A few questions on the content of the previous lecture

slido

If a patient following a stroke is significantly impaired on task A, but still performs within the expected range on task B, we call this...

ⓘ Start presenting to display the poll results on this slide.

slido

Following a stroke, patient CS is impaired on task A, but not on B, while another patient, MP, is impaired on task B, but not A, we call this...

ⓘ Start presenting to display the poll results on this slide.

TMS works by virtue of...

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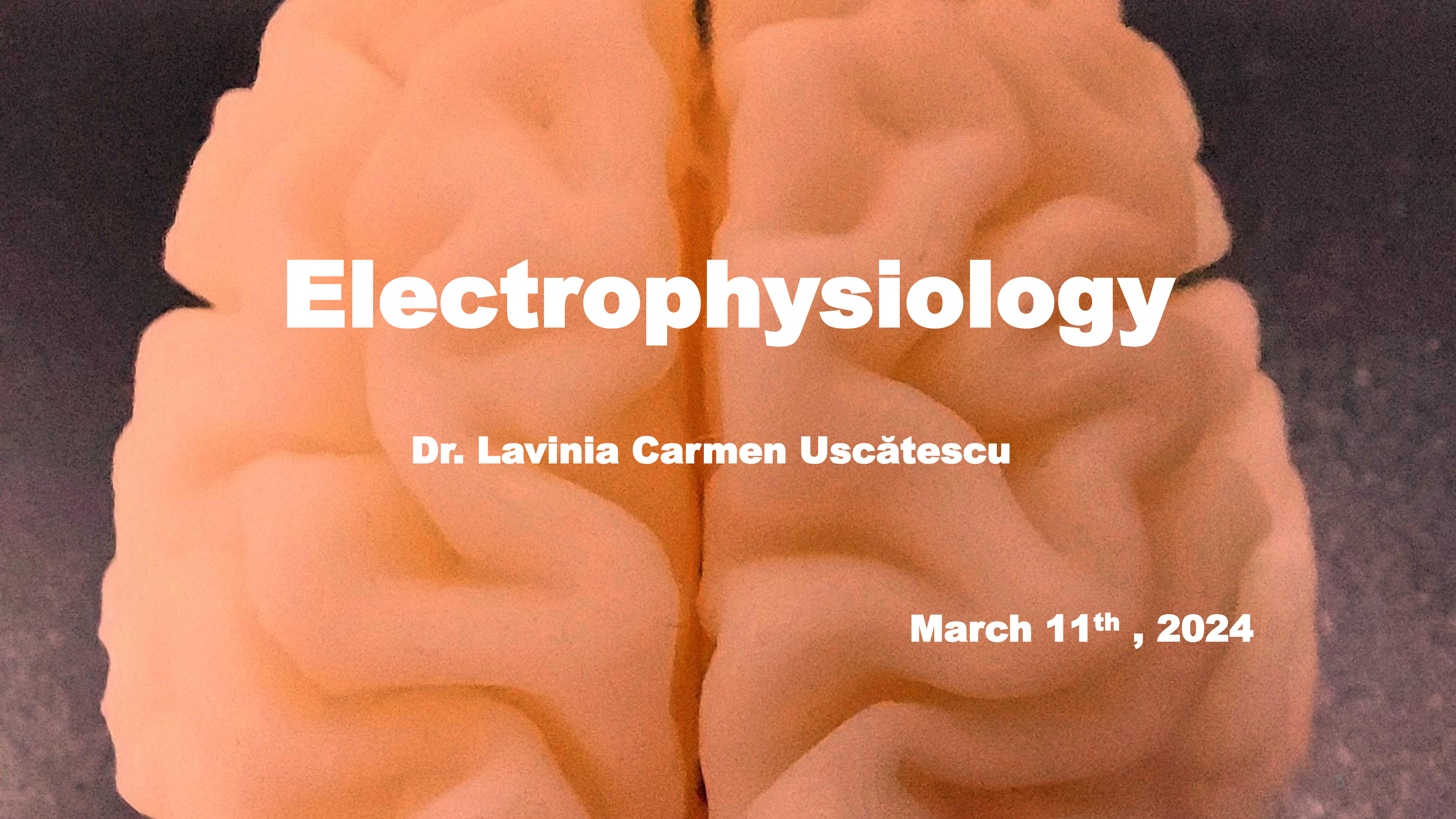


Electrophysiology

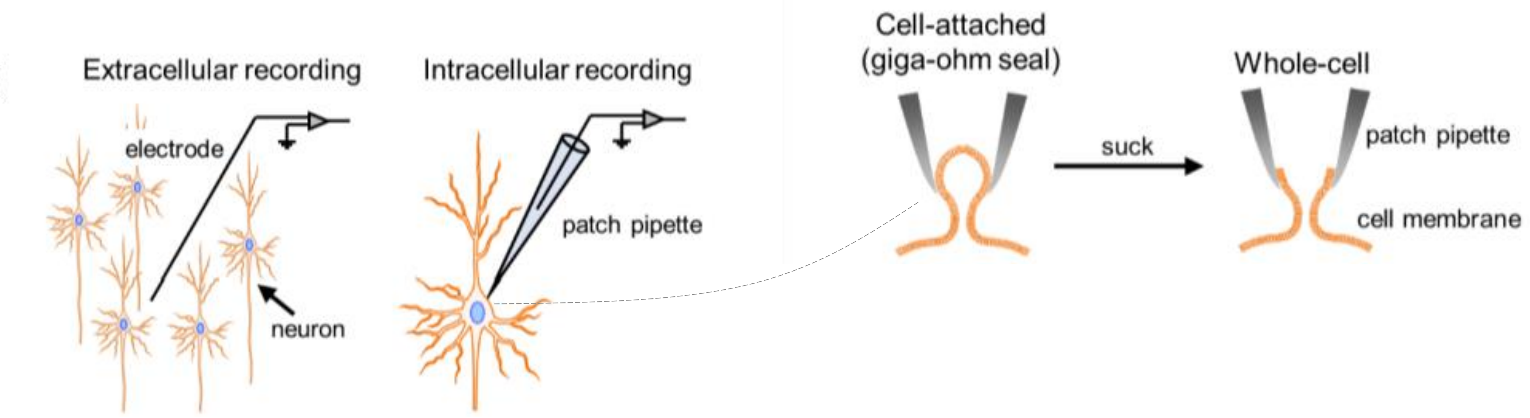
Dr. Lavinia Carmen Uscătescu

March 11th , 2024

Outline

1. From single cell recordings to electroencephalography (EEG)
2. Magnetoencephalography (MEG)
3. Mental chronometry
4. Prominent event-related potential (ERP) components

From single cell recordings to electroencephalography (EEG)



extracellular field potential

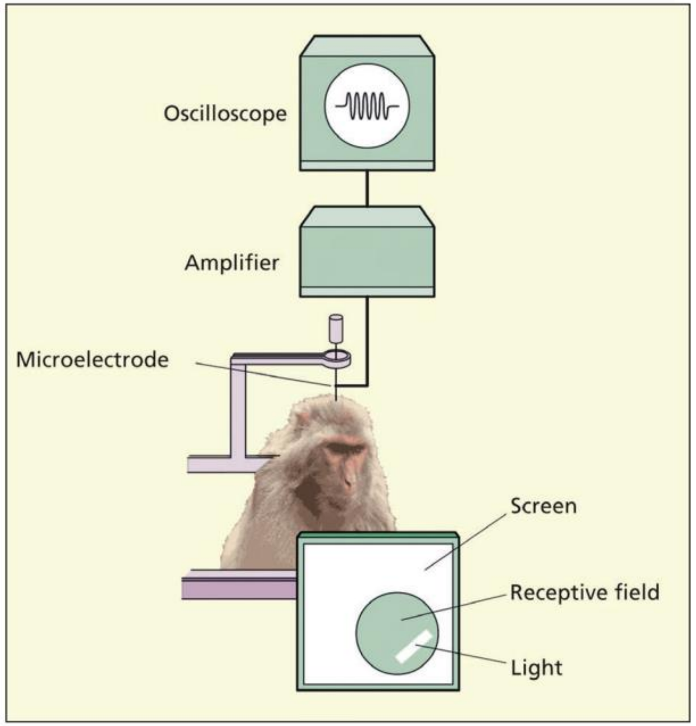
population spike + slower components

due to synaptic current flow

Andersen et al., (1971)

https://pubmed.ncbi.nlm.nih.gov/5123965/

Noguchi et al., (2021)
https://pubmed.ncbi.nlm.nih.gov/33669656/



Ward, (2020), p. 37

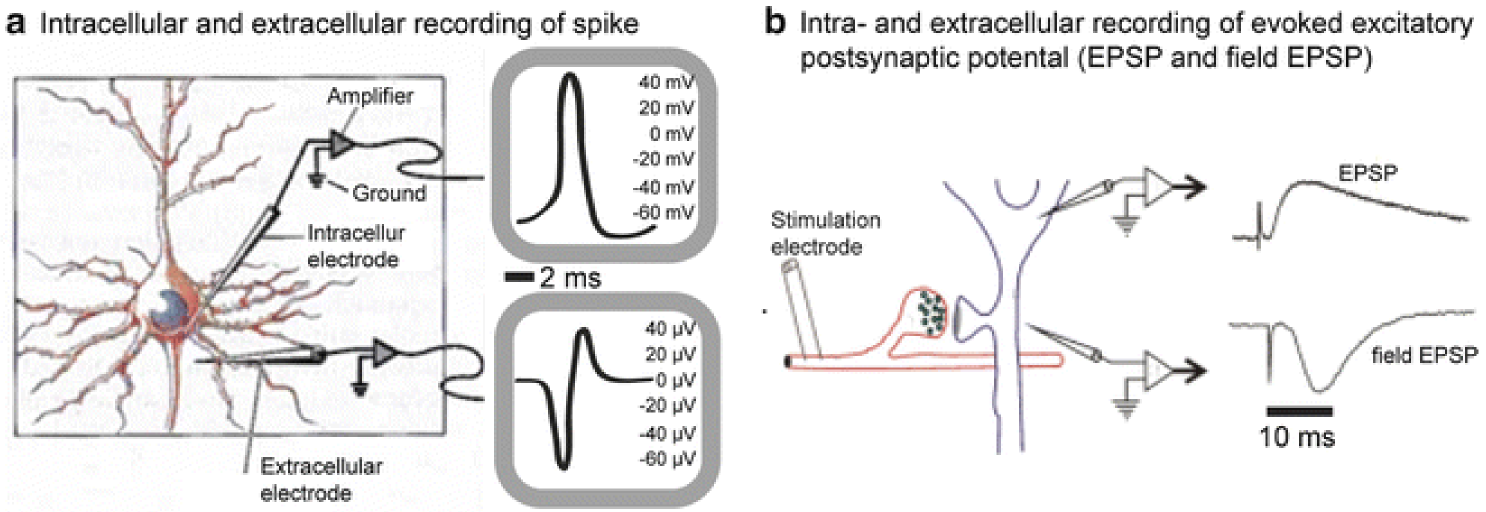


Fig. 3 Intra- and extracellular recordings of electrical activity. (**a**) Spike recordings by intra- and extracellular electrodes. Note that the extracellular potential is lower by a factor of 1,000. (**b**) Recordings of electrical evoked excitatory postsynaptic potential by intra- and extracellular electrodes

