CORSO DI:

ELABORAZIONE DI SEGNALI BIOMEDICI

(LUCIDI DELLE LEZIONI VI)

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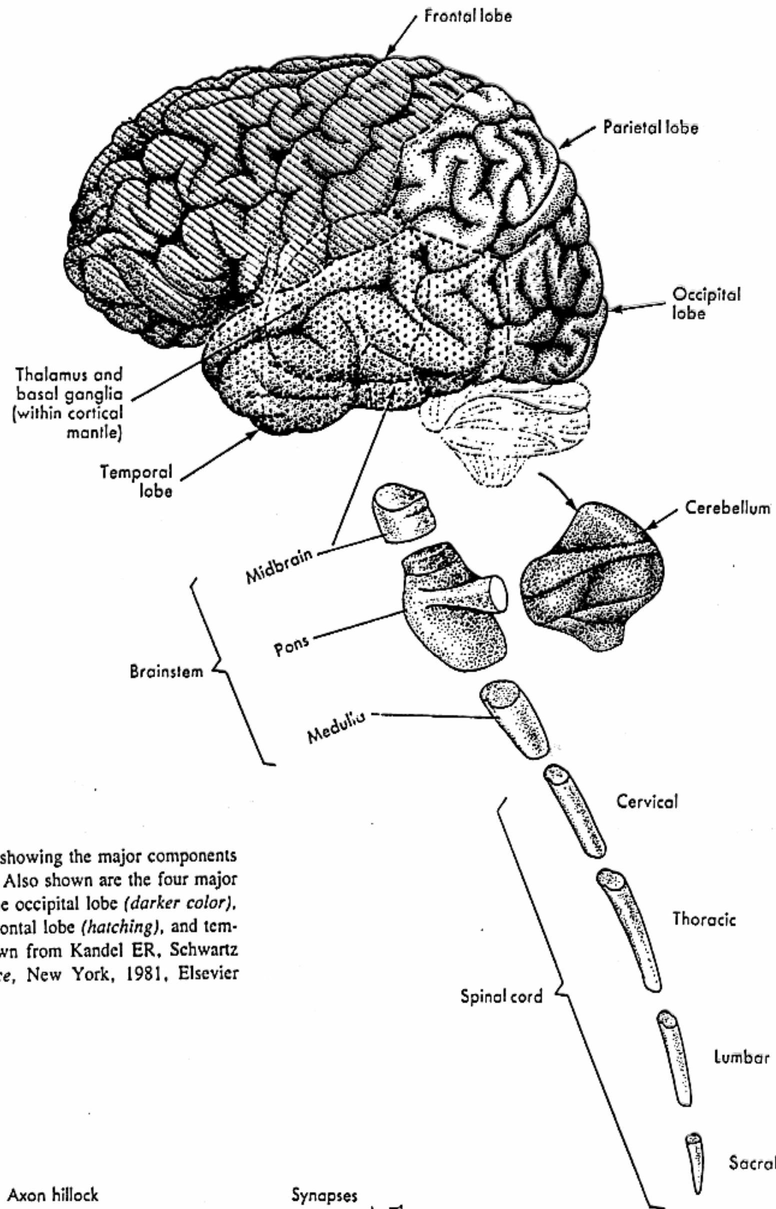
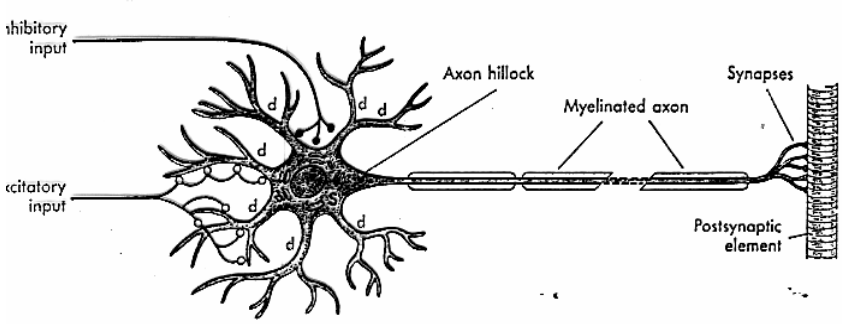
OTTOBRE 2004

SISTEMA NEUROSENSORIALE

E SENSORIMOTORIO



■ Fig. 6-2 Exploded view showing the major components of the central nervous system. Also shown are the four major divisions of cerebral cortex: the occipital lobe *(darker color)*, parietal lobe *(lighter color)*, frontal lobe *(hatching)*, and temporal lobe *(stippling)*. (Redrawn from Kandel ER, Schwartz JH: *Principles of neuroscience*, New York, 1981, Elsevier Science Publishing, Inc.)

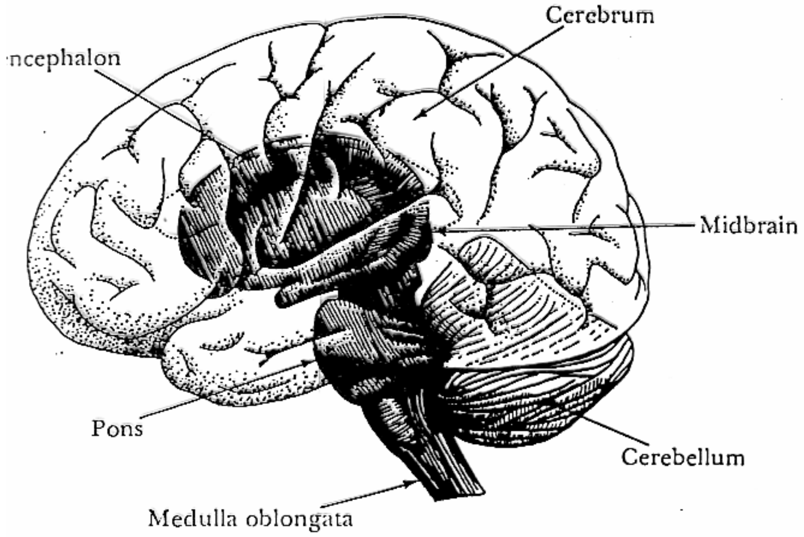


■ Fig. 6-6 Schematic diagram of an idealized neuron and its major components. Most afferent input from axons of other cells terminates in synapses on the dendrites *(d)*, although some may terminate on the soma *(S)*. Excitatory terminals tend to terminate more distally on dendrites than do inhibitory ones, which often terminate on the soma. (Redrawn from Williams PL, Warwick R: *Functional neuroanatomy of man*, Edinburgh, 1975, Churchill Livingstone.)

Sistema nervoso centrale
- tratto ascendente (sensoriale)
- tratto discendente (motorio)

Formato da

- Tronco encefalico
- Cervelletto (coordinazione movimenti)
- Cervello (funzioni superiori, ad es. coscienza)



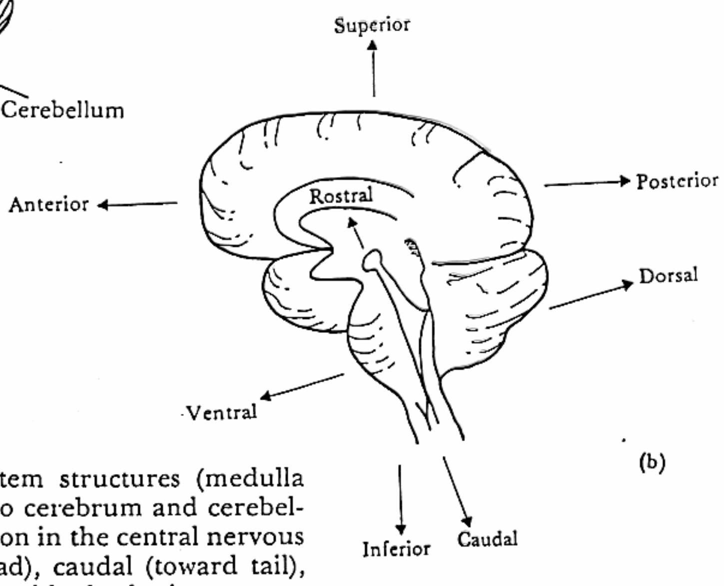


Figure 4.26 (a) Anatomical relation of brainstem structures (medulla oblongata, pons, midbrain, and diencephalon) to cerebrum and cerebellum. (b) General anatomic directions of orientation in the central nervous system. Here the directions rostral (toward head), caudal (toward tail), dorsal (back) and ventral (front) are associated with the brainstem; remaining terms are associated with the cerebrum. The terms medial and lateral imply nearness and remoteness, respectively, to central midline axis of brain. [Part (a) from Harry E. Thomas, *Handbook of Biomedical Instrumentation and Measurement,* 1974, p. 254. Reprinted with permission of Reston Publishing Company, Inc., a Prentice-Hall company, 11480 Sunset Hills Road, Reston, VA 22090.]

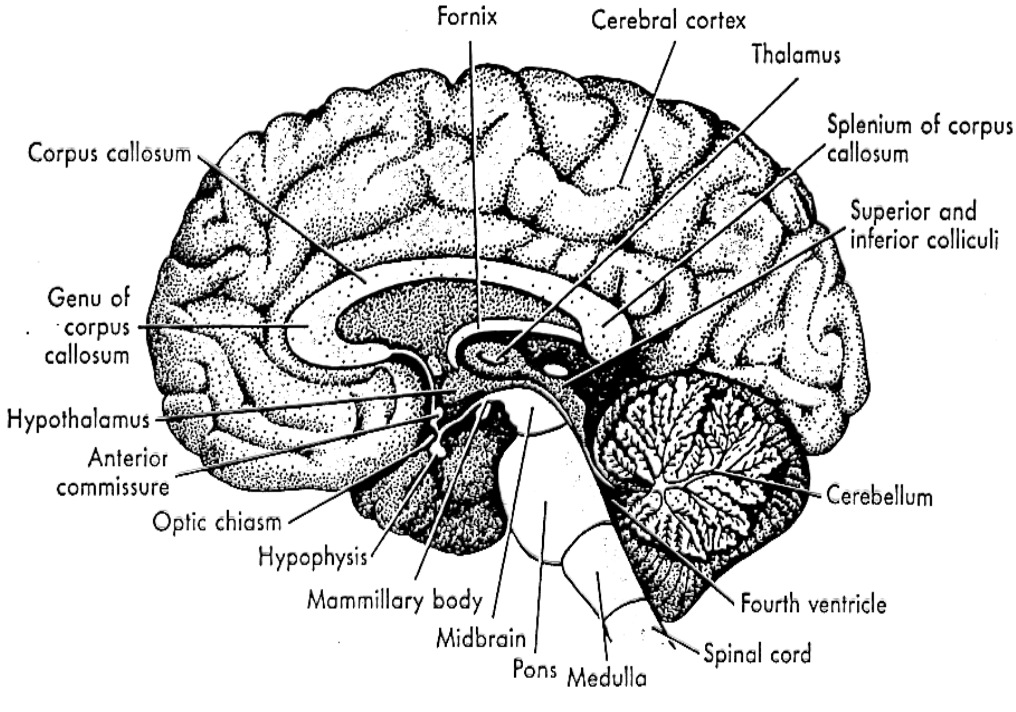
Il tronco encefalico è la parte del SNC filogeneticamente più antica.

Le sue funzioni sono:

1) Collega la spina dorsale con cervello e cervelletto

2) Integrazione di funzioni viscerali

3) Centro di integrazione riflessi motori



■ Fig. 6-3 Midsagittal section of the brain. Note the relationships among the cerebral cortex, cerebellum, thalamus, and brainstem plus the location of various commissures. (Redrawn from Kandel ER, Schwartz JH: *Principles of neuroscience*, New York, 1981, Elsevier North-Holland.)

