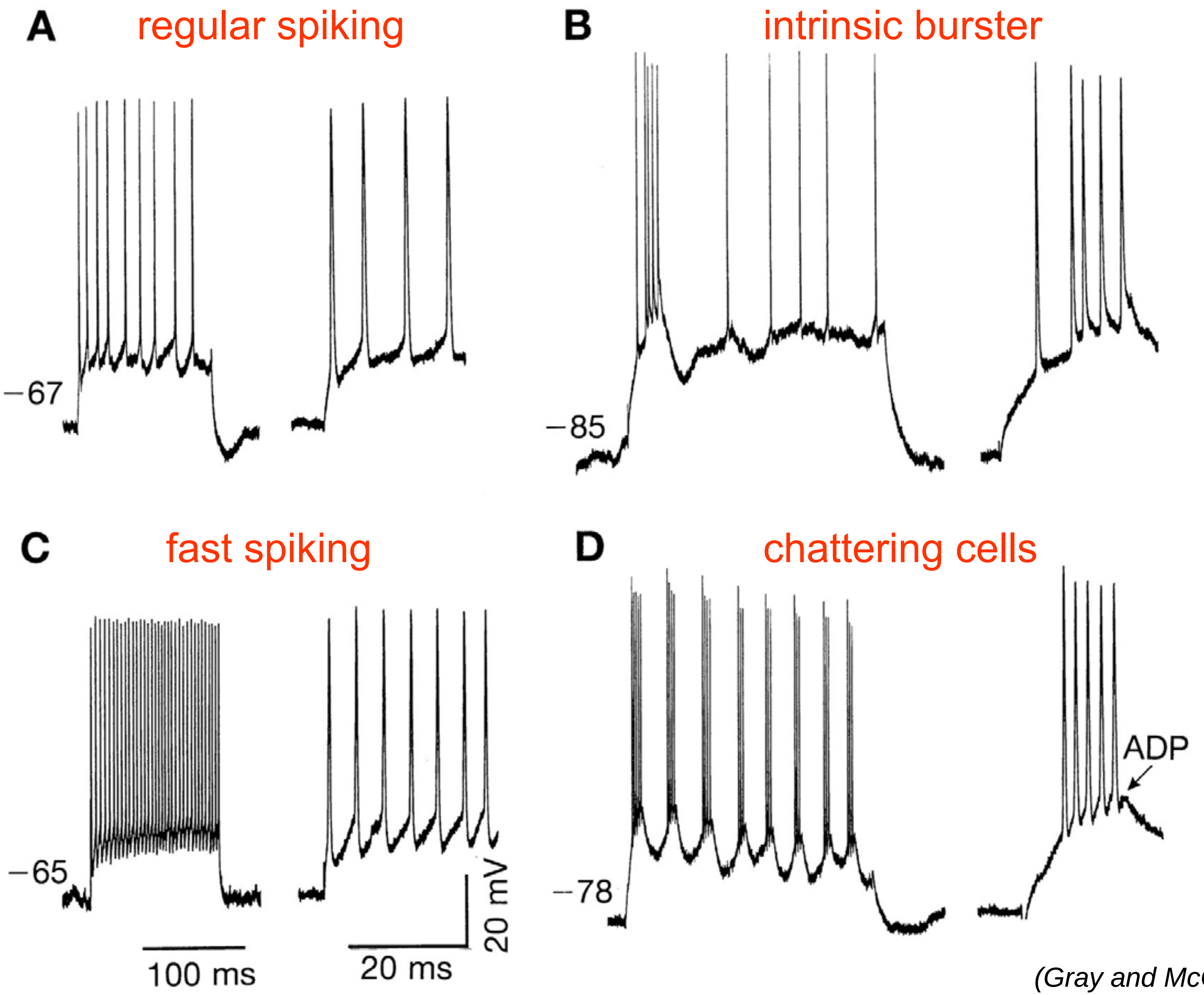
(Baker, Curio, Lemon, J Physiol., 2003)