Mathiesen et al., (2014)
https://link.springer.com/protocol/10.1007/978-1-4939-1059-5_11

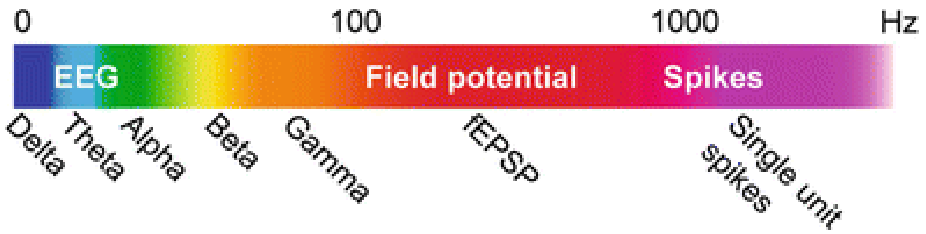


Fig. 4 Types of electrical signals recorded in vivo and their approximate frequencies

Mathiesen et al., (2014)
https://link.springer.com/protocol/10.1007/978-1-4939-1059-5_11

In practice, analyzing LFPs is very similar to analyzing rhythmic brain activity recorded from other modalities such as electroencephalography (EEG) or electrocorticography (ECoG). The primary difference is that the LFP is recorded from a depth electrode while EEG and ECoG are recorded on the surface of the head or brain, respectively. However, the propagation of electrical fields through the skull and brain parenchyma reduces both the signal amplitude and the spatial specificity of surface recordings (Nunez and Srinivasan, 2006, Srinivasan et al., 1998). Consequently, LFPs capture a more spatially localized field that is typically larger in magnitude than an EEG. Perhaps more importantly, LFPs can be recorded from regions deeper in the brain, thus representing activity from neuronal populations less accessible to noninvasive methods. Nonetheless, many insights learned from the decades of EEG research can be translated into LFP analysis.

Maling & McIntyre, (2016), in Closed Loop Neuroscience, pp. 67–80.

“Early studies demonstrated that **action potentials have a limited participation to the genesis of the EEG or LFPs**. The initial theory about the genesis of the EEG and LFP oscillations, the "circus movement theory", postulated that the frequency of oscillations was due to travelling pulses along loops of connected neurons (Rothberger, 1931; Bishop, 1936). Bremer (1938, 1949) was an opponent to this theory, and he was the first to propose that the EEG is not generated by action potentials but rather by oscillations of the membrane potential of neurons. **Eccles (1951) proposed that LFP and EEG activities are generated by summated postsynaptic potentials arising from the synchronized excitation of neurons.** Intracellular recordings from cortical neurons later demonstrated a **close correspondence between EEG/LFP activity and synaptic potentials** (Klee et al., 1965; Creutzfeldt et al., 1966a, 1966b). **The current view is that EEG and LFPs are generated by synchronized synaptic currents arising on cortical neurons, possibly through the formation of dipoles** (Niedermeyer and Lopes da Silva, 1998; Nunez and Srinivasan, 2005).”

http://www.scholarpedia.org/article/Local_field_potential

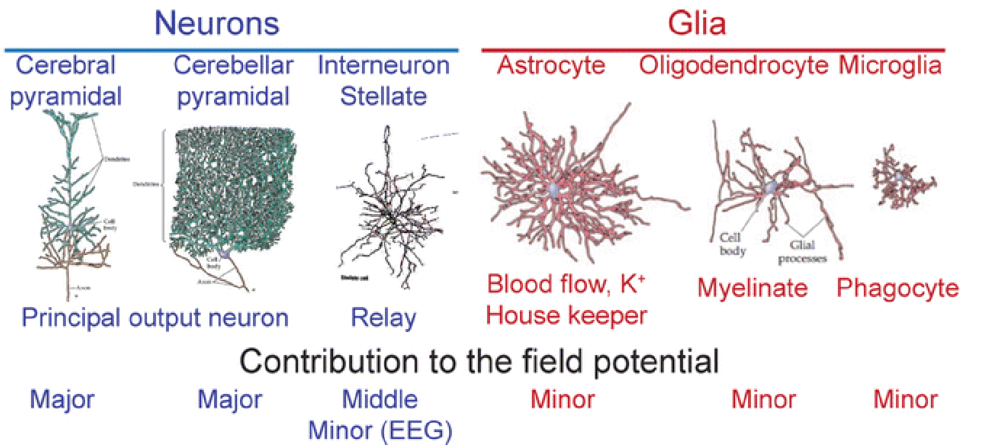


Fig. 2 Predominant cell types in the brain and their contribution to field potentials

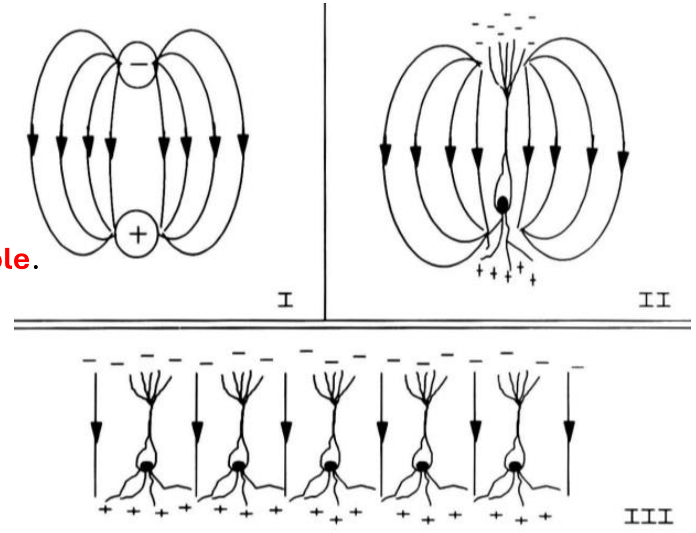
Mathiesen et al., (2014)
https://link.springer.com/protocol/10.1007/978-1-4939-1059-5_11

FIG. 1. Schematic diagrams of **dipoles** as they relate to the EEG. In each figure **arrows** depict the **direction of the movement of electrons**. Using this convention, **currents flow from the negative pole to the positive pole**.

I. An ideal **dipole**, composed of **two equal charges of opposite polarity** separated by a fixed distance. A schematic of the dipole's **electric field** is sketched around the **charges**.

II. A **dipole field** is depicted around a single neuron. Charge accumulation results from synaptic potentials.

III. An **array of cortical neurons** is depicted which can be modeled by a **dipole layer**.



Litt, (1991)
https://www.tandfonline.com/doi/pdf/10.1080/00029238.1991.11080363

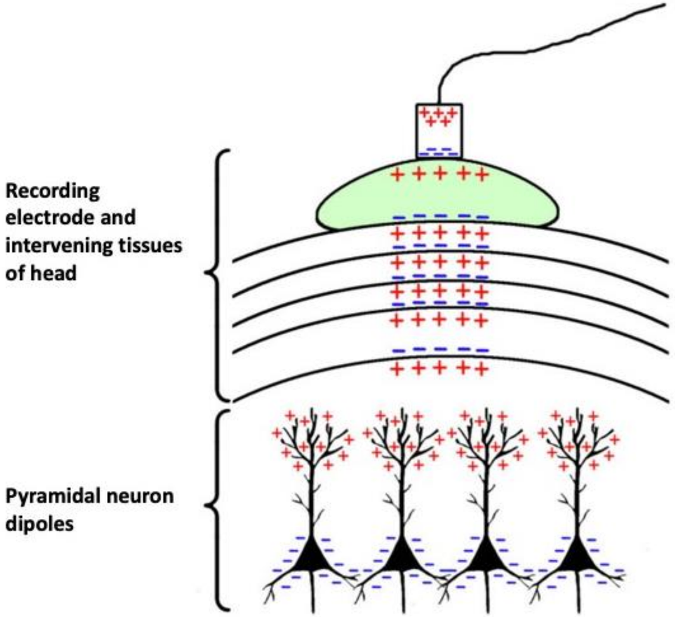


Figure 1. Pyramidal neurons can be identified by their cortical location and pyramidal shape of their cell bodies. In this illustration, **dipoles** are created in adjacent neurons due to postsynaptic EPSPs or IPSPs. Because **the cells are oriented perpendicular to the surface of the skull, the dipole is detected as a voltage deflection by the recording electrode (green).** The signal must propagate through the brain, meninges, skull bone, and electrode gel to reach the electrode. https://iastate.pressbooks.pub/curehumanphysiology/chapter/eeg/