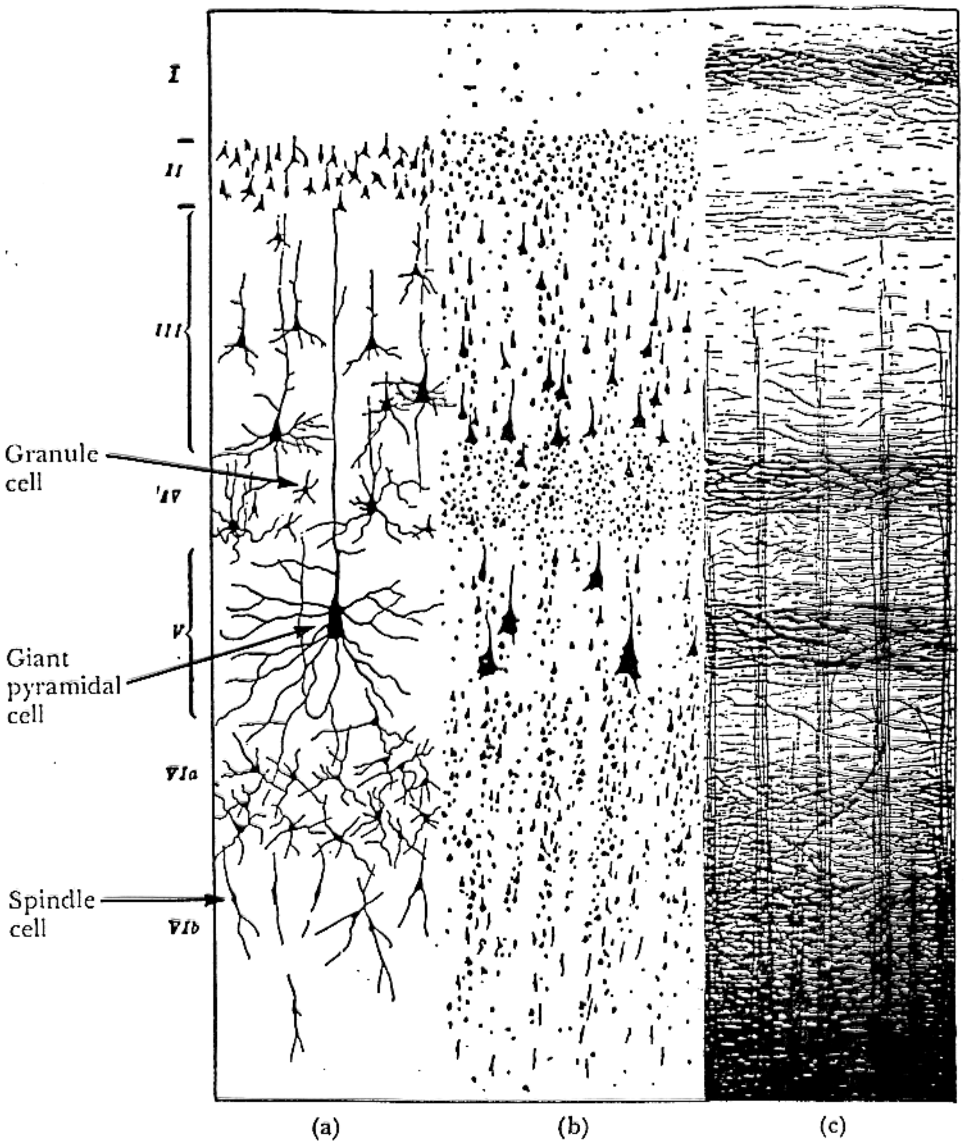


Figure 4.28 Structure of the cerebral cortex. Results obtained using different specific histological stains specific for cell bodies, dendritic and axonal processes, and myelin sheath are shown in (a) Golgi stain, (b) Nissl cellular stain, and (c) myelin sheath stain. The six layers of the cortex are also demonstrated: I = molecular layer, II = external granular layer, III = external pyramidal layer, IV = internal granular layer, V = large or giant pyramidal layer (ganglionic layer), VI = fusiform layer. (From

EEG

- Formazione Reticolare (RAS o Reticular Activating System):

→dipolo elettrico orientato radialmente

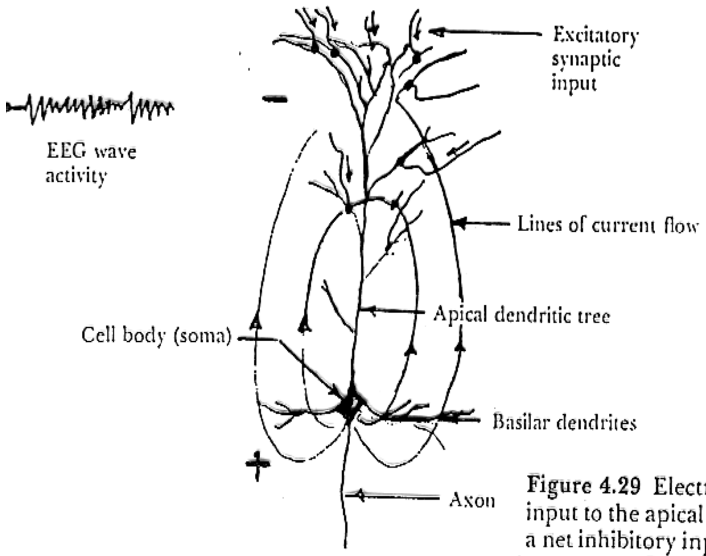


Figure 4.29 Electrogenesis of cortical field potentials for a net excitatory input to the apical dendritic tree of a typical pyramidal cell. For the case of a net inhibitory input, polarity is reversed and the apical region becomes a source (+). Current flow to and from active fluctuating synaptic knobs on the dendrites produces wave activity.

- E' il risultato di un'attività sincronizzata e/o desincronizzata delle cellule corticali e subcorticali della RAS in corrispondenza dell'elettrodo; è in sostanza un insieme di <u>potenziali post-sinaptici</u> eccitatori o inibitori

- EEG → Berger (1929)

  Elettrodi esterni (≅ 50 μV)

  Elettrodi corticali (≅ 1 mV max.)

  Elettrodi interni (≅ 1 mV →)

RILEVAZIONE SEGNALE EEG

Sistema 10-20

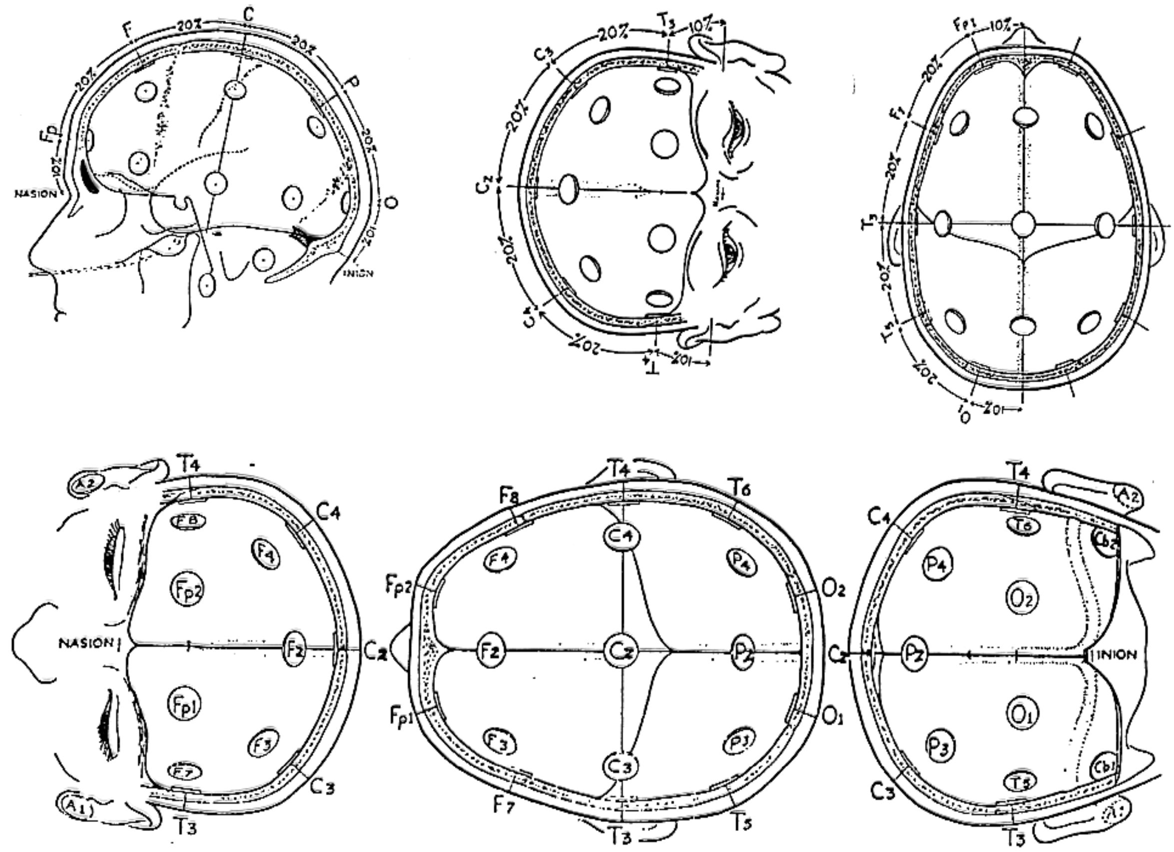


Figure 4.31 The 10-20 electrode system recommended by the International Federation of EEG Societies. (From H.H. Jasper, "The Ten-Twenty Electrode System of the International Federation in Electroencephalography and Clinical Neurophysiology," *EEG Journal*, 1958, **10** (Appendix), 371–375.)

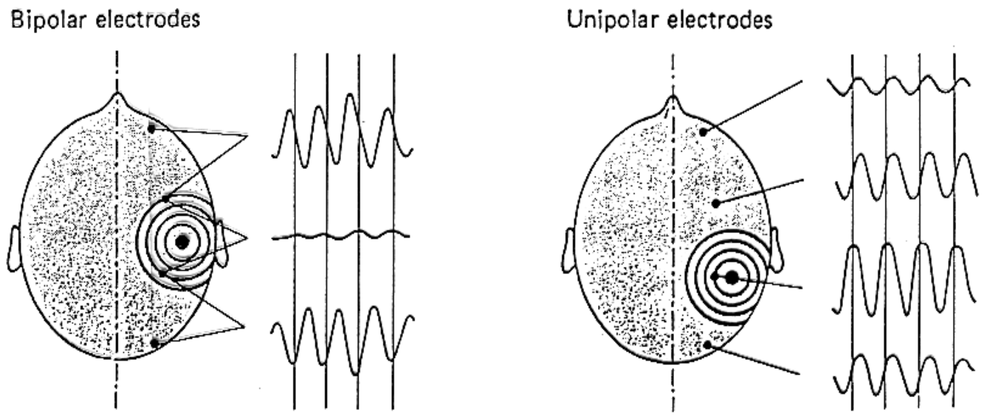
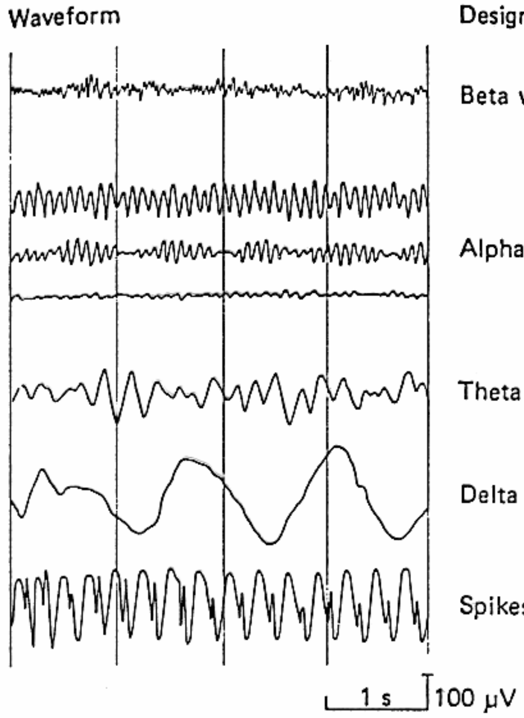


Figure 4.3 Both bipolar and unipolar electrode systems are used to facilitate the location of foci, that is, cortical areas from which abnormal waves spread. The phase relationship of the waves indicates the position of the focus and in some cases, enables the velocity at which the waves spread to be calculated.