Single-cell spike burst patterns: 111 vs 110



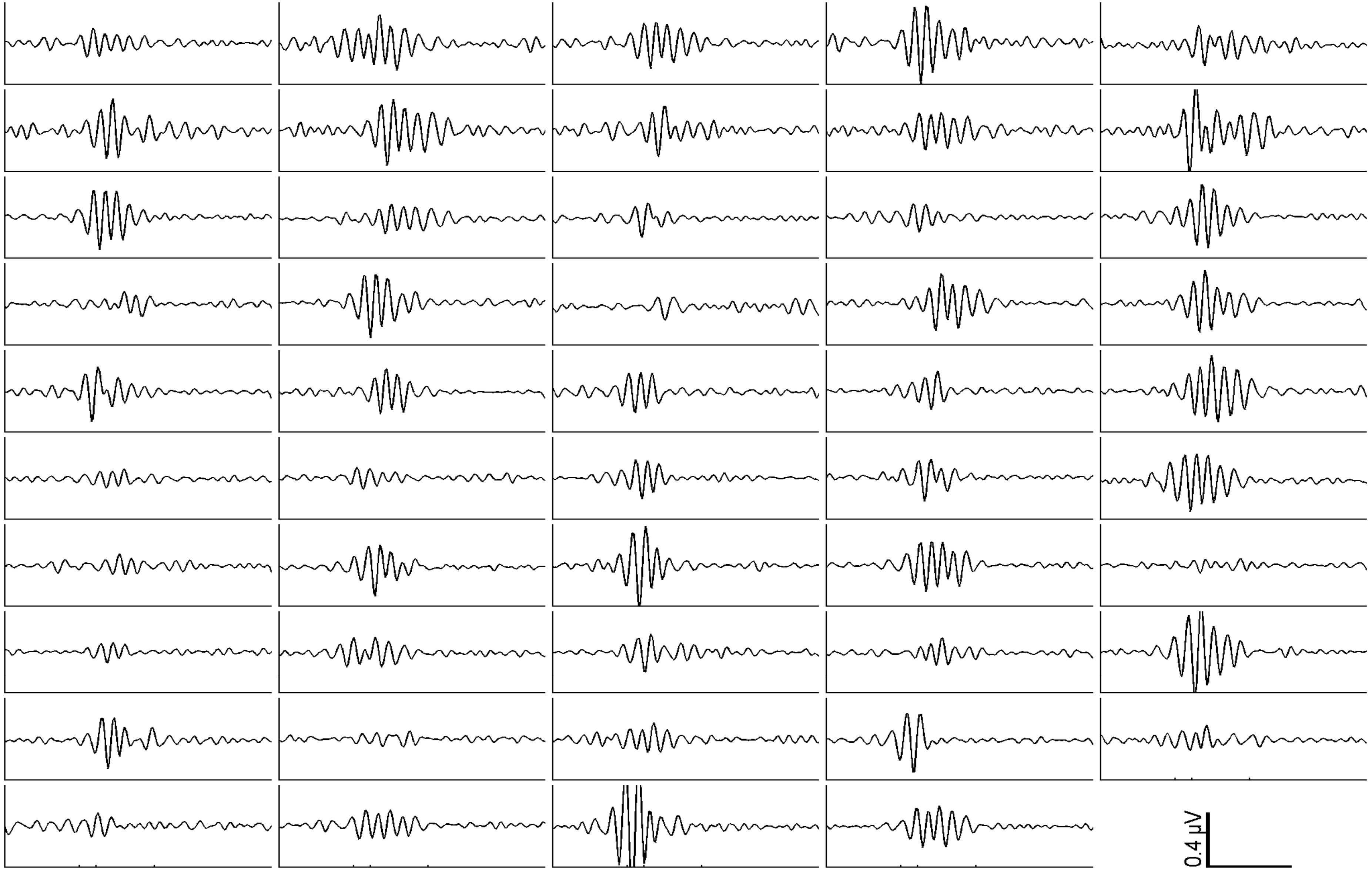
(Telenczuk et al., J Neurophysiol., 2011)