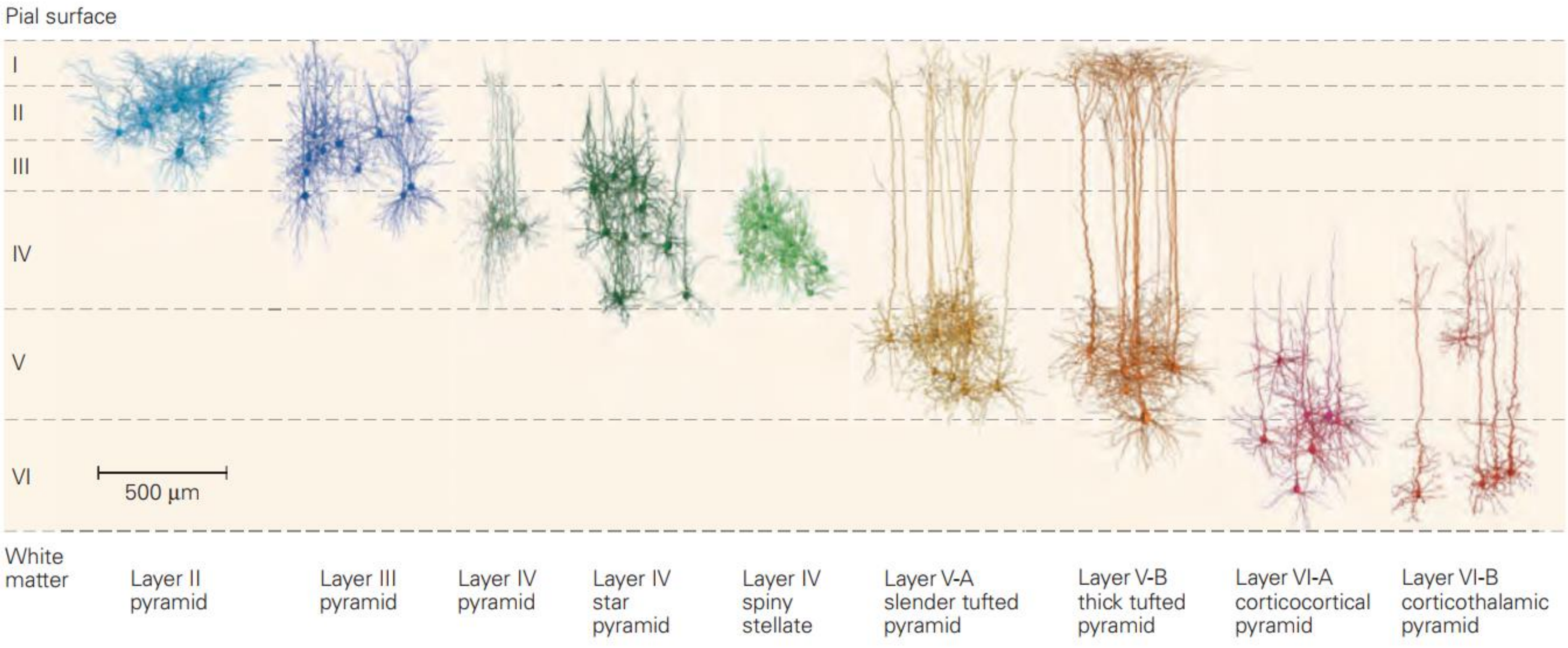


Figure 19–14 Columnar organization of the somatosensory cortex. Cortical excitatory neurons in the six layers have distinctive pyramidal-type shapes with large cell bodies, a single apical dendrite that projects vertically toward the cortical surface and arborizes in more superficial layers, and multiple basal dendrites that arborize close to the cell body. Pyramidal neurons differ in size, gene expression patterns, the length and thickness of their apical dendrite, and the projection targets of their axons. All of these neurons synapse on targets within the cerebral cortex. Additionally, the pyramidal neurons in layer V project subcortically to the spinal cord, brain stem, midbrain, and basal ganglia. Corticothalamic neurons in layer VI project back to the afferent thalamic nucleus providing sensory input to that column. Spiny stellate neurons in layer IV are the only excitatory cells shown that are not pyramidal neurons. (Adapted, with permission, from Oberlaender et al. 2012.)

Kandel et al. (2021), p. 453

Hans Berger
(1873 – 1941)

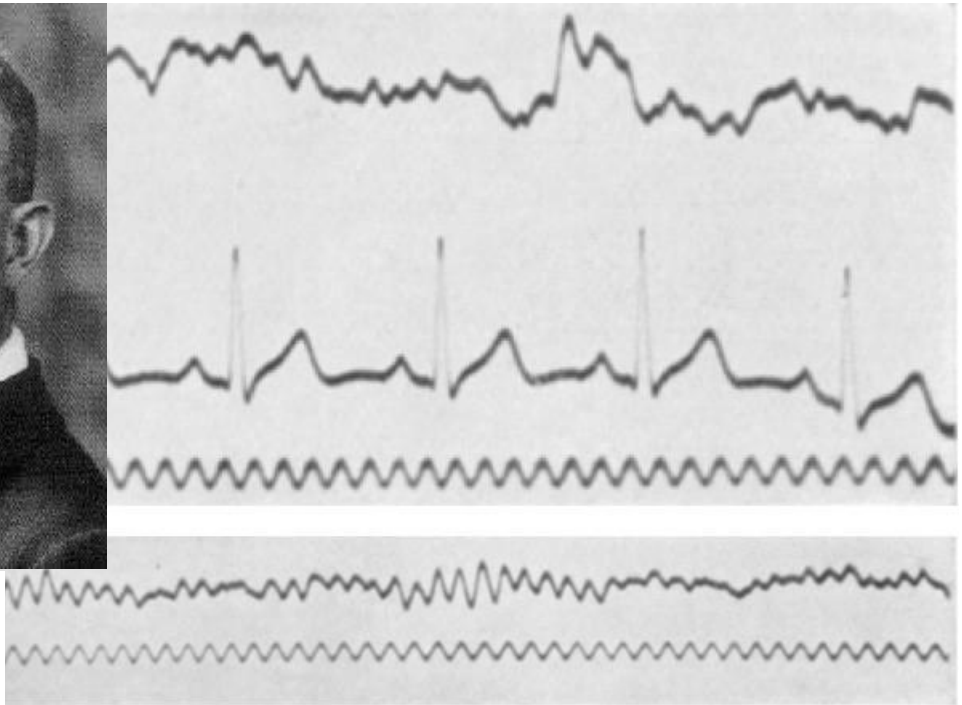


***Figure 1**: The **first reports of the human EEG** from the first publication from **Hans Berger (1929)**. Both represent samples of EEG recorded from his son Klaus (16 years old). The bottom figure represents a sample of what he would later call the **'alpha rhythm'** (a sinusoidal rhythm of approximately **10 Hz**) and the figure above what he would later call the 'beta rhythm' (or a desynchronized EEG with no obvious rhythmicity). The lowest tracing in both graphs is a generated 10 Hz sine wave, and the middle tracing from the top figure is the ECG. From: Berger (1929).*

https://brainclinics.com/history-of-the-eeg-and-qeeg/

> J Clin Neurophysiol. 2013 Feb;30(1):28-44. doi: 10.1097/WNP.0b013e31827edb2d.

Early history of electroencephalography and establishment of the American Clinical Neurophysiology Society

James L Stone [1], John R Hughes

Affiliations + expand
PMID: 23377440 DOI: 10.1097/WNP.0b013e31827edb2d

Abstract

The field of electroencephalography (EEG) had its origin with the discovery of recordable electrical potentials from activated nerves and muscles of animals and in the last quarter of the 19th century from the cerebral cortex of animals. By the 1920s, Hans Berger, a neuropsychiatrist from Germany, recorded potentials from the scalp of patients with skull defects and, a few years later, with more sensitive equipment from intact subjects. Concurrently, the introduction of electronic vacuum tube amplification and the cathode ray oscilloscope was made by American physiologists or "axonologists," interested in peripheral nerve recordings. Berger's findings were independently confirmed in early 1934 by Lord Adrian in England and by Hallowell Davis at Harvard, in the United States. In the United States, the earliest contributions to human EEG were made by Hallowell Davis, Herbert H. Jasper, Frederic A. Gibbs, William Lennox, and Alfred L. Loomis. Remarkable progress in the development of EEG as a useful clinical tool followed the 1935 report by the Harvard group on the electrographic and clinical correlations in patients with absence (petit mal) seizures and altered states of consciousness. Technical aspects of the EEG and additional clinical EEG correlations were elucidated by the above investigators and a number of others. Further study led to gatherings of the EEG pioneers at Loomis' laboratory in New York (1935-1939), Regional EEG society formation, and the American Clinical Neurophysiology Society in 1946.

https://pubmed.ncbi.nlm.nih.gov/23377440/

A

AMERICAN SOCIETY
OF
ELECTROENCEPHALOGRAPHY

First Annual Meeting

June 13, 14, and 15, 1947

MARLBOROUGH-BLENHEIM HOTEL
ATLANTIC CITY, N. J.

B

PANEL DISCUSSIONS

AFTERNOON SESSION, FRIDAY, JUNE 13, 1947

ELECTRODES — 2:00 P.M.

- Basic Principles . . . . L. F. NIMS
- Experiments and Practice . . . . . D. B. LINDSLEY
- Recommendations . . . . A. FORBES (CHAIRMAN)
- Discussion

ELECTRODE POSITIONS AND METHODS OF ATTACHMENT — 3:00 P.M.

- Pros and Cons of Positions in Use . . . J. KERSHMAN
- Methods of Attachment . . . . . . J. A. ABBOTT
- Recommendations . . . . R. S. DOW (CHAIRMAN)
- Discussion

RECORDING APPARATUS — 4:00 P.M.

- Characteristics of Existing Equipment . . H. DAVIS
- Ideal Characteristics . . . . J. L. O'LEARY
- Scope and Limitations of Various Types of Amplifiers for Neurophysiological Investigation . . . . PROF. K. S. LION (by invitation)
- Recommendations . . . . E. J. BALDES (CHAIRMAN)
- Discussion

C

EVENING SESSION, FRIDAY, JUNE 13, 1947

TRAINING AND QUALIFICATIONS — 8:30 P.M.

- Existing Training Programs . . . . F. A. GIBBS
- Ideal Training Programs and Qualifying Examinations . . . . R. B. AIRD
- Recommendations . . . . R. S. SCHWAB (CHAIRMAN)
- Discussion

RESOLUTIONS — 9:30 P.M.

SCIENTIFIC SESSION

MORNING SESSION, SATURDAY, JUNE 14, 1947

CALIBRATIONS OF E. E. G. AND ASSOCIATED EQUIPMENT — 9:30 A.M.
L. A. GEDDES (by invitation)

THE ELECTROENCEPHALOGRAM FOLLOWING OCCIPITAL LOBOTOMY — 10:00 A.M.
RICHARD L. MASLAND, FRANCIS C. GRANT and GEORGE M. AUSTIN

VALUE OF SIMULTANEOUS UNIPOLAR, BIPOLAR AND AUTONOMIC RECORDS (TWELVE CHANNELS WITH POLYGRAPH) — 10:30 A.M.
CHESTER W. DARROW and CHARLES E. HENRY

D

EVENING SESSION, SATURDAY, JUNE 14, 1947

ROUND TABLE

HISTORICAL INTERLUDE — 8:30 P.M.
ALEXANDER FORBES and DONALD J. MACPHERSON

THE GREY WALTER ANALYZER IN ACTION — 9:00 P.M.
MARY A. B. BRAZIER

OPEN DISCUSSION

SUNDAY, JUNE 15, 1947

BUSINESS MEETING — 10:00 A.M.