BANDE EEG-GRAFICHE



Designation	Frequency, Hz	Occurrence
Beta waves (β)	13–30	Normally parietally and frontally
Alpha waves (α)	8–13	Normally occipitally
Theta waves (ϑ)	4–8	Children, sleeping adults
Delta waves (δ)	0,5–4	Premature babies, infants, sleeping adults
Spikes and waves	~ 3	Epilepsy – petit mal

Figure 4.4 Some examples of EEG waves.

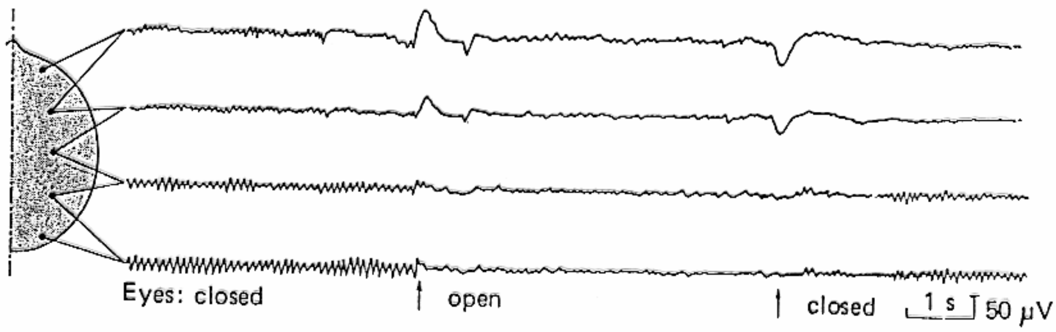


Figure 4.5 Normal EEG illustrating the extinction of alpha rhythm that occurs when the eyes are opened.

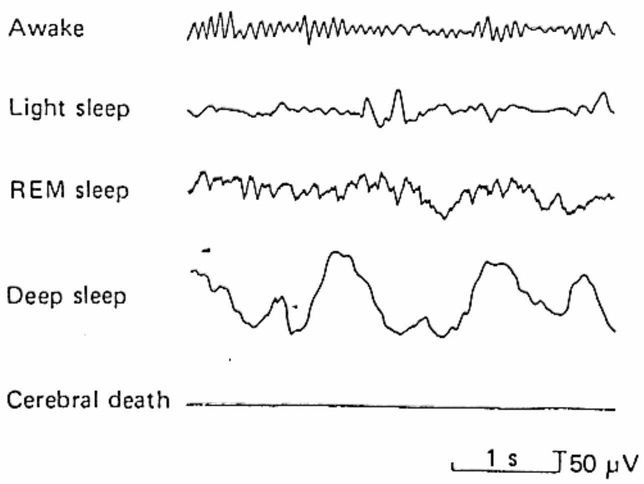
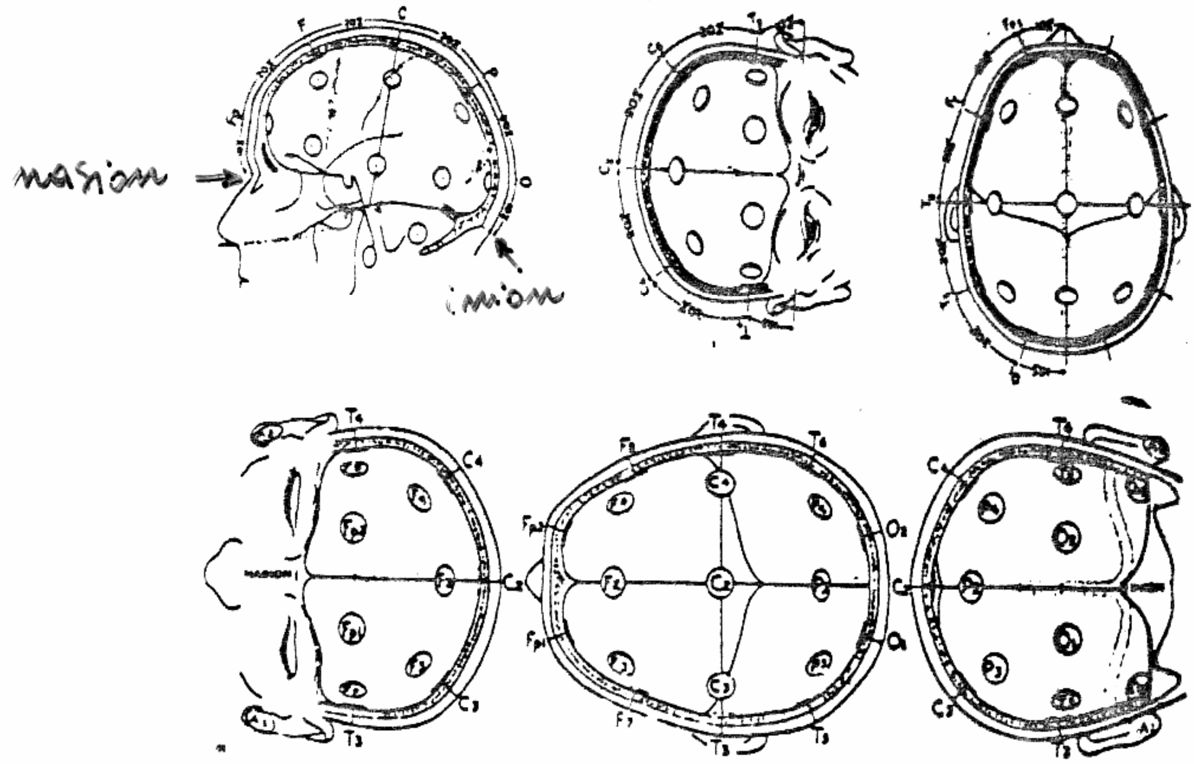


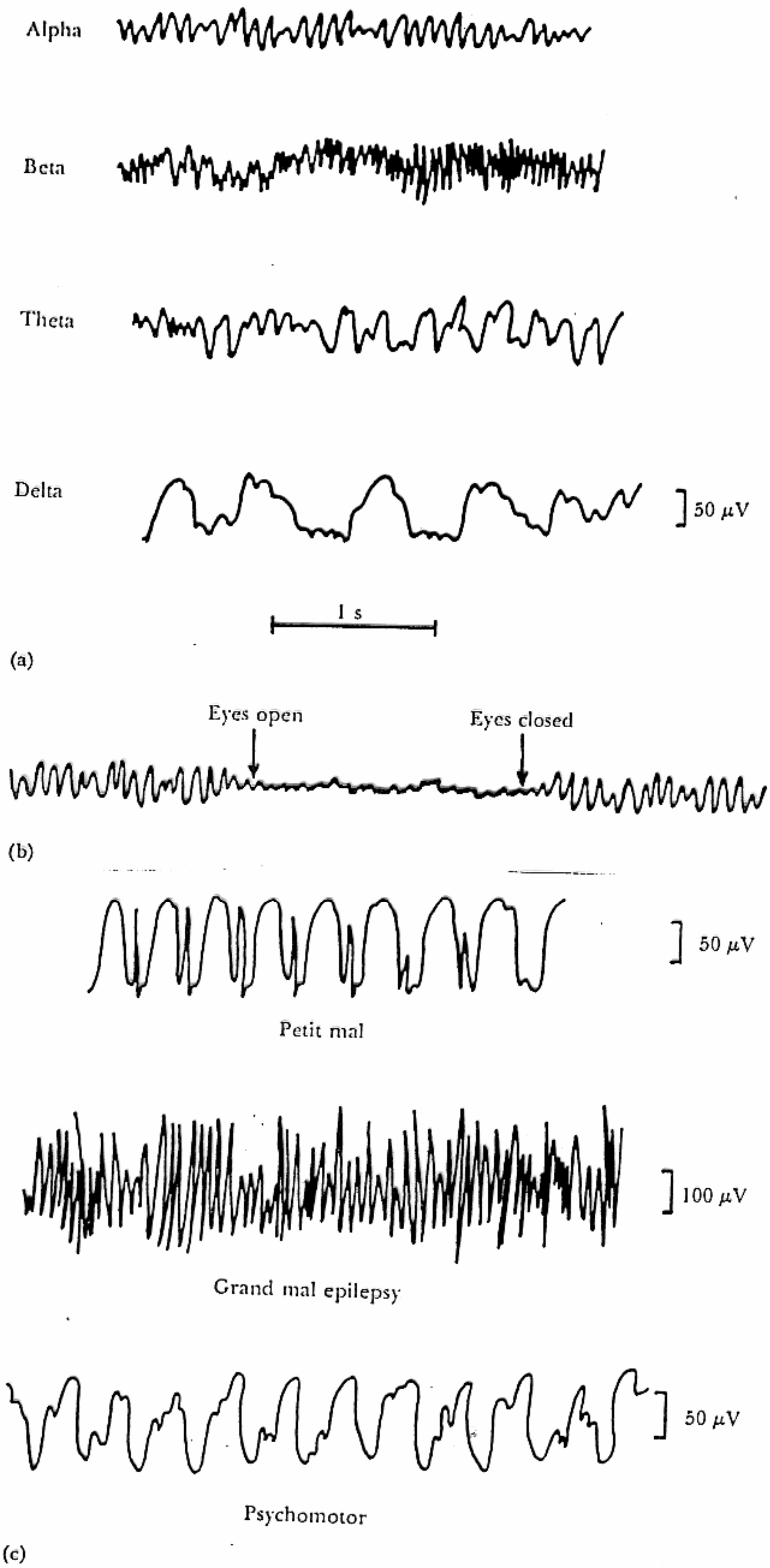
Figure 4.6 EEG activity is dependent on the level of consciousness.

➤ Le misure antero-posteriori sono basate sulla distanza <u>nasion-inion</u> lungo la linea mediana passante per il vertice.

➤ Misure sul piano coronale sono basate sulla distanza tra i punti pre-auricolari destro e sinistro lungo la linea passante per il vertice.



* Le rilevazioni possono essere bipolari o unipolari: le prime rilevano la d.d.p. tra due elettrodi, le seconde quella tra un elettrodo ed uno di riferimento (in genere o quello centrale o quello della fossetta occipitale).



(From A.C. Guyton, *Structure and Function of the Nervous System*, 2nd ed., Philadelphia: W.B. Saunders, 1972; used with permission.)

Figure 4.30 (a) Different types of normal EEG waves. (b) Replacement of alpha rhythm by an asynchronous discharge when patient opens eyes. (c) Representative abnormal EEG waveforms in different types of epilepsy.