Physiology in cat V-1: burst neurons



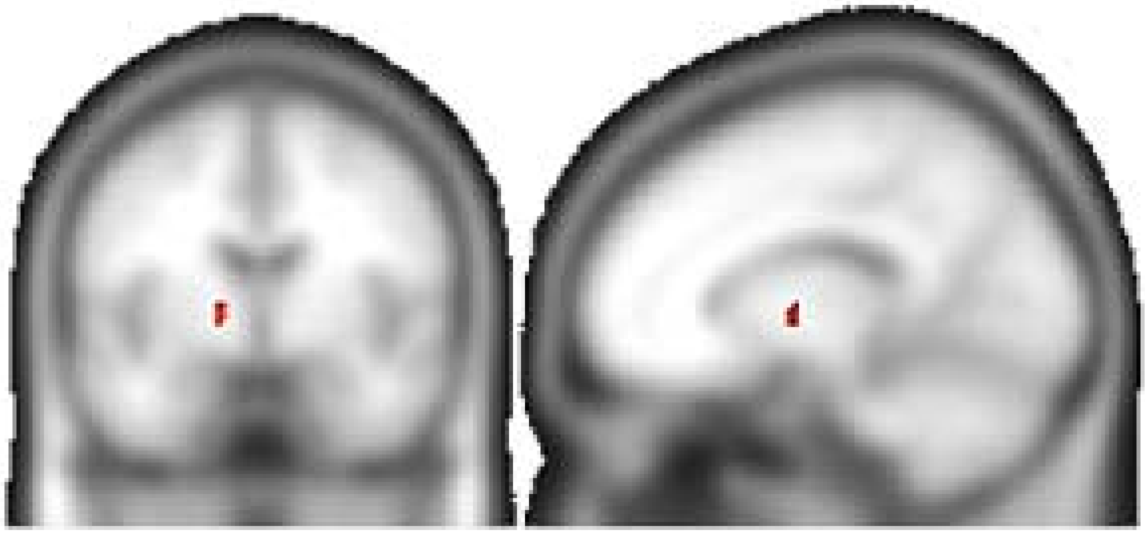
(Gray and McCormick, 1996)

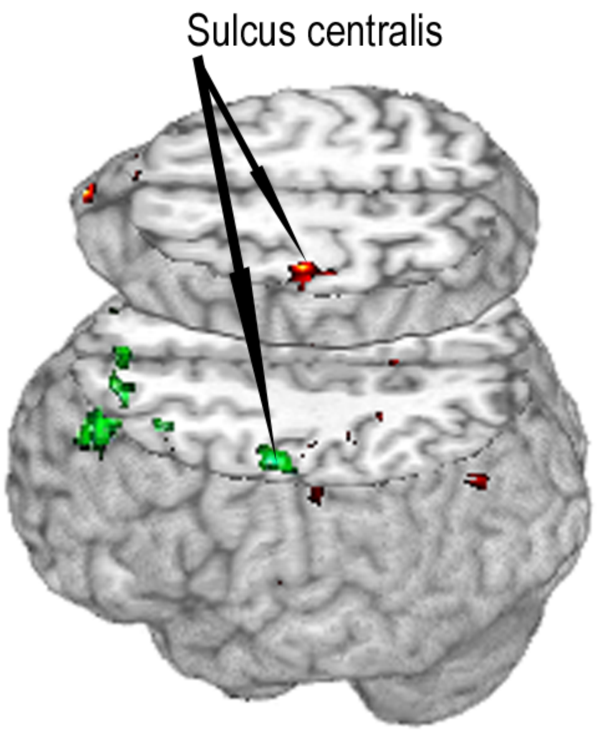
SEP bursts can be recovered during fMRI (n=49)