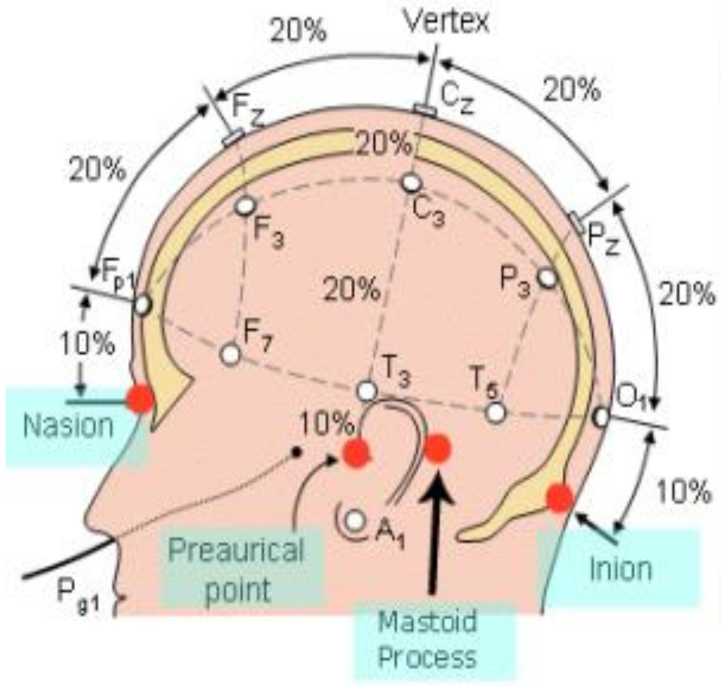
All members of the American Neurological Association and physicians and scientific workers interested in electroencephalography and neurophysiology are invited to attend the meetings on June 13 and 14.

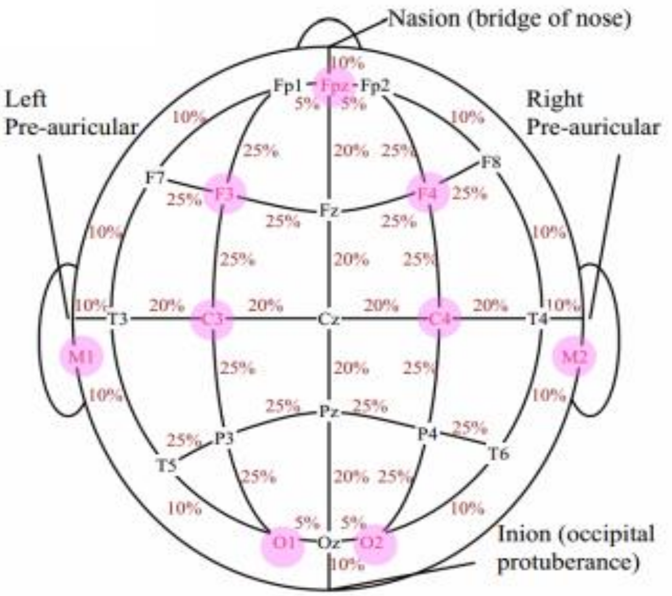
On June 15, the business meeting is open only to members.

FIG. 9. **A–D**, Brochure from the first meeting of the "American Society of EEG" held in Atlantic City, NJ, June 13–15, 1947.

https://pubmed.ncbi.nlm.nih.gov/23377440/

The 10/20 international electrode placement standard





https://tinyurl.com/yr2wsf48

Electrode naming	Location on scalp (left vs. right)
Fp = Frontal pole	Even numbers = right side
F = Frontal	Odd numbers = left side
T = Temporal	Z = midline
C = Central	
P = Parietal	(The higher the number, the
O = Occipital	farther the electrode is located
M = Mastoid	from the midline)

This method was developed to maintain **standardized testing** methods ensuring that a subject's study outcomes (clinical or research) could be **compiled, reproduced, and effectively analyzed and compared** using the scientific method. The system is based on the relationship between the location of an electrode and the underlying area of the brain, specifically the cerebral cortex.

The "10" and "20" refer to the fact that the **actual distances between adjacent electrodes** are either 10% or 20% of the total front–back or right–left distance of the skull.

https://en.wikipedia.org/wiki/10%E2%80%9320_system_(EEG)

Band	Frequency (Hz)	Amplitude (mV)	Brain Location	Example
Delta	1-4	<0.1	Variable	Adult slow wave sleep
Theta	4-8	<0.1	Variable	Drowsiness
Alpha	8-12	.02-.06	Occipital	Relaxation, meditation, idling brain
Beta	14-30	.02-.03	Frontal and parietal	Active thinking; cognitive tasks
Mu	8-13	<0.05	Motor cortex	Motor neurons at rest
Gamma	25-100	<0.05	Somatosensory cortex	Sensory processing

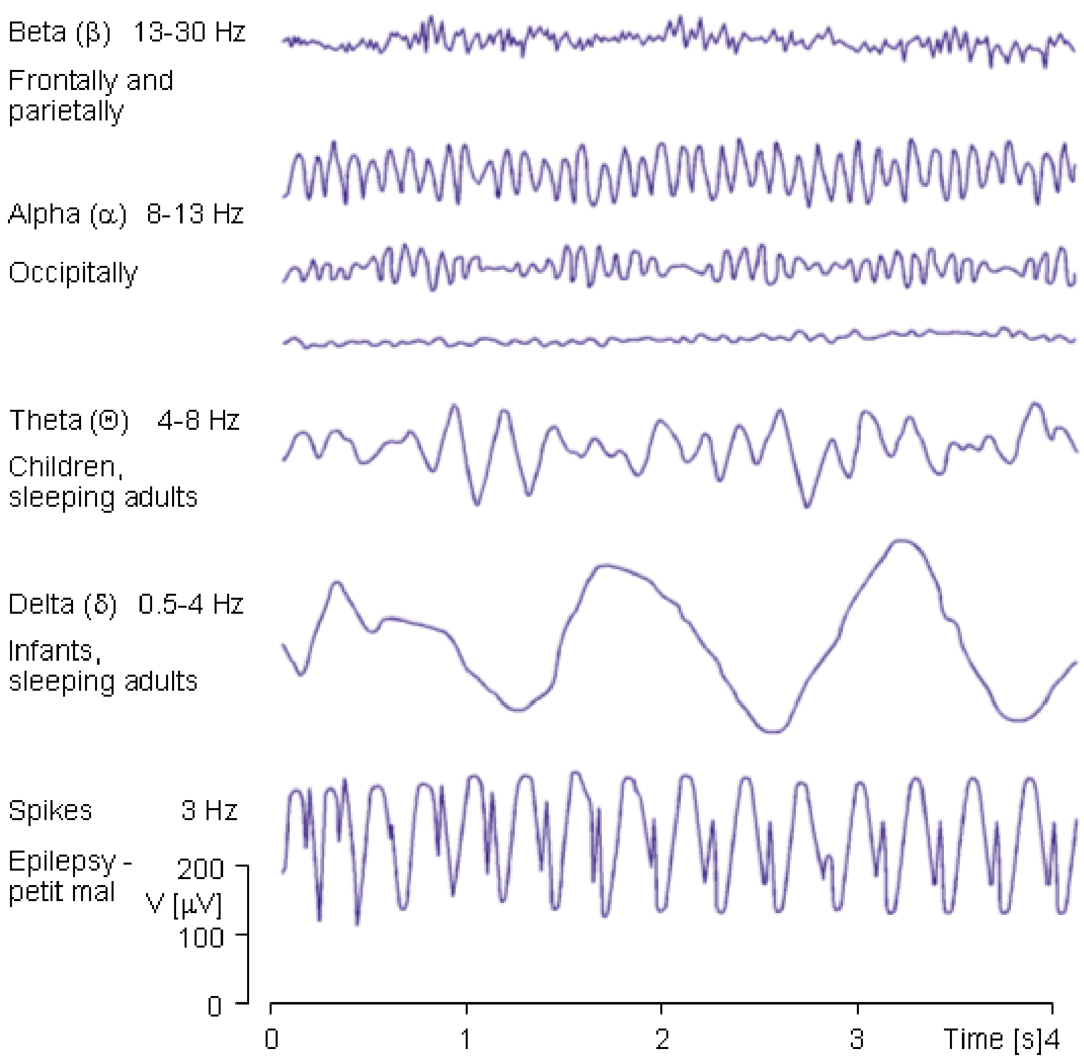
Table 1. *EEG waveforms are described by their frequency, amplitude, and location in the cerebral cortex.*

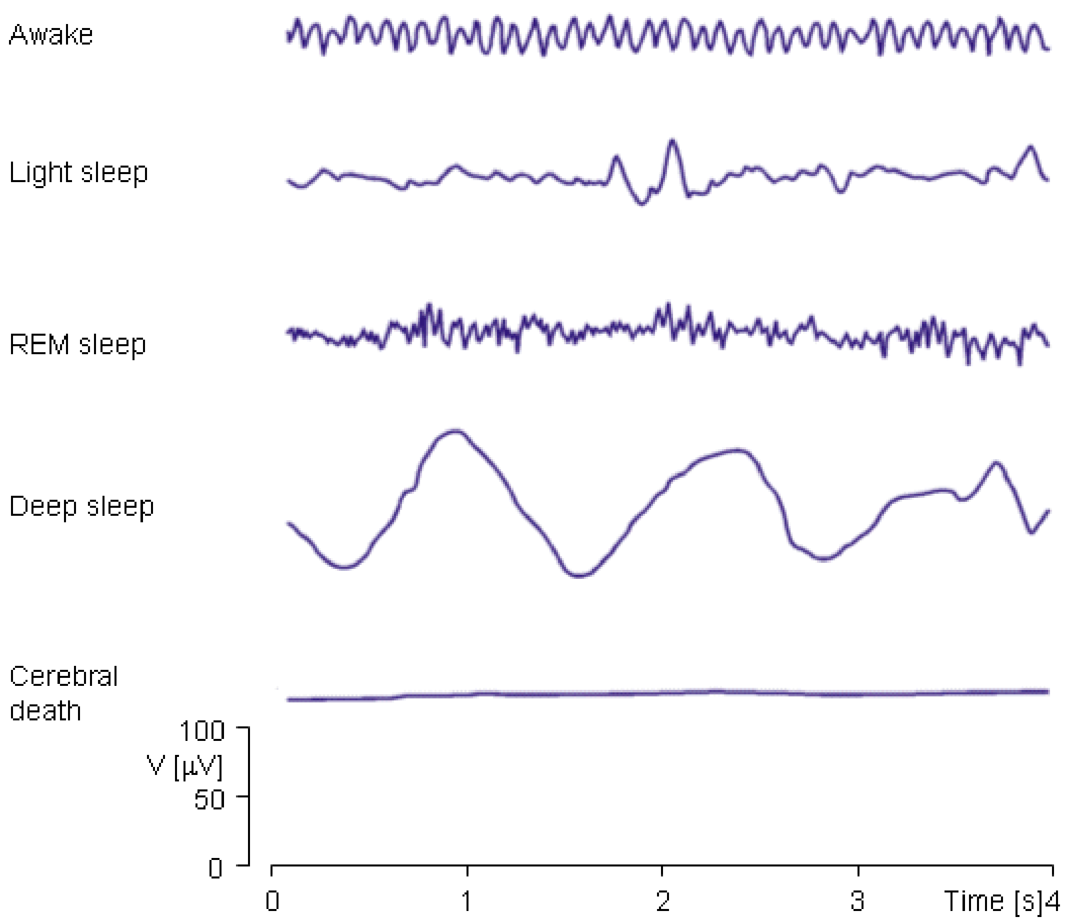
Source	Amplitude (mV)	Bandwidth (Hz)
ECG	1-5	0.05-100
EEG	0.001-0.01	0.5-40
EMG	1-10	20-2000
EOG	0.01-0.1	dc-10

Table 2. *The range of standard biopotential amplitudes and frequencies.*

Note the amplitude of EEG waves is significantly lower than the amplitudes recorded for other biopotentials.

https://tinyurl.com/yr2wsf48





Malmivuo & Plonsey, (1995), pp. 373-374

event-related potential (ERP)

time-locked EEG activity; the average amount of change in voltage at the scalp that is linked to the timing of particular cognitive events (e.g., stimulus, response)

- can be **elicited** by a wide variety of **sensory**, **cognitive** or **motor** events;
- are thought to **reflect the summed activity of postsynaptic potentials** produced when a large number of **similarly oriented cortical pyramidal neurons** (in the order of thousands or millions) **fire in synchrony** while processing information;
- ERPs in humans can be divided into 2 categories:

  (a) early waves/components peaking roughly **within the first 100 ms** after stimulus onset, are termed **'sensory'** or **'exogenous'** as they depend largely on the **physical parameters of the stimulus**;

  (b) ERPs generated in **later** parts reflect the manner in which the subject evaluates the stimulus and are termed '**cognitive**' or '**endogenous**' ERPs as they examine **information processing**.