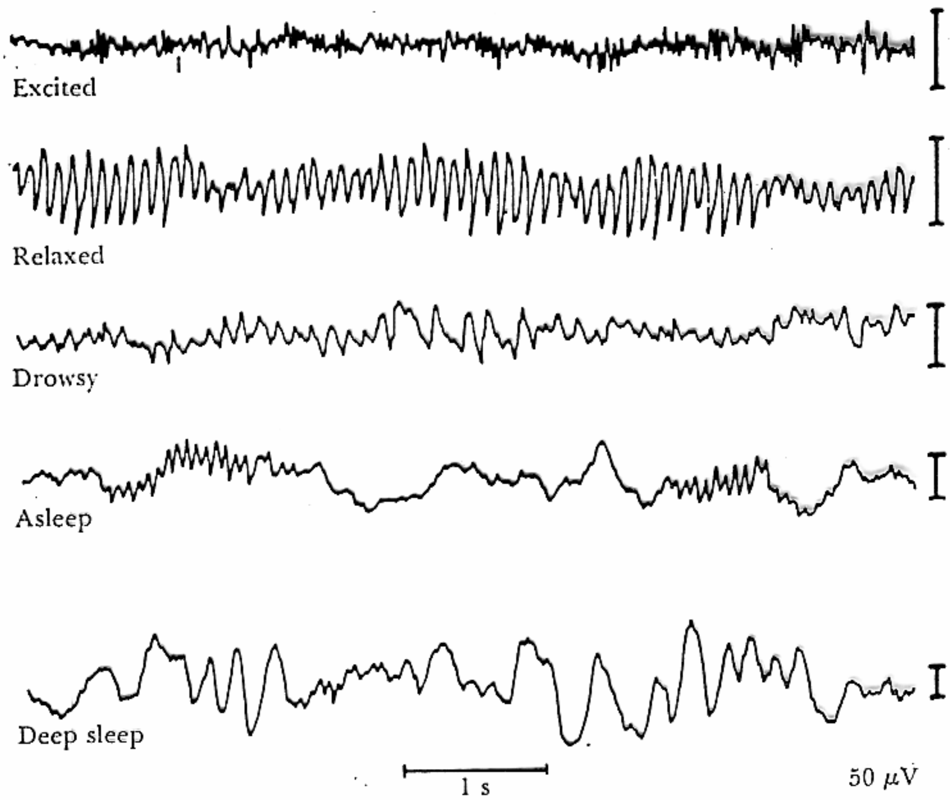


Figure 4.32 The electroencephalographic changes that occur as a human subject goes to sleep. The calibration marks on the right represent 50 μV. (From H.H. Jasper, "Electroencephalography," in *Epilepsy and Cerebral Localization,* edited by W.G. Penfield and T.C. Erickson. Springfield, Ill.: Charles C. Thomas, 1941.)

EEG IN ANESTESIA

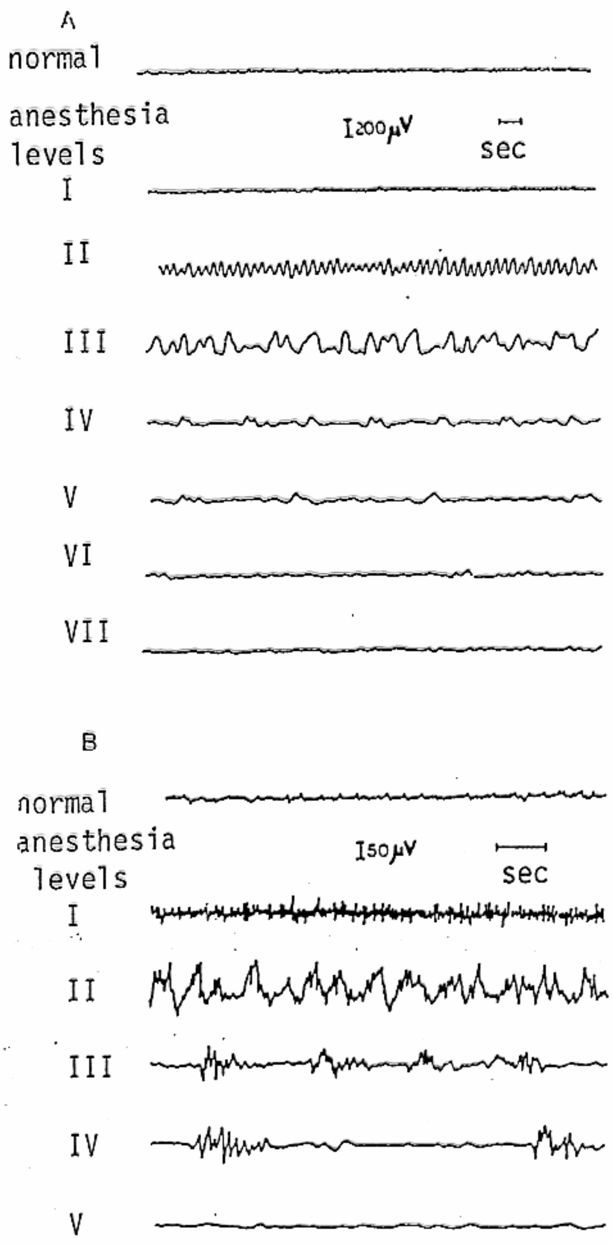


Figure 1 : Guedel classification of EEG patterns in anesthesia From (14) - A) Ethilic ether as anesthetic agent : seven levels have been distinguished - B) Pentothal as anesthetic agent : it is possible to distinguish only five of the previously introduced states.

EEG: UTILITÀ DIAGNOSTICA

(Livello corticale e subcorticale)

- alterazione dei ritmi principali
- lateralizzazione dei ritmi (asimmetrie emisferi dx e sx)
- ritmi con focalizzazione

Applicazioni:

- tumori, ematomi
- deficienze di O_2 per emboli o emorragie
- livelli di coscienza (coma)
- ritmi parossistici
- studio fasi del sonno
- anestesia
- valutazione farmaci agenti sul SNC
- morte clinica

CATEGORIES OF EEG ACTIVITIES

Spontaneous non-paroxysmal activity

Activities without significant temporal changes
- Normal spontaneous waking activity
- Alpha variants
- Beta activity
- Continuous slow rhythm
- Polymorphous slow activity

Activities slowly changing with time
- Sleep activity
- Postictal background activity
- Fluctuating activity in coma
- Hyperventilation activity
- Seizure discharges

Activities of intermittent type
- Sigma activity in form of sleep spindles
- Mu-rhythm
- Intermittent slow rhythms
- Psychomotor variant pattern

Spontaneous paroxysmal activity

- Spikes, Sharp Waves
- Spike/wave-complexes
- Rhythmic 3/sec Spike and Wave formations
- Paroxysmal slow waves
- 14+6/sec positive spikes
- SSLE complexes
- K-complexes and Vertex potentials in sleep

Evoked activity

- Evoked transient potentials
- Photic driving (well suited for spectral analysis)
- Arousal activity
- Eye-closing effects
- Lambda waves

Segnale EEG → fondamentale per il monitoraggio del paziente durante interventi chirurgici (in particolare in neurochirurgia): quantificazione del livello di anestesia, effetto di farmaci, etc.

Segnale EEG → problema della post-elaborazione

ANALISI DEL SEGNALE EEG DI TIPO TRADIZIONALE

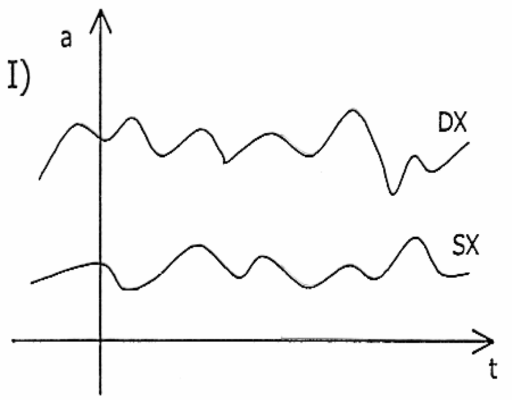
I) dominio del tempo : auto e cross-correlazione

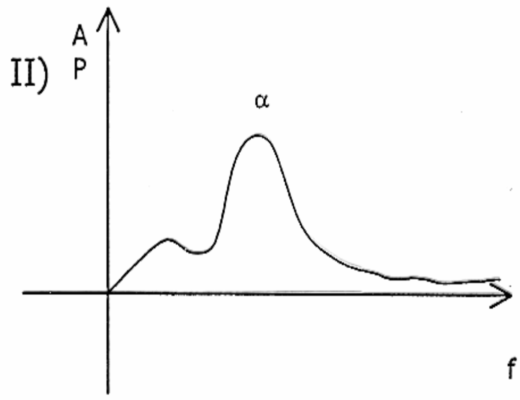
zero-crossing

descrittori di pendenza

riconoscimento di configurazioni

II) dominio della frequenza: analisi spettrale (Fourier, Walsh, Hilbert,etc.)





- 4 derivazioni
- 8 derivazioni
- 16 derivazioni
- tutte e 21 (10-20)

$f_c \rightarrow 100 - 200$ Hz

precisione $\rightarrow 8 - 12$ bit

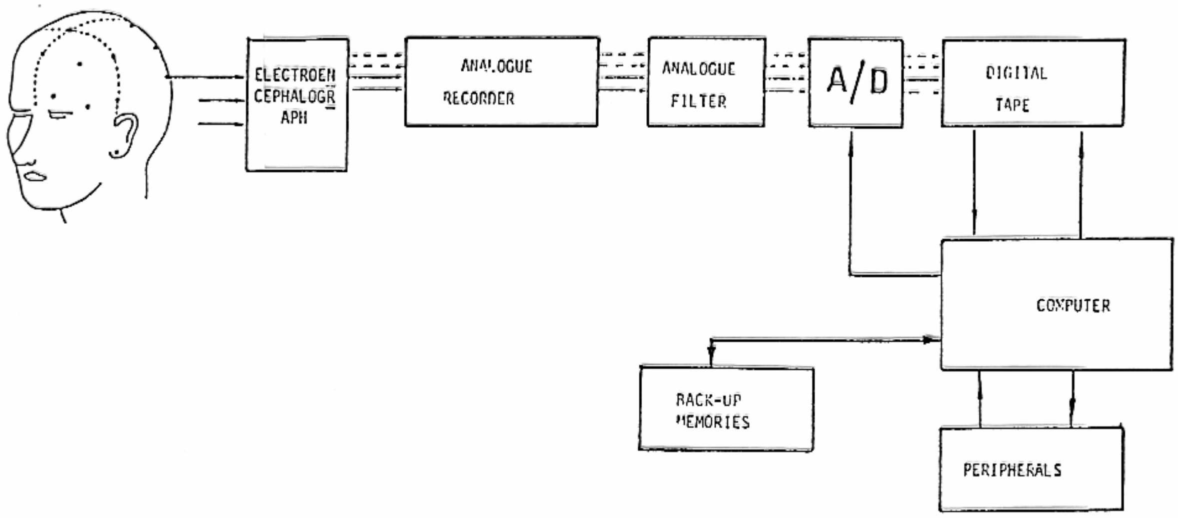


Fig. 2 Block-diagram of acquisition and pre-processing procedures.