Cp5; 400-1000 Hz

BOLD covariation with SEP components





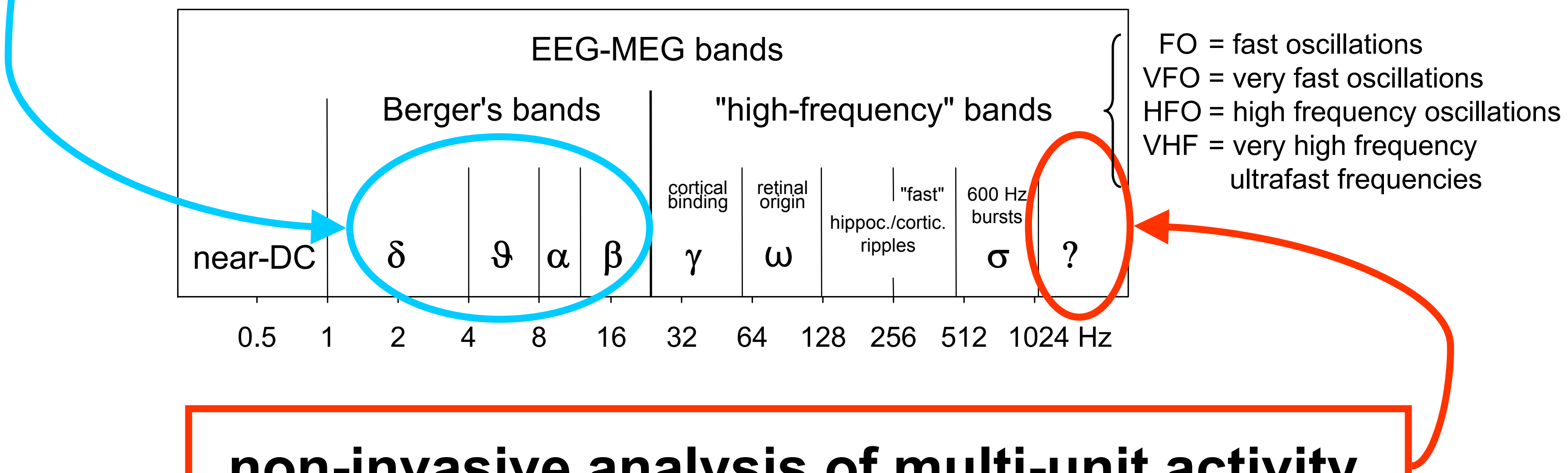
Thalamic BOLD covariation
with early burst

S-1 BOLD covariation
with N20
and late burst

(Ritter et al., NeuroImage, 2008)