Sur & Sinha, (2009)
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3016705/

Waveforms are described according to **latency** and **amplitude**

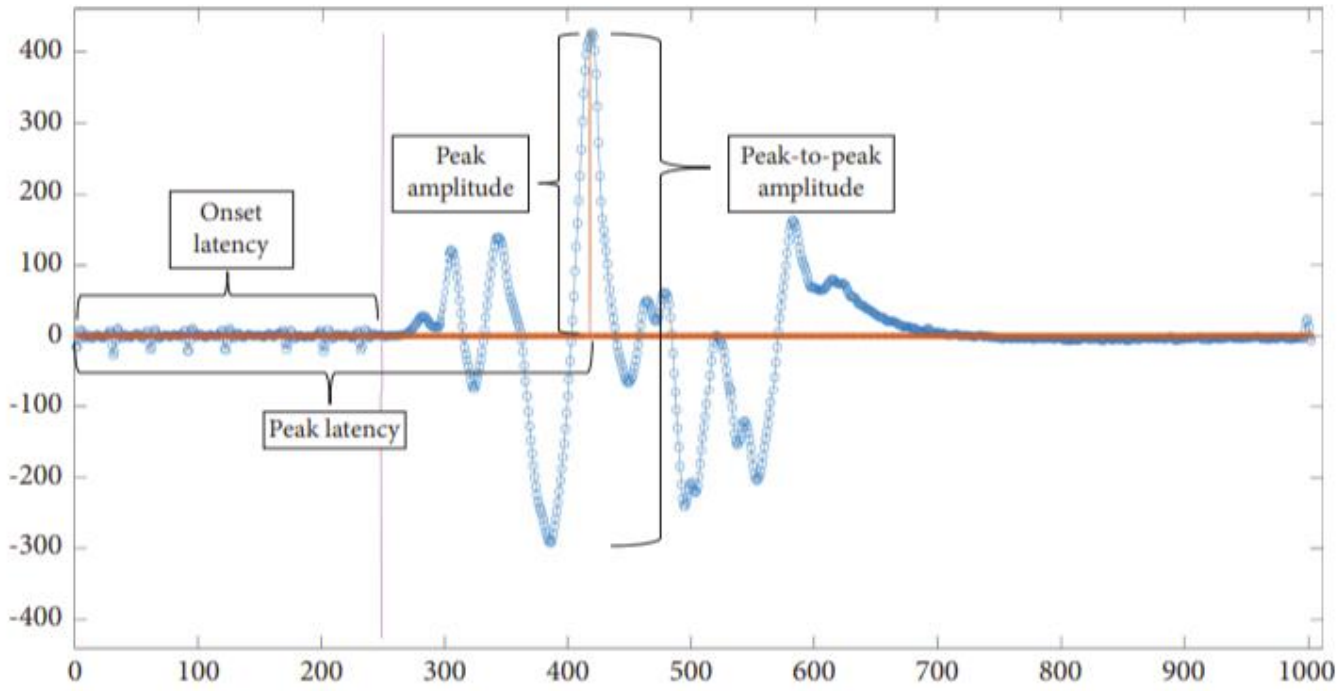


FIGURE 2: Onset latency, peak-to-peak amplitude, peak amplitude, and peak latency labels on raw MEP signal.

Jamaludin et al., (2022)
https://pubmed.ncbi.nlm.nih.gov/35634043/

waveform

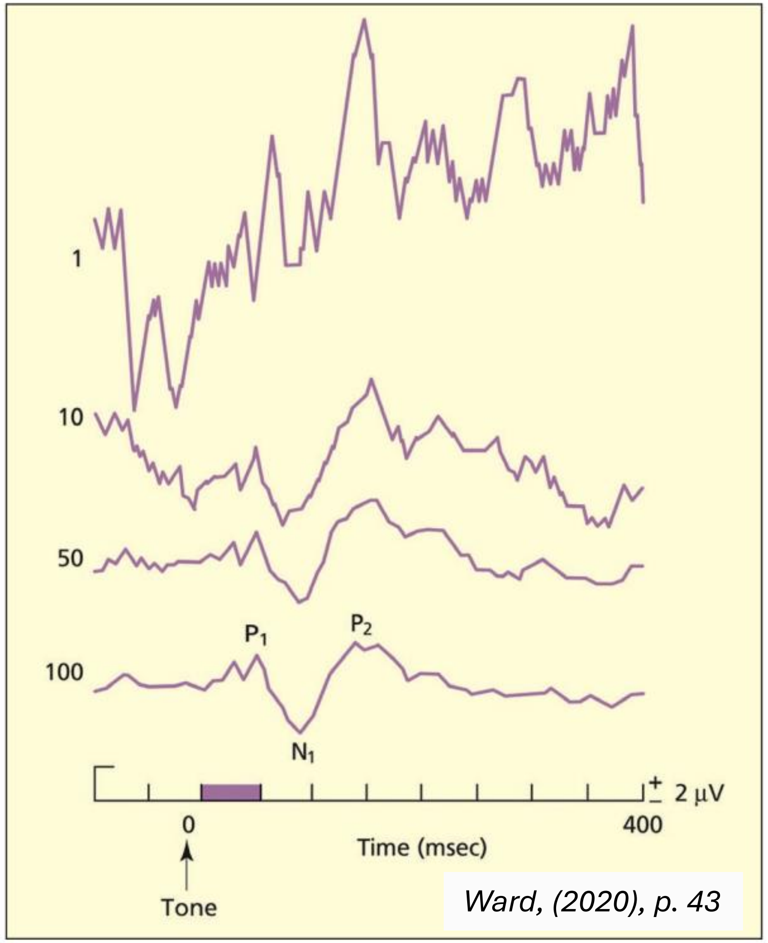
a graphical representation of a signal, characterized by frequency and amplitude

motor evoked potential (MEP)

reflets electrical signaling through the motor pathways of your nervous system, as recorded using electromyography (EMG)

visual evoked potential (VEP)

measures the electrical signal generated at the visual cortex in response to visual stimulation

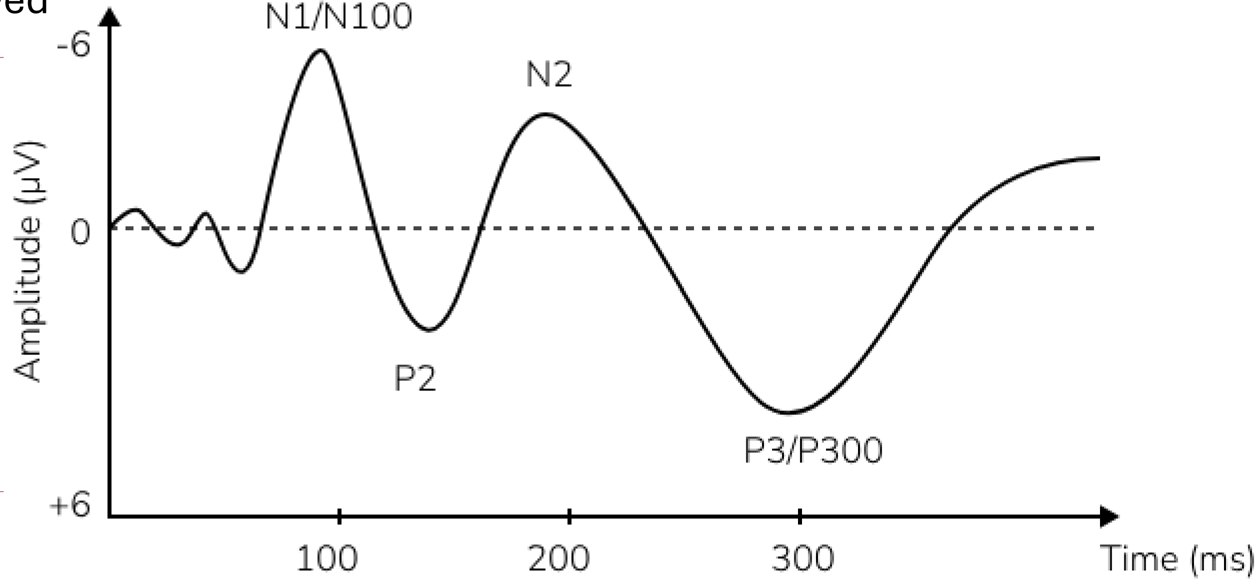


Components **naming convention**

negative components: **N** + the approximate **latency** at which that component can be observed

positive components: **P** + the approximate **latency** at which that component can be observed