EEG $\rightarrow$ segnale pseudocasuale

$\Rightarrow$ si elabora con metodi statistici e non deterministici

$\Rightarrow$ EEG generato da un processo stocastico STAZIONARIO e GAUSSIANO

Ruolo del teorema del limite centrale

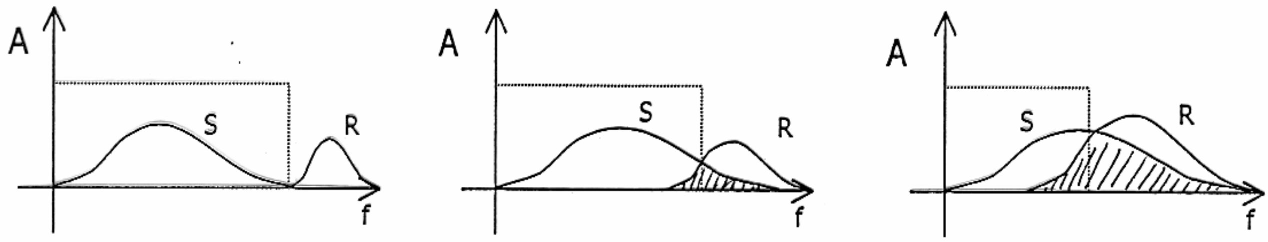
- Deviazione dall'ipotesi di Gaussianità

- Test per Gaussianità (χ^2 o Kolmogoroff-Smirnov)

- Stazionarietà ed ergodicità

Filtraggio numerico

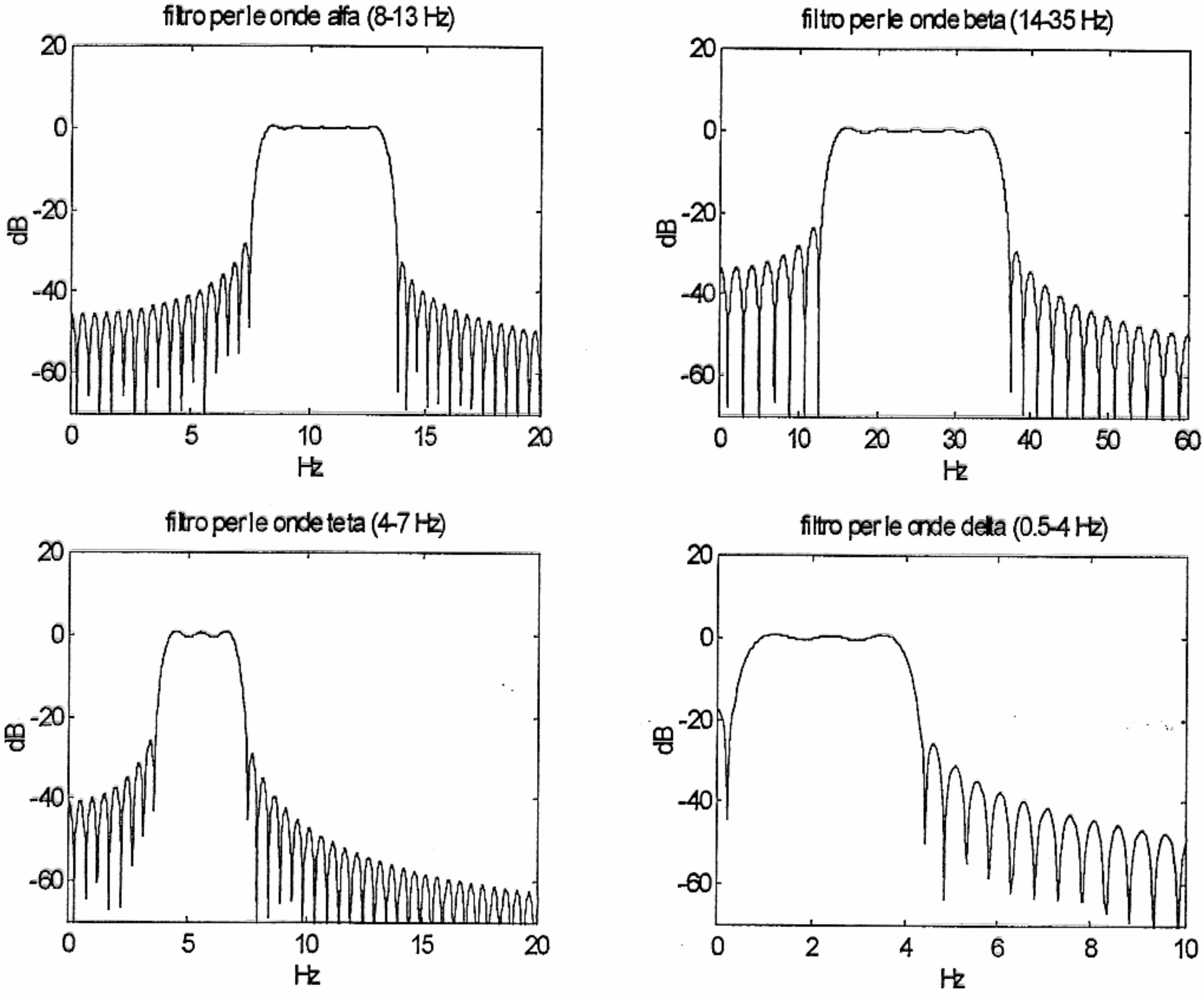
I) Riduzione del rumore (R) sovrapposto al segnale (S) $\Rightarrow$ miglioramento rapporto S/R (segnale/rumore)

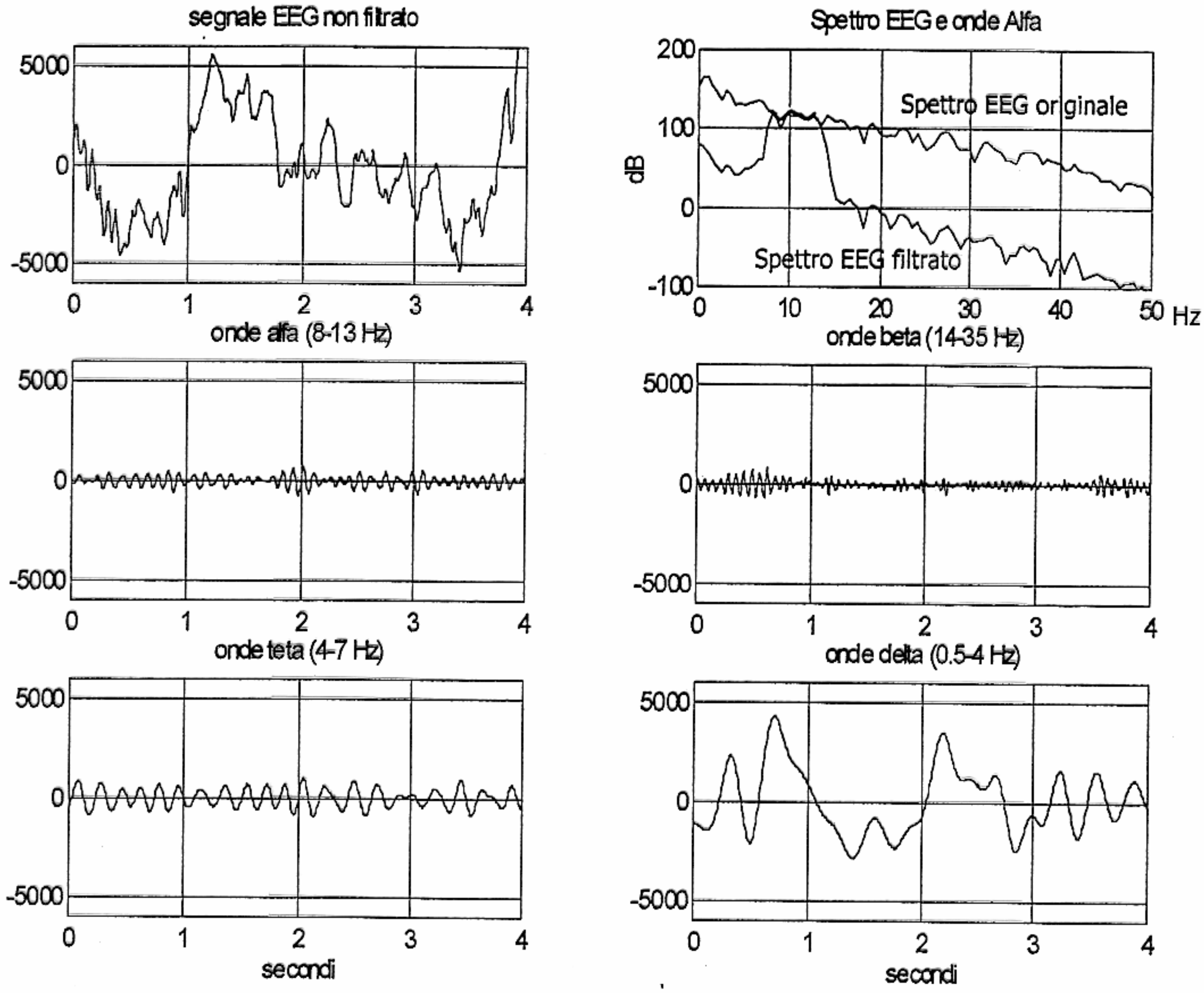


Filtro numerico

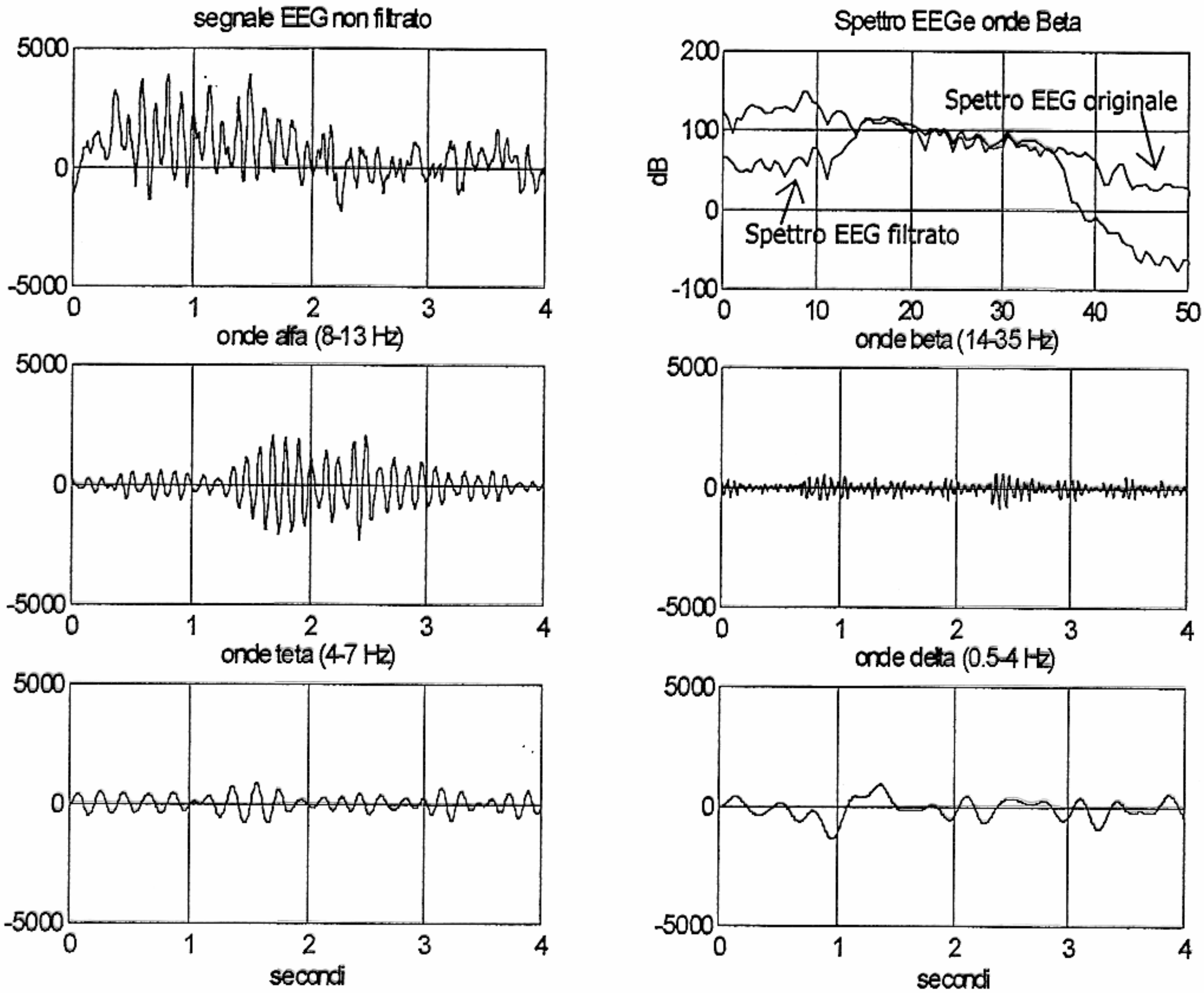
II) Risalto dell'informazione a scopo clinico