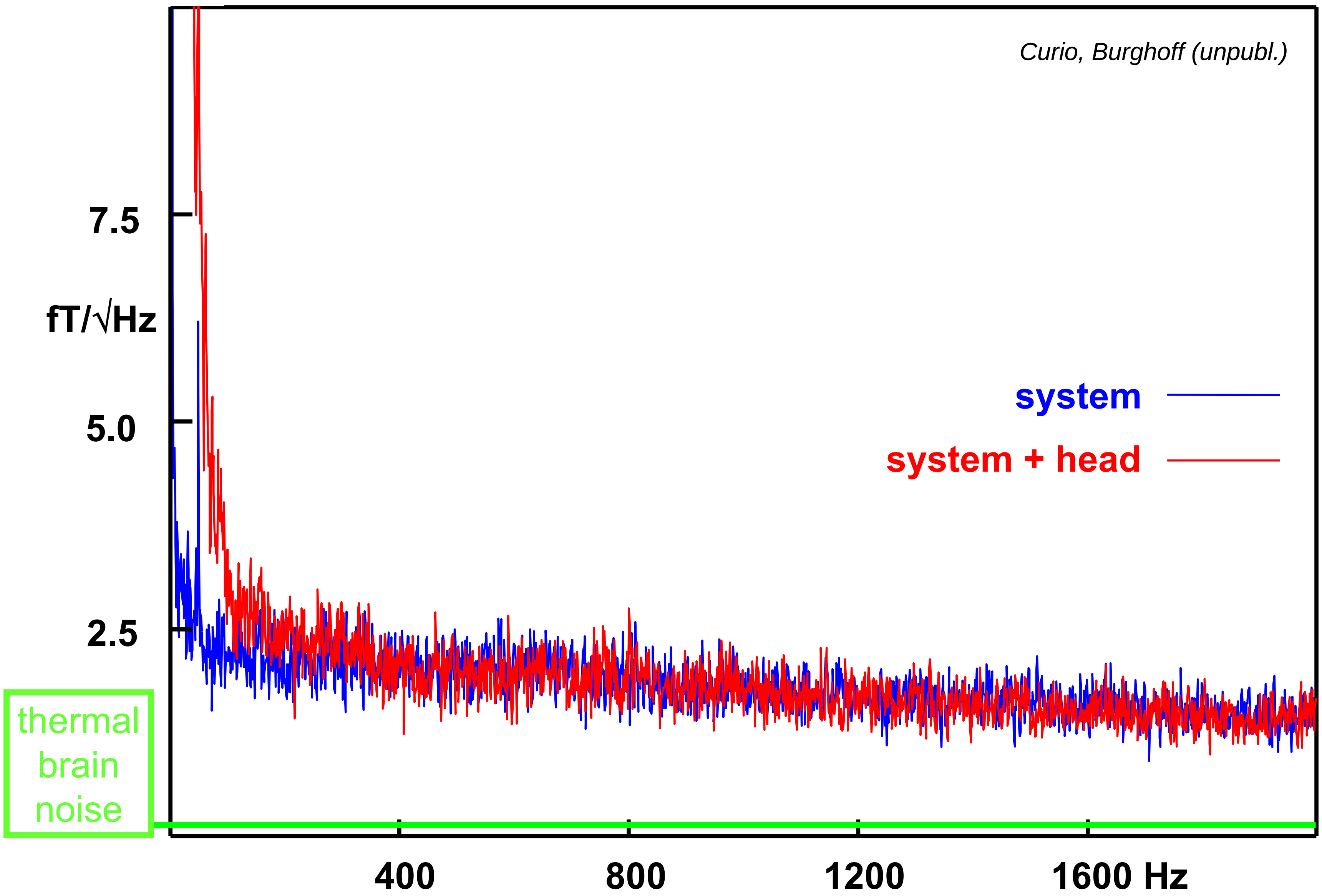
Berger's bands – and far beyond

standard low-frequency EEG bands



non-invasive analysis of multi-unit activity

MEG noise analysis: amplitude spectra



JULY, 1928 PHYSICAL REVIEW VOLUME 32

THERMAL AGITATION OF ELECTRICITY IN CONDUCTORS

BY J. B. JOHNSON

Thermal Johnson–Nyquist noise (electrode-skin impedance)

$$V(t) = \sqrt{4k_B \cdot T \cdot R \cdot \Delta f}$$

$k_B = 1.38 \cdot 10^{-23}$ J/K

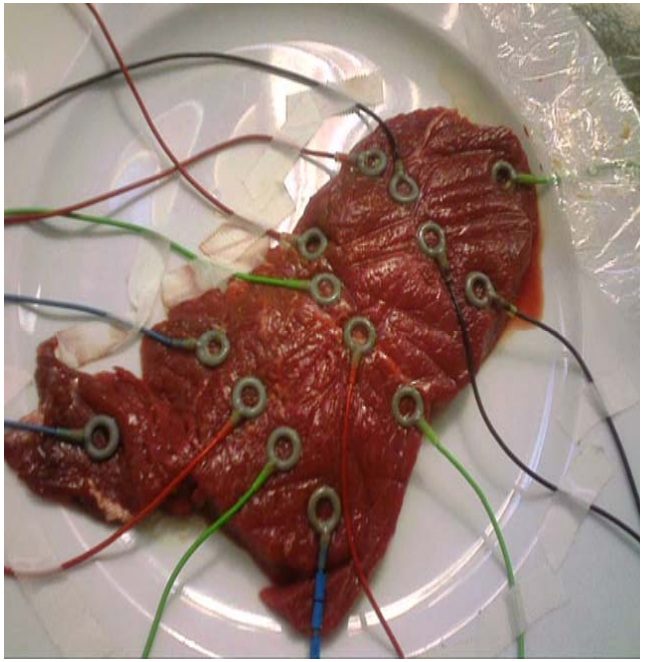
$T = 310$ K (37° C)