note that the negative and positive are sometimes plotted counter-intuitively



https://tinyurl.com/5euuhu4z

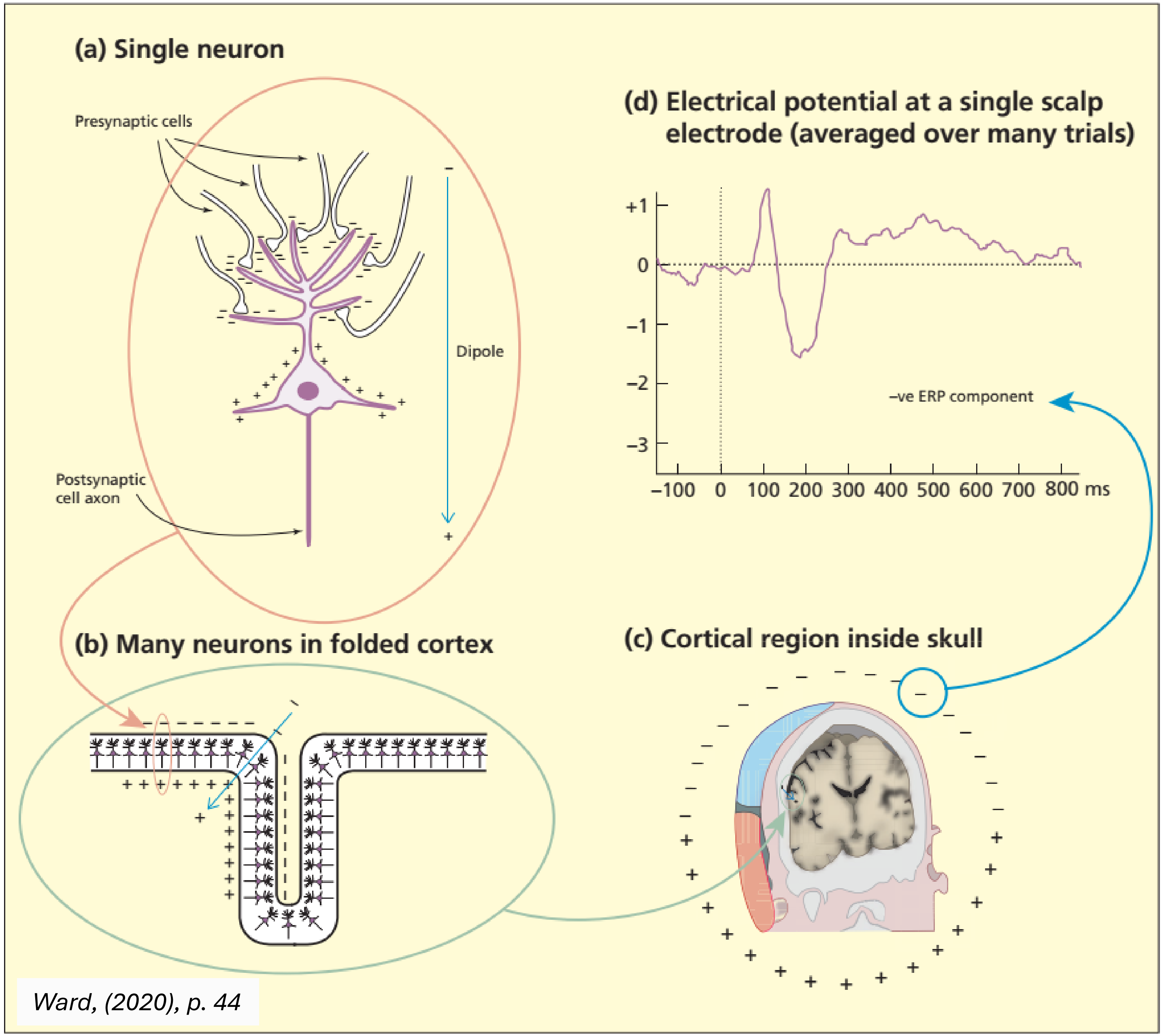
FIGURE 3.9: When different **EEG waves are averaged** relative to presentation of a stimulus (e.g., a tone), the **signal-to-noise ratio (SNR)** is **enhanced**, and an ERP is observed. The figure shows the mean EEG signal to 1, 10, 50 and 100 trials.

Signal-to-noise ratio (SNR)

a measure used in science and engineering that compares the level of a **desired signal** to the level of background **noise**

(a) Release of an **excitatory neurotransmitter** results in **positively charged ions** flowing into the postsynaptic neuron (and a net negativity in the extracellular region)

(b) This sets up a **dipole** that may **sum together with dipoles** from surrounding neurons (which tend to be **aligned** in the same way)

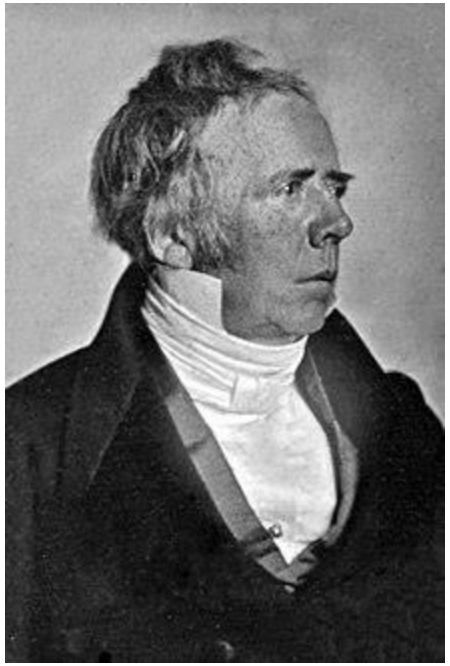


(d) Changes in the negative or positive potential **at a given site** over time are **the neural basis for the ERP signal**

(c) This **conducts** to the **scalp** as **a distribution of positive and negative charges**

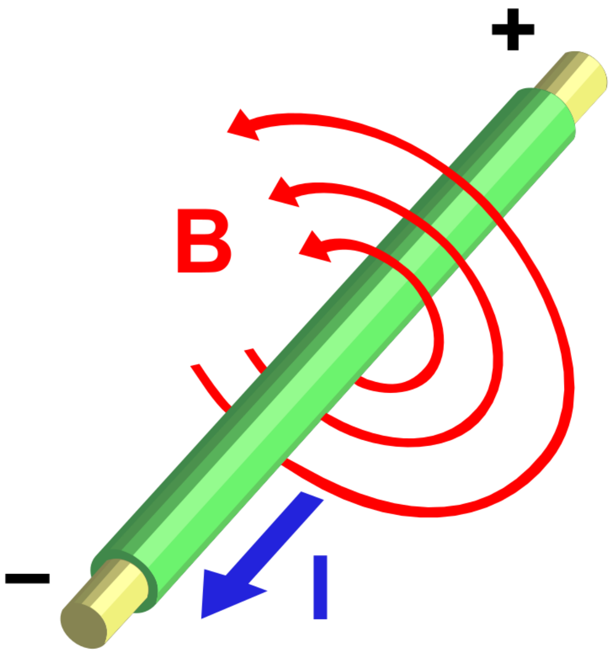
FIGURE 3.10: From electrical activity of neurons to a scalp-recorded event-related potential.

Magnetoencephalography (MEG)

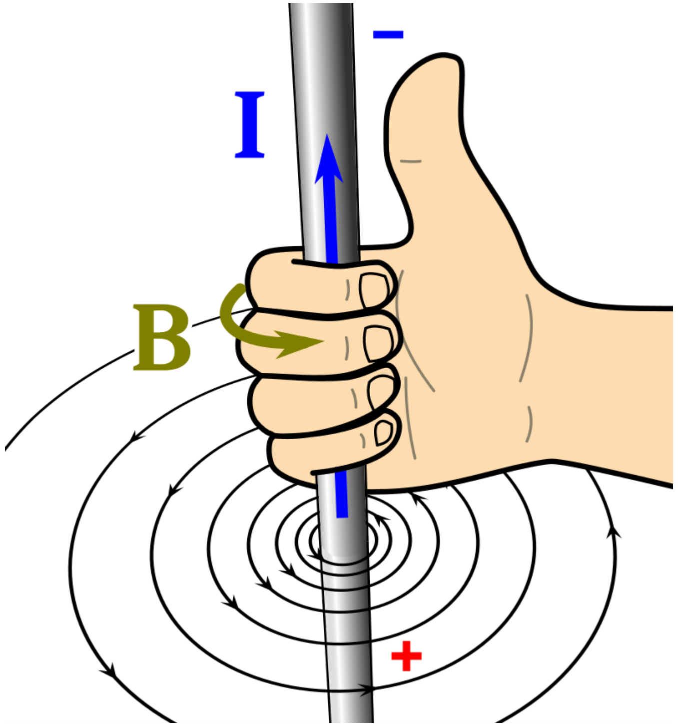


Hans Christian Ørsted
(1777 – 1851)

Ørsted's law (also spelled Oersted's law) in electromagnetism, is the physical law stating that **an electric current creates a magnetic field**

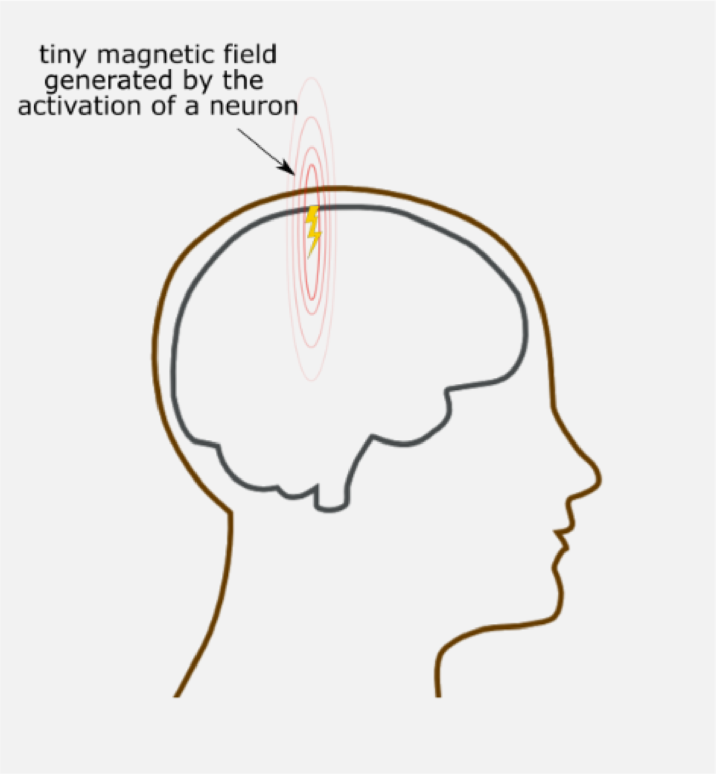


The magnetic field (marked B, indicated by red field lines) around wire carrying an electric current (marked I)