- Filtraggio nelle bande classiche dell'EEG ($\delta,\theta,\alpha,\beta$) o in altre bande da definire a seconda delle applicazioni
- Accezione più ampia del concetto di filtraggio per la fase di estrazione dei parametri e di classificazione


filtro per le onde alfa (8-13 Hz)
dB
Hz
filtro per le onde beta (14-35 Hz)
dB
Hz
filtro per le onde teta (4-7 Hz)
dB
Hz
filtro per le onde delta (0.5-4 Hz)
dB
Hz



sonno fase 3-4


segnale EEG non filtrato
Spettro EEGe onde Beta
Spettro EEG originale
Spettro EEG filtrato
dB
onde alfa (8-13 Hz)
onde beta (14-35 Hz)
onde teta (4-7 Hz)
onde delta (0.5-4 Hz)
secondi
secondi

sonno fase 2

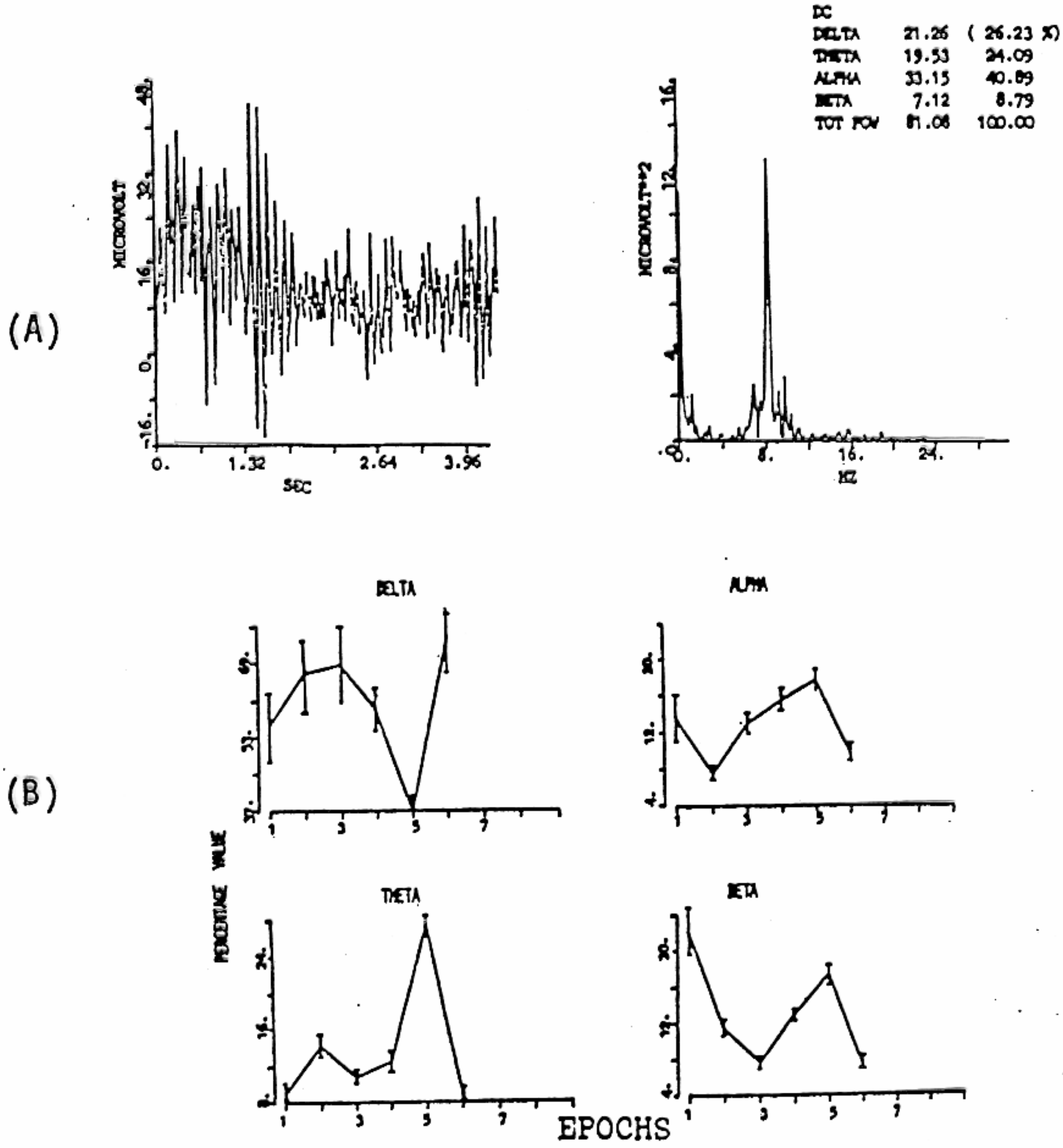


Figure 4 : A : EEG basal and its associated power spectrum (1024 points via FFT algorithm). B : trends of the values of averaged power spectra bands in percentage values in respect to the total power. Standard error is superimposed. From (38).

METHODS OF EEG ANALYSIS, IN ROUGH CHRONOLOGICAL ORDER WITHIN CATEGORY

[Infrequently used methods bracketed]

METHODS MAINLY IN THE TIME DOMAIN

Amplitude Analysis (Drohocki)

Period Analysis (Burch &A)

Autocorrelation, Cross-correlation (Brazier &A)

[Unstimulated Summation (Bernstein, Livanov)]

Normalized Slope Descriptors (Hjorth)

[Reverse Correlation (Kaiser, Petersen)]

[Iterative Interval Analysis (Schenk, Matejcek)]

[Mimetic Analysis (Rémond &A)]

METHODS MAINLY IN THE FREQUENCY DOMAIN

Frequency (later spectrum) Analysis (Grey Walter &A)

Cross-spectrum, coherence (D.O. Walter &A)

[Bispectrum, bicoherence (Johnson, Dumermuth)]

METHODS PRIMARILY IN TIME, BUT CLOSE TO FREQUENCY

[Phase Analysis (Darrow)]

[Toposcopy (Grey Walter)]

Autoregression (Fenwick &A)

[Autocorrelation of filtered records (Grindel')]

[Alpha Average (Remond)]

[Wiener Input-Output Kernels]

METHODS PRIMARILY IN FREQUENCY, BUT CLOSE TO TIME

Complex Demodulation

[Causality Analysis (Granger, Gersch)]

[Inverse Filtering (Lopes da Silva &A)]

[Cepstrum Analysis (Childers, Saltzberg)]

[Kalman Filtering (Isaksson)]

[Adaptive Segmentation (Creuzfeldt)]

Descrittori di pendenza normalizzati $\{D_n\}$

(Hijorth, 1970-1973)

$$D_n = \frac{1}{T}\int_t^{t+T} \frac{d^n}{dt^n} f^2(t)dt = \int_{-\infty}^{+\infty} \omega^{2n} S(\omega)d\omega$$

A = activity = $D_0 = \frac{1}{T}\int_t^{t+T} \frac{d^n}{dt^n} f^2(t)dt = \int_{-\infty}^{+\infty} S(\omega)d\omega \rightarrow$ potenza media

M = mobility = $\left[\frac{D_1}{D_0}\right]^{\frac{1}{2}} \rightarrow$ frequenza media

C = complexity = $\left[\frac{D_2}{D_1} - \frac{D_1}{D_0}\right]^{\frac{1}{2}} \rightarrow$ larghezza di banda

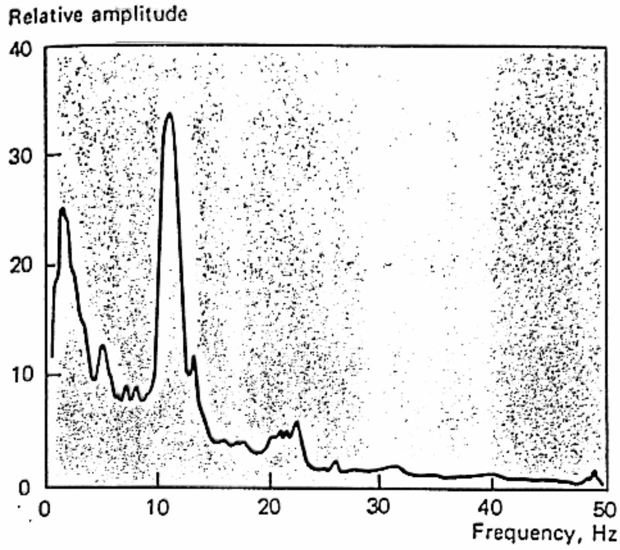


Figure 4.7 Frequency spectrum of a normal EEG with a maximum in the alpha region.

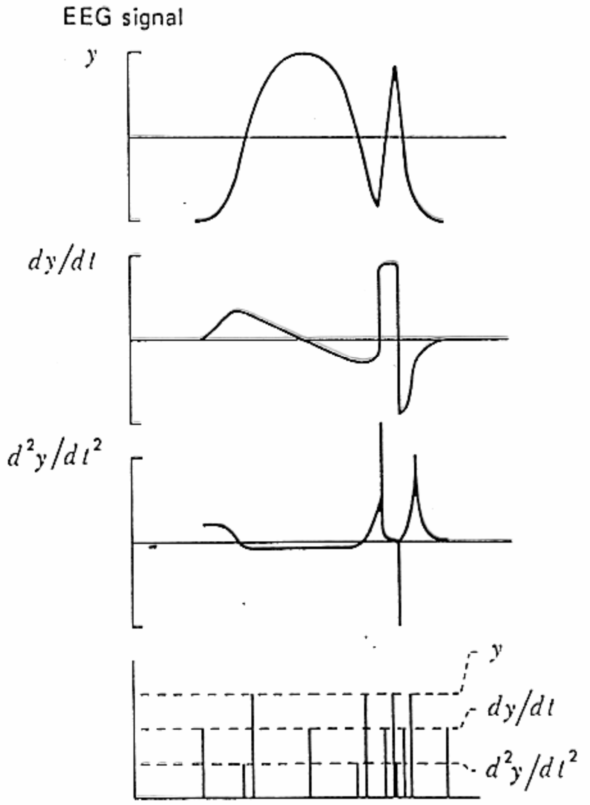


Figure 4.10 Pattern recognition of spike-and-wave complex by means of the time relations between zero-crossings for the signal and its first and second derivatives.

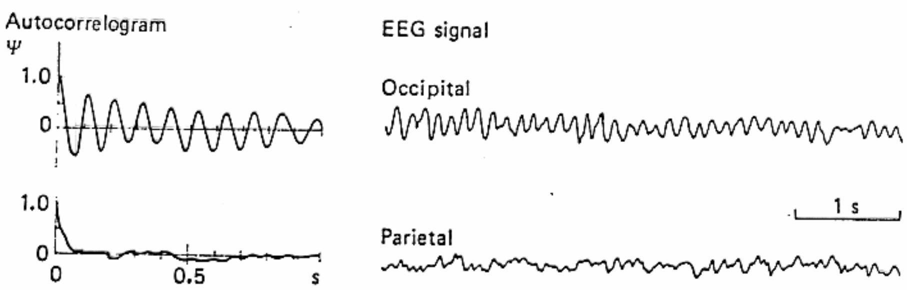


Figure 4.8 Normalized autocorrelogram for alpha activity recorded from the occipital and parietal leads for 1 minute.