$R = 1$ kOhm

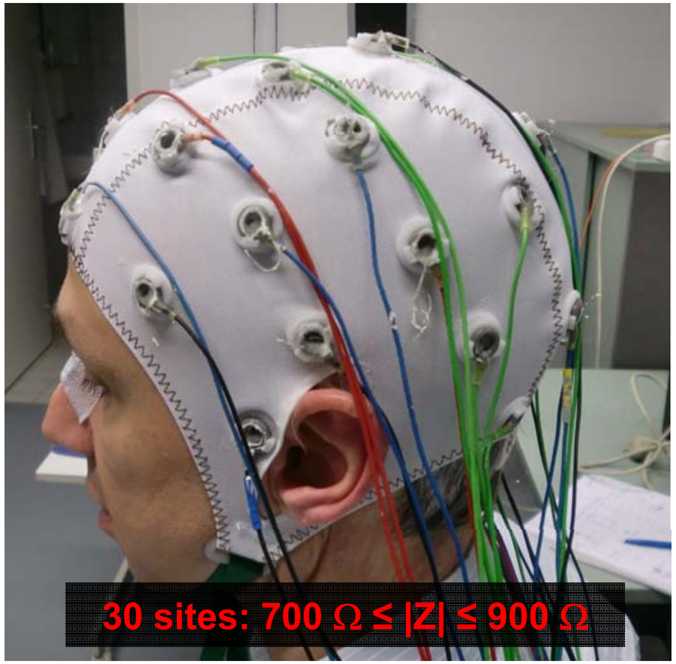
$\Delta f = 1$ Hz

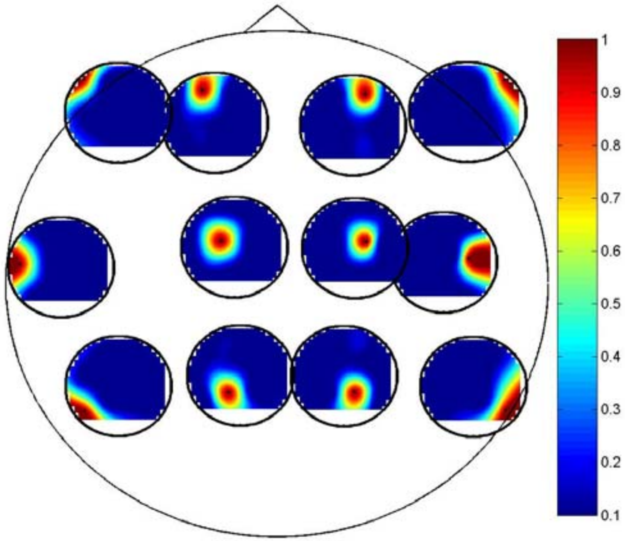
$\approx 4.1\ \mathrm{nV} / \sqrt{\mathrm{Hz}}$

Impedances – checking the limits

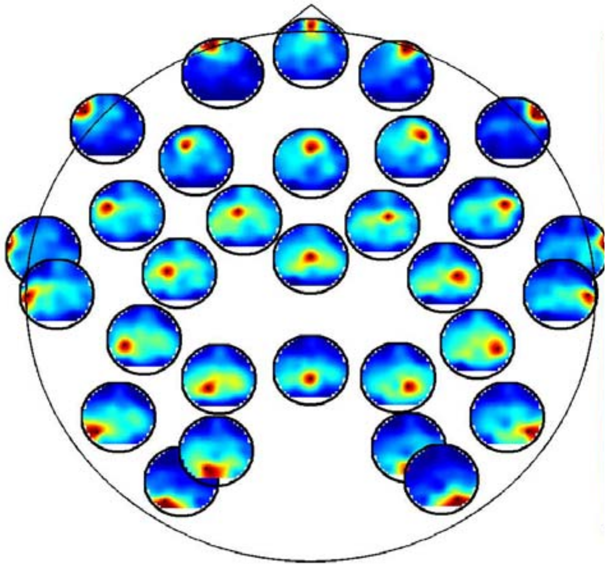


Ch1	215 Ω
Ch2	125 Ω
Ch3	205 Ω
Ch4	95 Ω
Ch5	150 Ω
Ch6	205 Ω
Ch7	95 Ω
Ch8	155 Ω
Ch9	215 Ω
Ch10	120 Ω
Ch11	150 Ω
Ch12	240 Ω