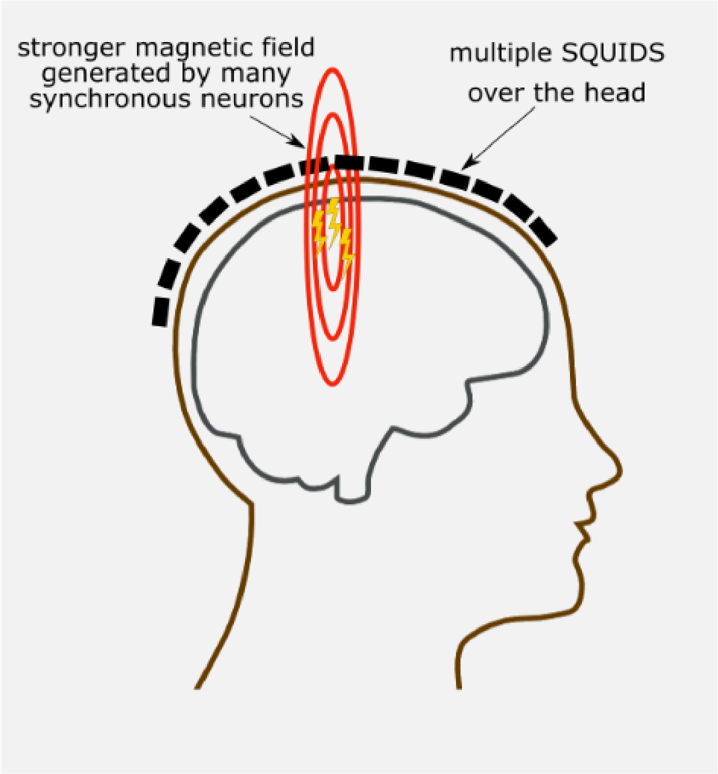


Using the right-hand rule to find the direction of the magnetic field

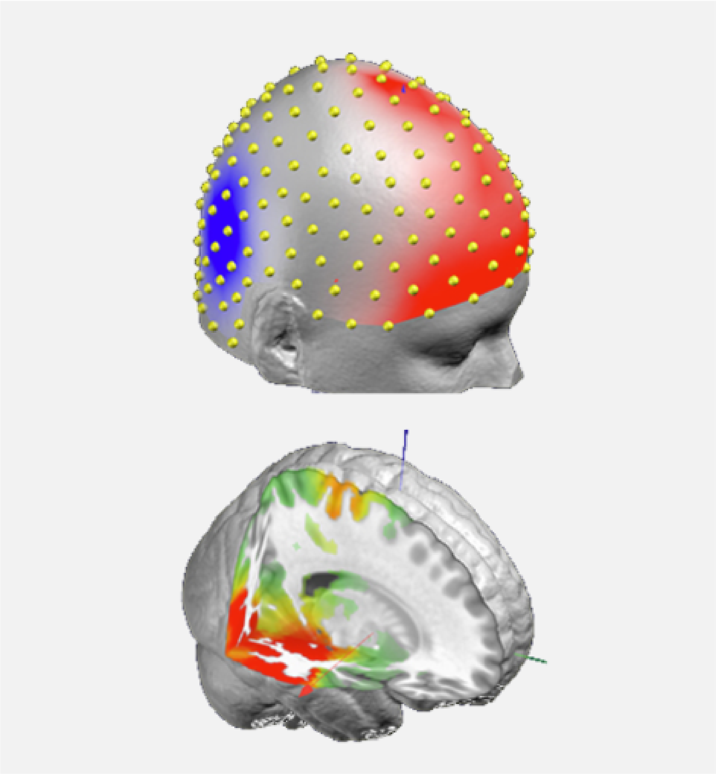
https://en.wikipedia.org/wiki/Oersted%27s_law



The activation of a neuron produces a tiny magnetic field.



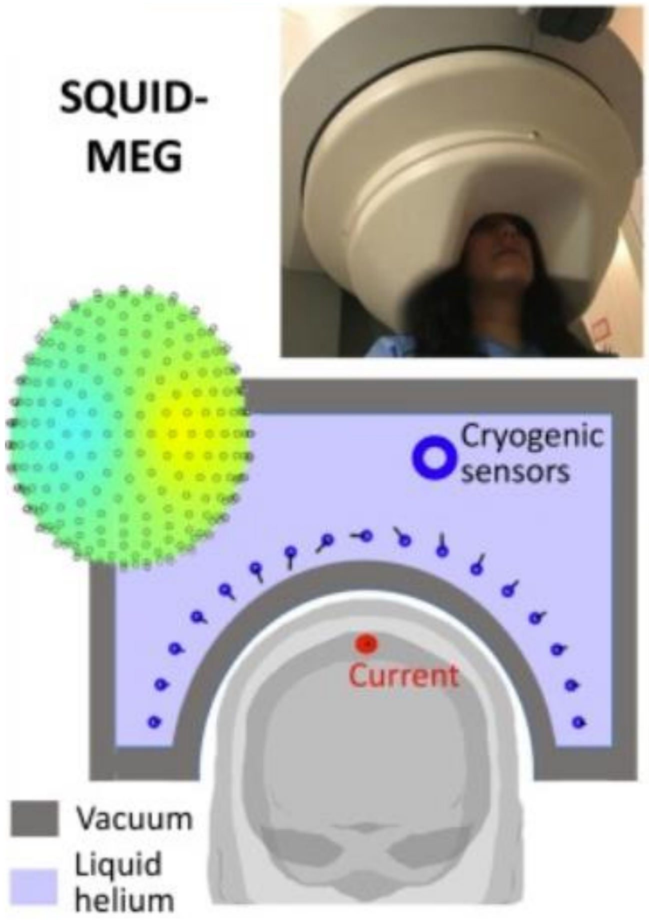
When many nearby neurons are activated synchronously, their magnetic fields sum up. The resulting magnetic field is still very small but can be measured with extremely sensitive sensors called SQUID*.



The final measurements can be represented as a heatmap of brain activation.

*Superconducting QUantum Interference Device

https://hnp.fcbg.ch/project/meg-2022/



Brooked et al., (2022)
https://pubmed.ncbi.nlm.nih.gov/35779970/

At the cellular level, individual **neurons** in the brain have **electrochemical properties** that result in the **flow of electrically charged ions** through a cell. **Electromagnetic fields** are **generated** by the net effect of this slow ionic current flow. While the magnitude of fields associated with an individual neuron is negligible, the effect **of multiple neurons** (e.g., 50,000 – 100,000) excited together in a specific area generates a **measureable magnetic field outside the head**. These neuromagnetic signals generated by the brain are **extremely small**—a billionth of the strength of the earth's magnetic field.

Therefore, **MEG** scanners require **superconducting sensors (SQUID, superconducting quantum interference device).** The SQUID sensors are **bathed** in a large **liquid helium cooling unit** at approx. -269 °C. Due to **low impedance** (resistance) at this temperature, the SQUID device can **detect and amplify magnetic fields** generated by neurons a few cm away from the sensors. A **magnetically shielded room** houses the equipment and mitigates interference. https://ilabs.uw.edu/what-magnetoencephalography-meg/

A schematic representation of conventional **MEG** [**superconducting quantum interference device (SQUID)-**MEG].

A participant sits with their head in a static helmet containing an **array of field sensors** (blue circles).

Sensors require **cryogenic cooling** and are consequently bathed in **liquid helium**.

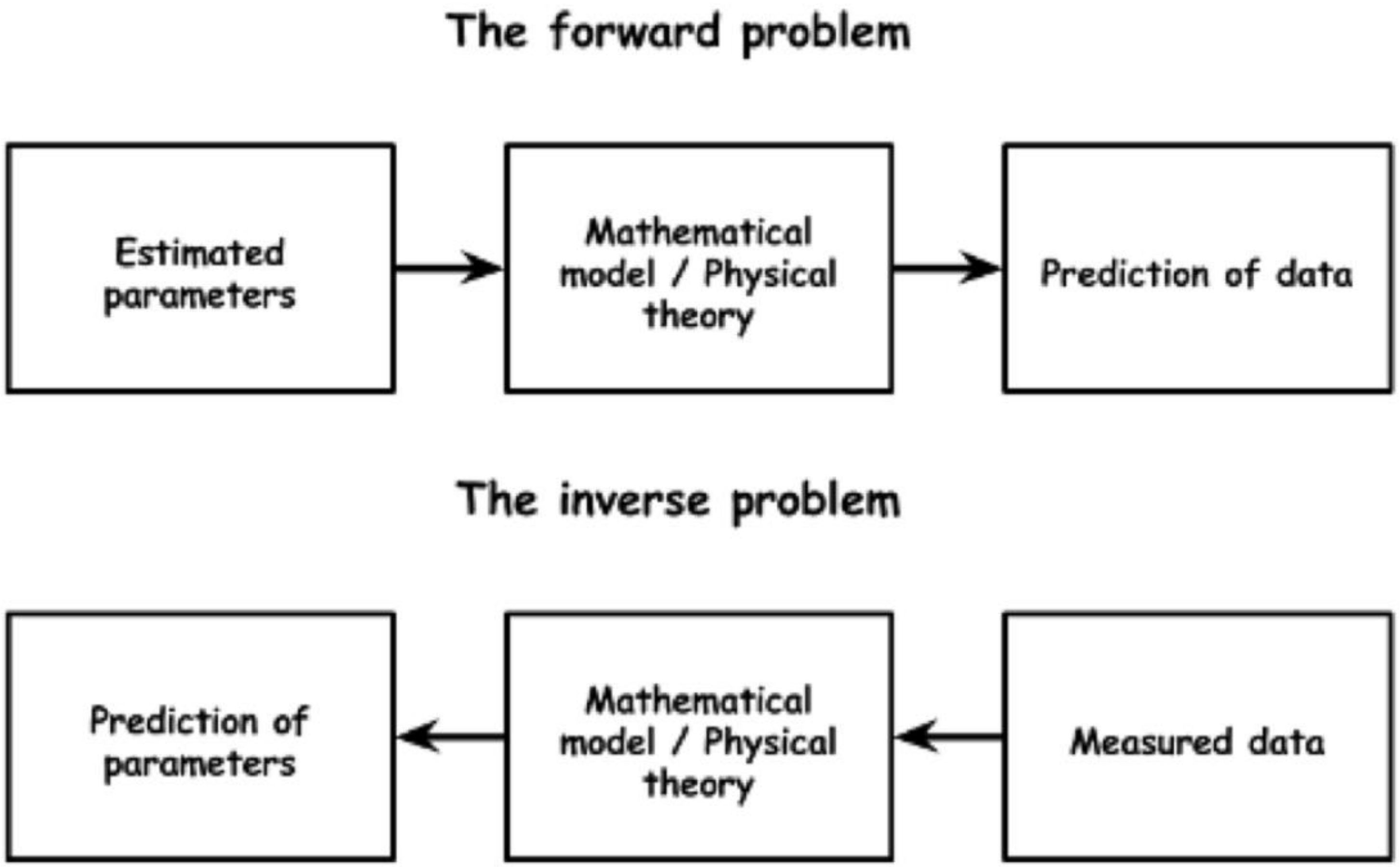
Ward, (2020), p. 53

MEG	EEG
• Signal unaffected by skull, meninges, etc.	• Signal affected by skull, meninges, etc.
• Poor at detecting deep dipoles	• Detects deep and shallow dipoles
• More sensitive to activity at sulci	• Sensitive to gyri and sulci activity
• Millisecond temporal resolution	• Millisecond temporal resolution
• Potentially good spatial resolution (2–3 mm)	• Poor spatial resolution
• Expensive and limited availability	• Cheaper and widely available