Momenti statistici $\{X_i\}$

Momento di ordine r

$$\overline{X}^r = \frac{X_1^r + X_2^r + \ldots + X_N^r}{N} = \frac{\sum_{j=1}^{N} X_j^r}{N} = \frac{\sum X^r}{N}$$

Per r=1 → Media

$$m_r = \frac{\sum_{j=1}^{N}\left(X_j - \overline{X}\right)^r}{N} = \frac{\sum\left(X - \overline{X}\right)^r}{N} = \overline{\left(X - \overline{X}\right)^r}$$

Momento centrale di ordine r

Per $r = 1 \rightarrow m_1 = 0$

$r = 2 \rightarrow m_2 = \sigma^2$

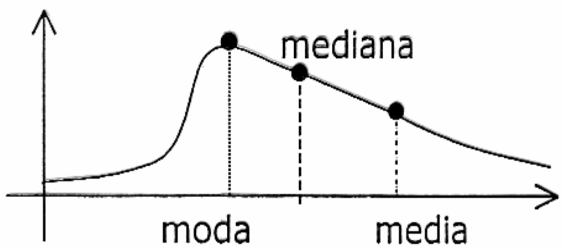
Asimmetria (Skewness)

oeff. di asimmetria

$$A = \frac{\overline{X} - \text{moda}}{s}$$

$s = \sqrt{m_2}$ = scarto quadratico medio

Es. {3, 4, 4, 5, 6, 8, 8, 8, 10} moda = 8



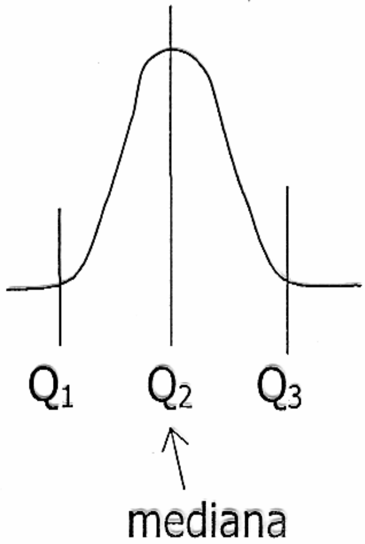
mediana = 6

media = 6.2

Asimmetria in termini di quantili e percentili

$$A = \frac{(Q_3 - Q_2) - (Q_2 - Q_1)}{Q_3 - Q_1}$$

$$A = \frac{(P_{90} - P_{50}) - (P_{50} - P_{10})}{P_{90} - P_{10}}$$



A = momento del III ordine

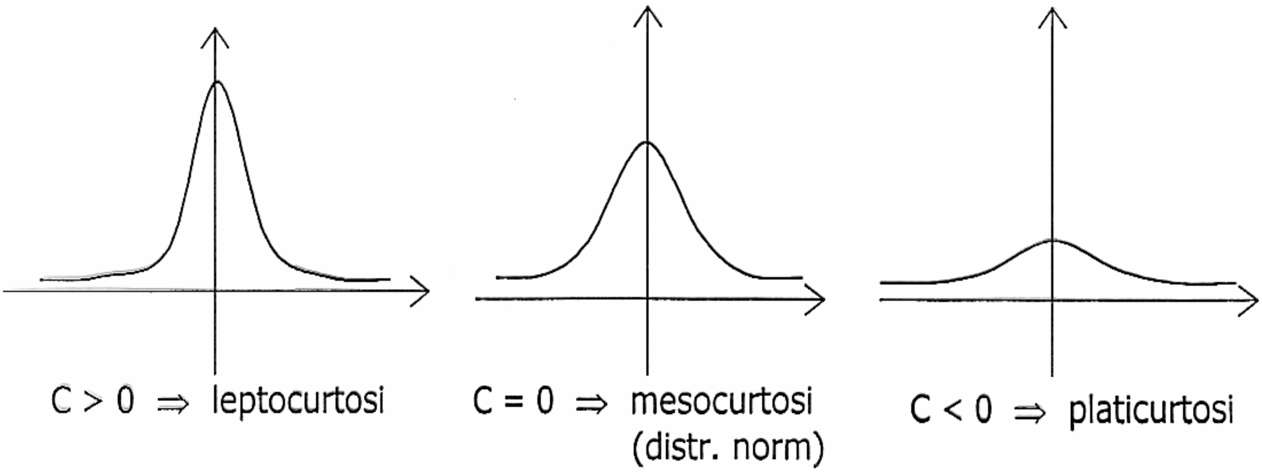
$$A = \frac{m_3}{s^3} = \frac{m_3}{\left(\sqrt{m_2}\right)^3} = \frac{m_3}{\sqrt{m_2^{\,3}}}$$

Curtosi (kurtosis)

$$C = \frac{m_4}{s^4} - 3 = \frac{m_4}{m_2^{\,2}} - 3$$

$$C = \frac{\frac{1}{2}(Q_3 - Q_1)}{P_{90} - P_{10}}$$

Per una distribuzione normale $\Rightarrow$ C = 0



ATTIVITÀ EEG EVOCATA

POTENZIALI EVOCATI
- visivi
- acustici
- somato-sensoriali (somestesici)

Metodo di elaborazione classica: Averaging o Media Sincronizzata

$$x_i(t) = s(t) + n_i(t)$$

Ipotesi:

1) <u>additività</u> segnale + rumore per produrre x_i (risposta evocata)

2) Il contributo del segnale ad ogni singola sweep è lo stesso, cioè s(t) non varia al variare dell' i-esima sweep $\Rightarrow$ stazionarietà del segnale al variare della sweep

3) Il rumore è un processo casuale <u>stazionario</u>, <u>scorrelato</u> , a <u>valore medio nullo e varianza σ^2</u>

AVERAGING (O MEDIA SINCRONIZZATA)

$$E[\hat{s}] = \overline{X}_i(t) = E\left[\frac{1}{N}\sum_{i=1}^{N} X_i(t)\right] = s(t) + \frac{1}{N}E\left[\sum_{i=1}^{N} n_i(t)\right]$$

Se N ↑↑ $\quad \overline{X}_i(t) \to s(t)$ (stima non polarizzata)

$$\hat{\sigma}^2 = E[\hat{s}(t) - s(t)]^2 = E\left[\frac{1}{N}\sum_{i=1}^{N} n_i(t)\right]^2 = \frac{1}{N^2}E\left[\sum_{i=1}^{N} n_i^{\,2}(t)\right] =$$

$$= \frac{1}{N^2} N \cdot \sigma^2 = \frac{\sigma^2}{N}$$

$\rightarrow \dfrac{1}{N}$ nella varianza $\Rightarrow \dfrac{1}{\sqrt{N}}$ nella deviazione standard

$$SNR_{x_i} = \frac{\overline{s^2(t)}}{\overline{n_i^{\,2}(t)}} = \sigma^2_{x_i}$$

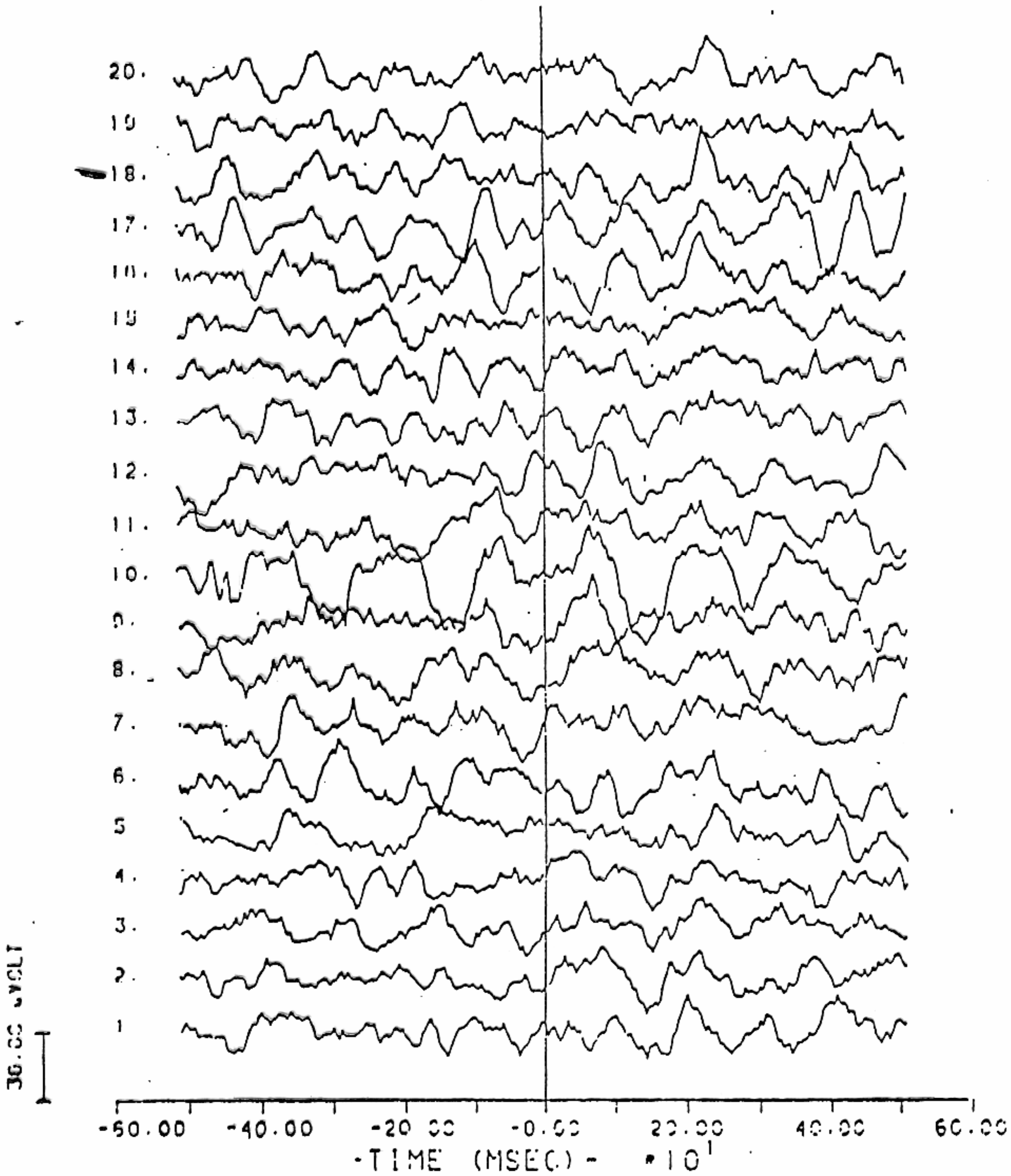
$$SNR_{Nx_i} = \frac{N^2\,\overline{s^2(t)}}{N\,\overline{n_i^{\,2}(t)}} = N \cdot \sigma^2_{x_i}$$