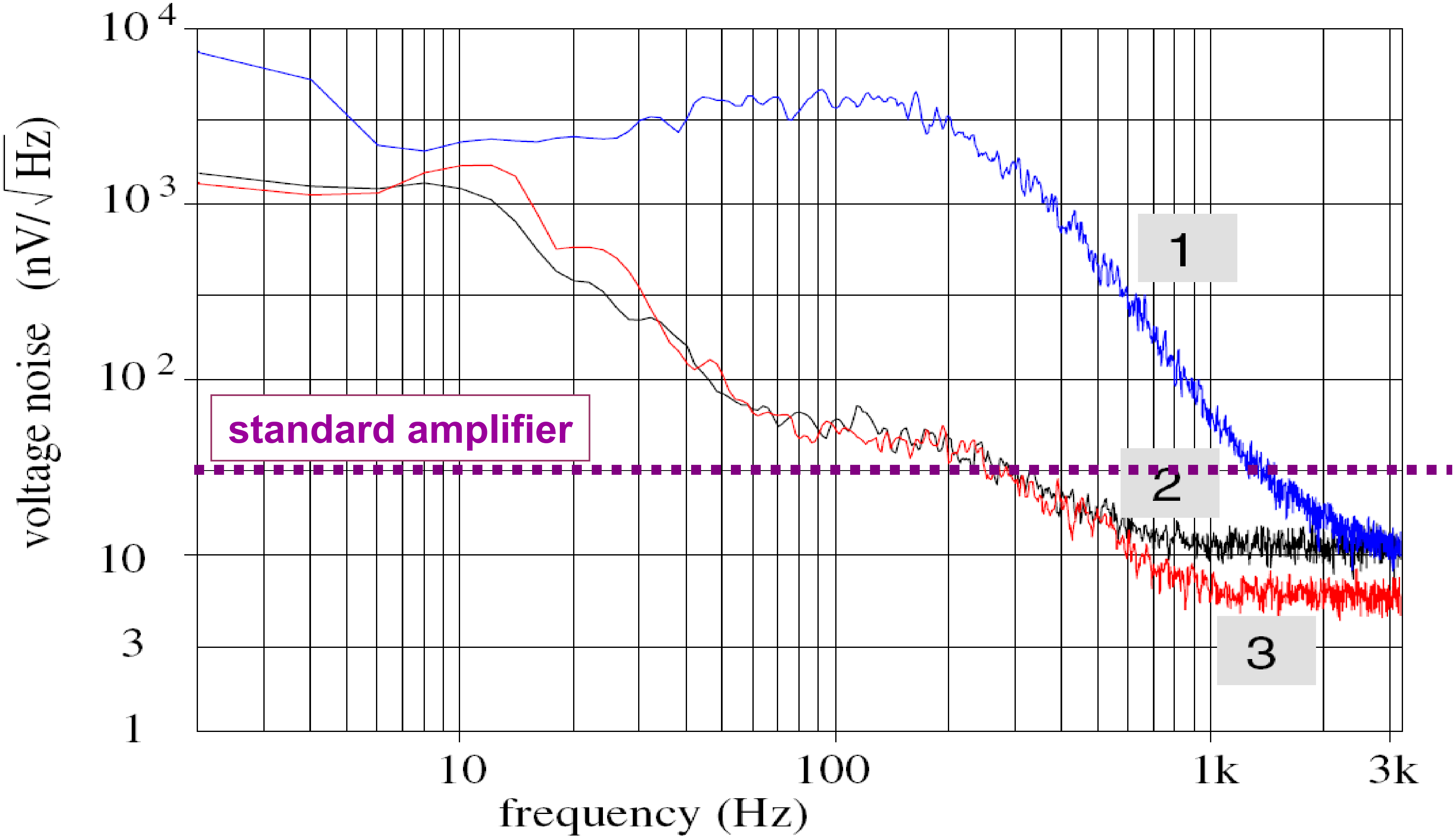




coherence at 1 kHz:
no physical cross-talk



White noise level of EEG spectra



1 = m. masseter innervation

2 = relaxed, 12 nV/√Hz amplifier

3 = relaxed, 4.8 nV/√Hz amplifier

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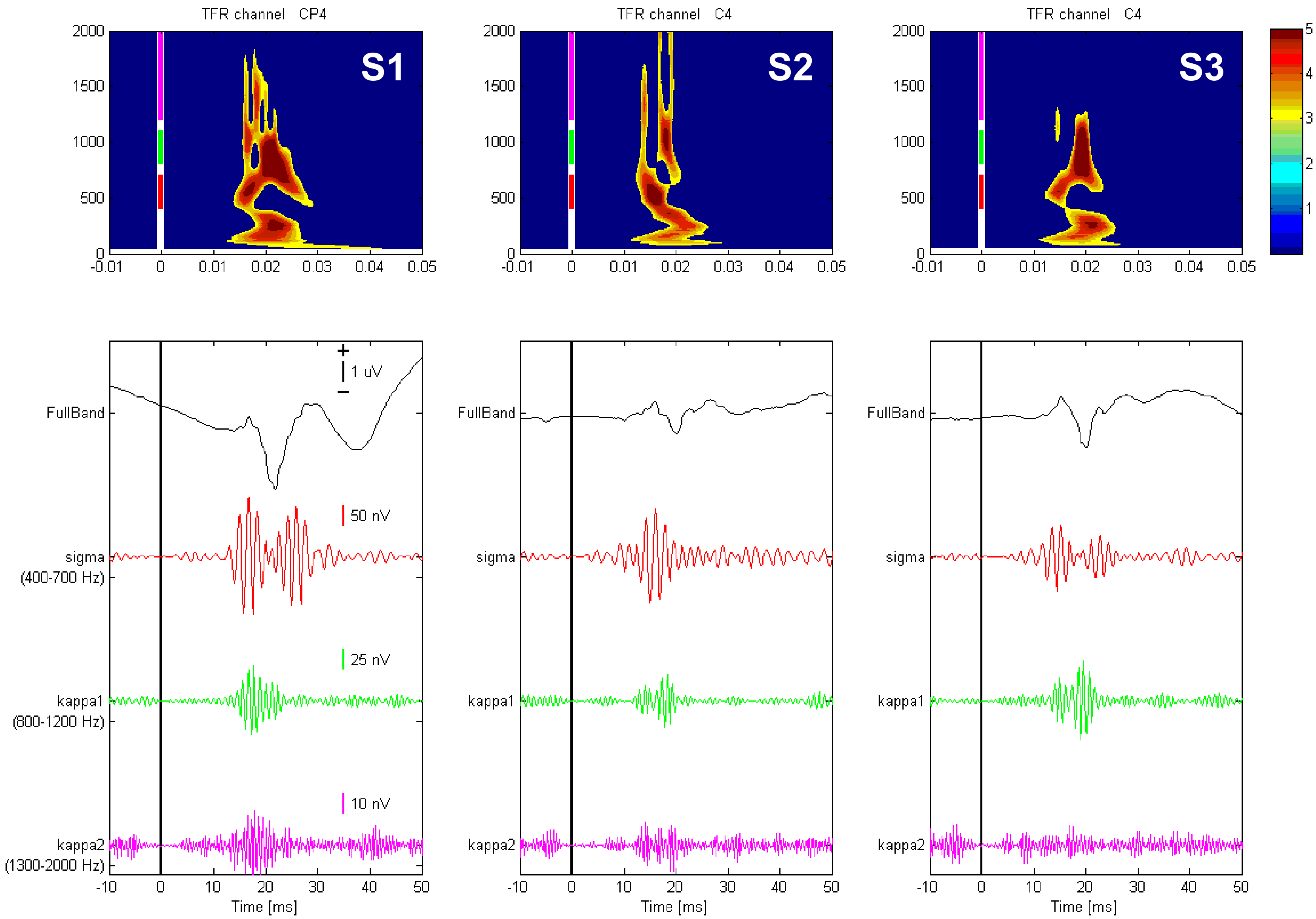
Averaged SEP: Stockwell transform (time-freq.)



(Fedele et al., 2012)

Yesterday’s noise may be tomorrow’s signal:
Where are today’s limits for
high-resolution high-frequency surface EEG?

RECIPE: a) dedicated low-noise amplifier (< 5 nV/ √Hz)
b) electrode-skin impedances a.l.a.p. (< 1 kOhm)

RESULT: a) non-invasive detection of SEP components > 1 kHz
b) multi-channel mappings delineate cortical/subcortical sources

PERSPECTIVE for „MUA“:
non-invasive monitoring of Multi-Unit spike Activity

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B. Telenczuk
L. Trahms
A. Villringer
G. Waterstraat
DIY: σ-burst recipe
- montage: CP3-F3
- impedance: ≤ 1 kΩ
- bandpass: 5-1500 Hz
- averages: 2000
- stim. freq.: 1.1/s + 8.1/s