Ad esempio $\quad V_{pp}(EEG) \cong 50\ \mu V \quad V_{pp}(EP) \cong 5\ \mu V$

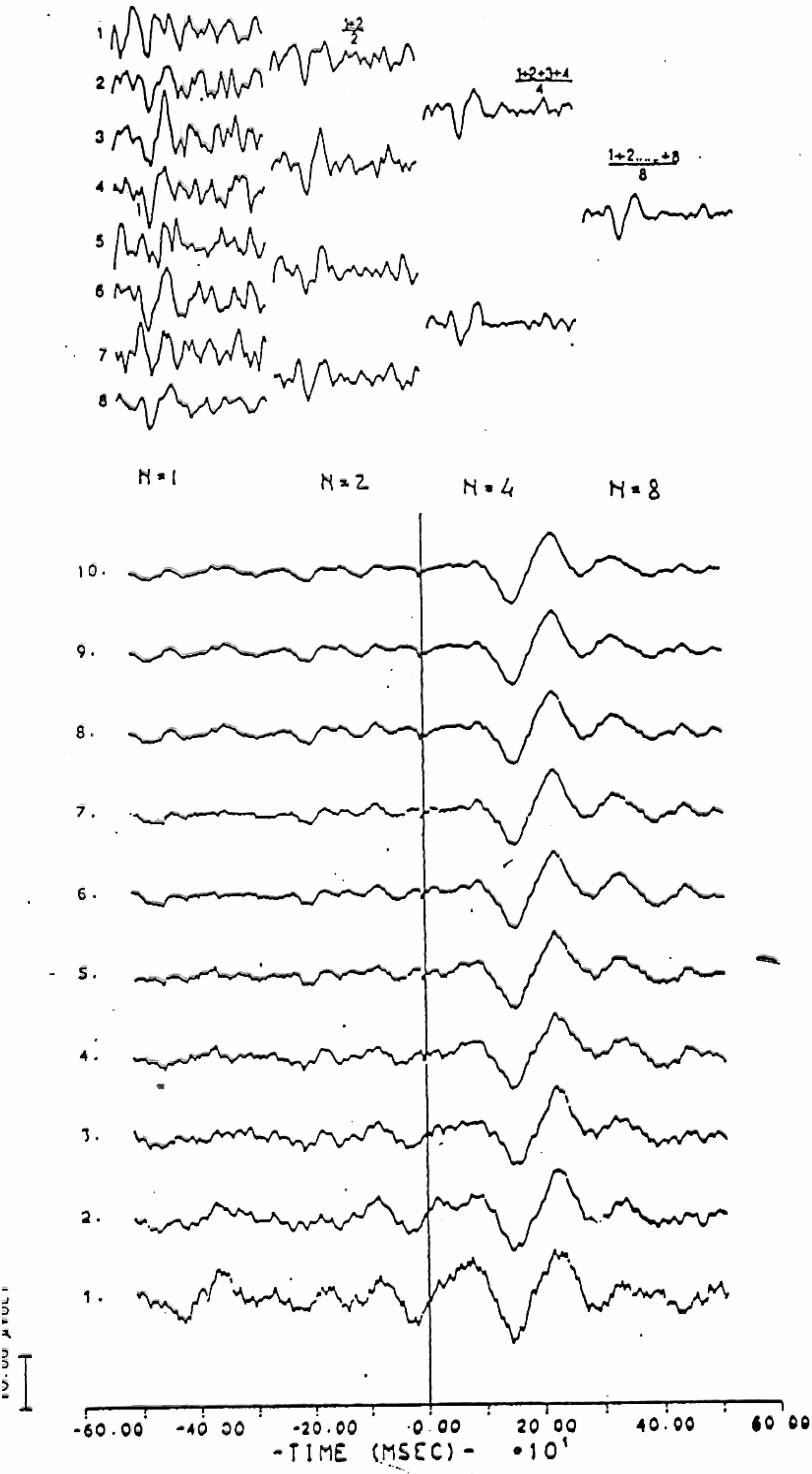
per avere $V_{pp}(EEG) \cong V_{pp}(EP)$ occorre N=100 $\Rightarrow \sqrt{N} = 10$

<u>Strumentazione molto semplice</u>

SINGLE UNFILTERED VEP'S



Axx.SGL



1
2
3
4
5
6
7
8
1+2 / 2
1+2+3+4 / 4
1+2....+8 / 8
N=1
N=2
N=4
N=8
10.
9.
8.
7.
6.
5.
4.
3.
2.
1.
-60.00
-40.00
-20.00
0.00
20.00
40.00
60.00
-TIME (MSEC)- *10¹

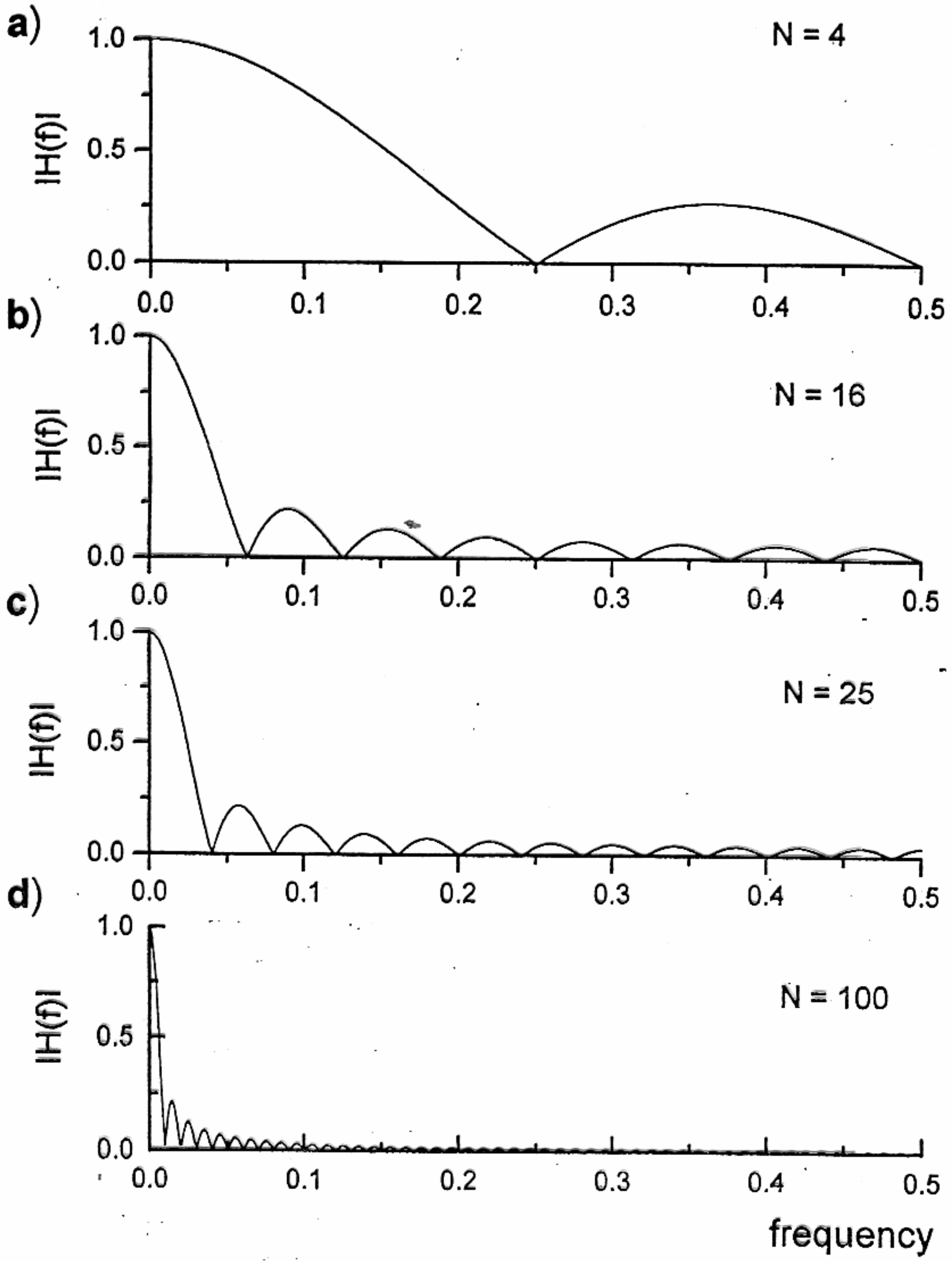
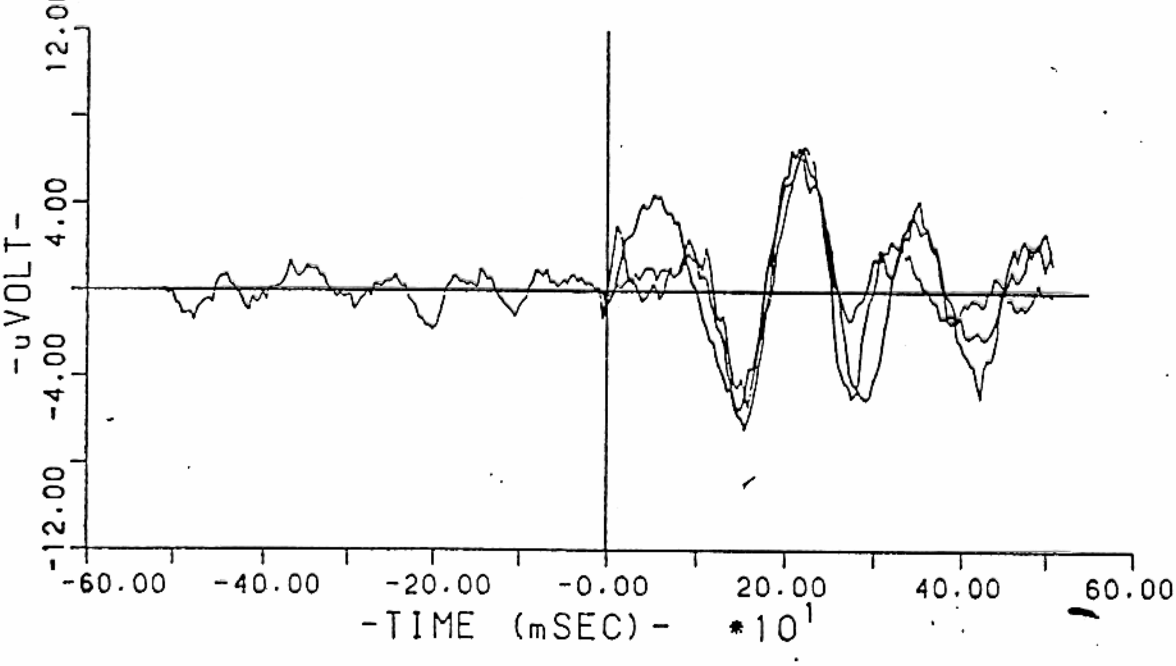
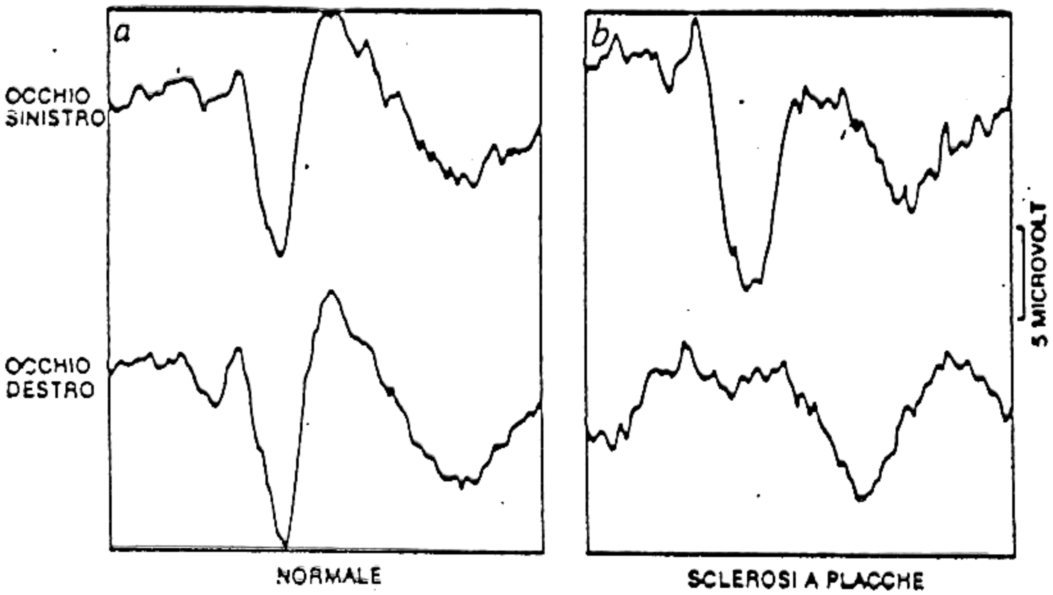


FIGURE 55.14 Equivalent frequency response for the signal-averaging procedure for different values of N

A10MED.FF8 VAR= 4.40 (F.Scala=7.50)
A90MED.FF8 VAR= 4.90 (F.Scala=12.71)
CHA.AVV VAR= 0.00





'ig. 1.5.2.2 Alterazione del potenziale evocato dovuta a sclerosi a placche (Regan, 1980)