https://www.youtube.com/watch?v=tnZlR6DXail

https://www.youtube.com/watch?v=Kt20IO5ZZAA

Source localization in EEG & MEG



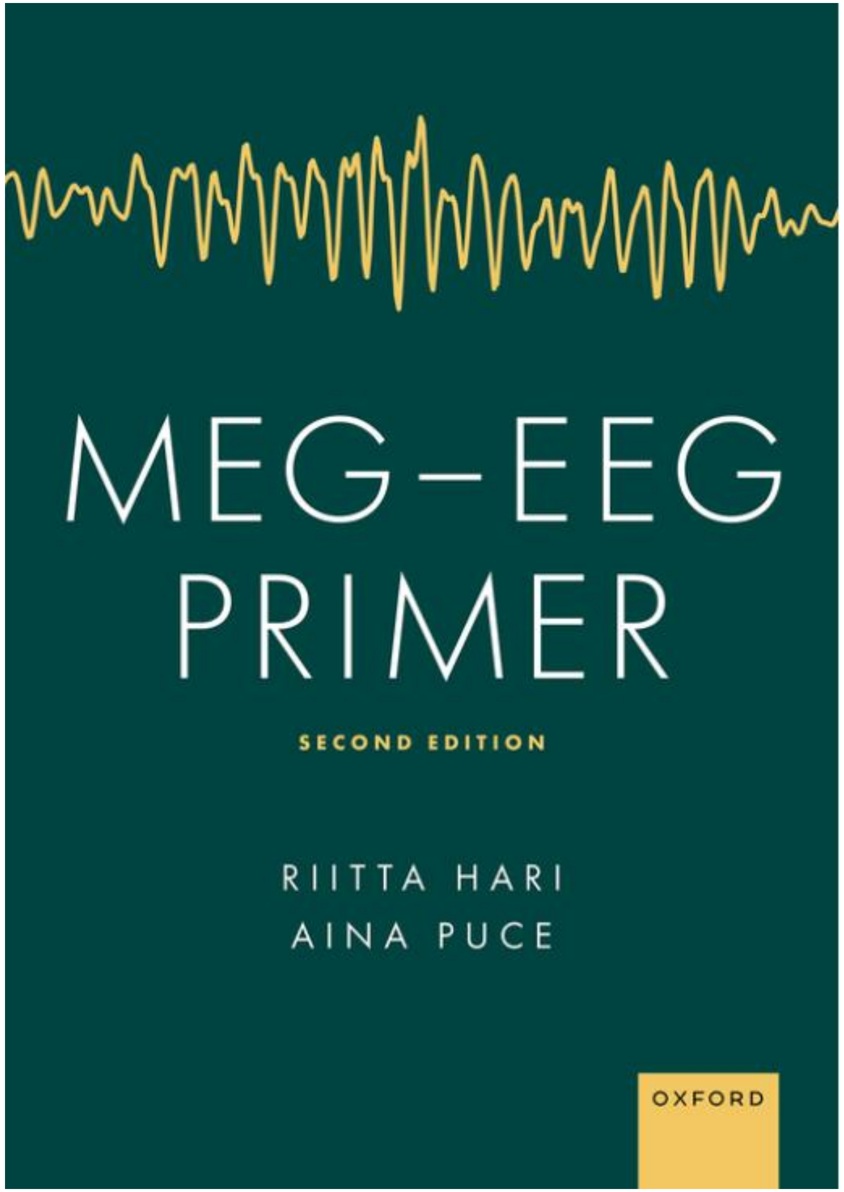
forward problem

involves computing the scalp potentials or external magnetic field at a finite set of sensor locations for a putative source configuration

inverse problem

the difficulty of locating the sources of electrical activity from measurements taken at the scalp

https://sapienlabs.org/lab-talk/the-inverse-problem-in-eeg/



Aina Puce

Riita Hari

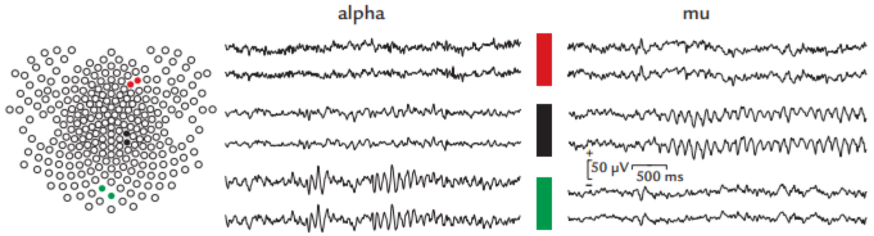


FIGURE 4.2. **EEG alpha and mu rhythms in healthy subjects.** Left: A 256-channel electrode array identifies two right frontal (red circles), central (black circles), and posterior (green circles) scalp electrodes. Middle: EEG displayed from six electrodes at the anterior, central, and posterior scalp shows a clear alpha rhythm that waxes and wanes over the posterior scalp (green electrodes, bottom traces) but is not visible in the other electrodes. In this subject, the sinusoidal rhythm peaks at around 10 Hz. Right: EEG in another healthy subject displayed from the same six electrodes. The central sites over the sensorimotor scalp (black electrodes, middle traces) show a clear mu rhythm that waxes and wanes and is not visible at the anterior and posterior sensors. The signals are low-pass filtered at 45 Hz. The average reference configuration is used to display these data. Calibration bars depict amplitude in μV and time in milliseconds. Data recorded in the Social Neuroscience Laboratory, Indiana University, USA.

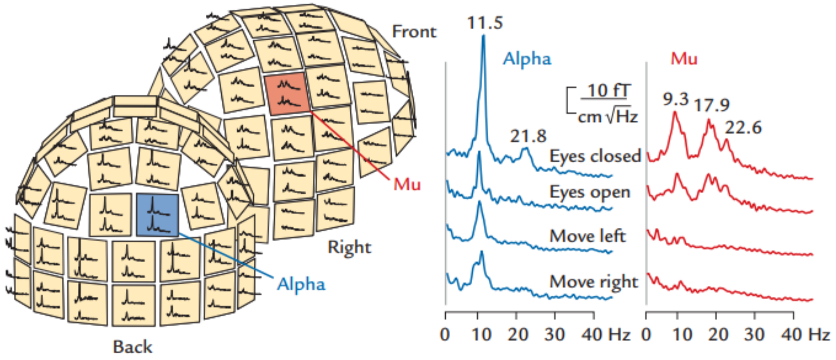


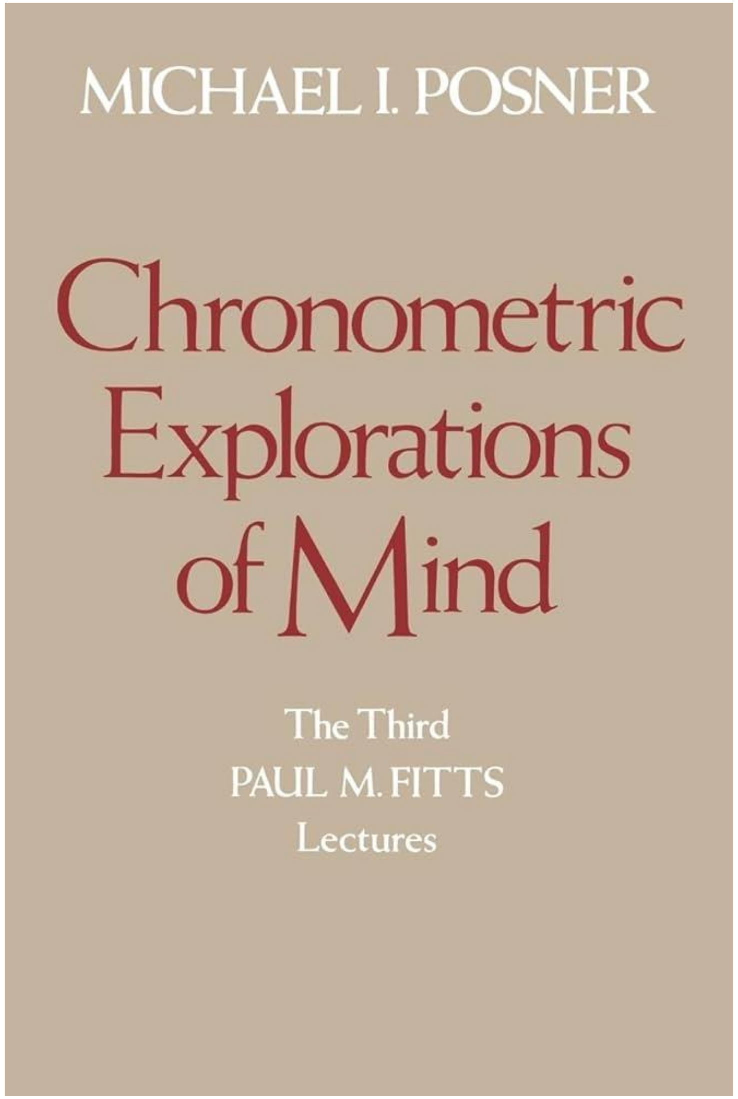
FIGURE 4.3. **Amplitude spectra of MEG alpha and mu rhythms.** Left: A 122-channel sensor array shown from two viewing angles (back and right). On each sensor unit, spectra are displayed from two orthogonal planar gradiometers. Alpha rhythm (blue) is strongest in the posterior MEG sensors, with a peak at 11.5 Hz, and mu rhythm (red) is strongest in sensors over the sensorimotor cortex. Right: Magnified amplitude spectra from the left panel. Alpha rhythm is greatly diminished by opening of the eyes, and mu rhythm is abolished during unilateral hand movements. Adapted and reprinted from Hari R, Salmelin R: Human cortical oscillations: a view through the skull. *Trends Neurosci* 1997, 20: 44–49. With permission from Elsevier.

Mental chronometry

mental chronometry

The study of the **timecourse of information processing** in the human nervous system

Michael Posner



reaction time

the **time** taken **between the onset** of a stimulus/event and the production of a behavioral **response** (e.g., a button press). Also referred to as **response time**

The basic idea is that **changes** in the nature or efficiency **of information processing** will manifest themselves in the **time** it takes **to complete a task.**

additive factors method

a general method for dividing

reaction times into different stages

Saul Sternberg

Acta Psychologica 30 *Attention and Performance II* (*W. G. Koster, ed.*) 1969, 276–315

THE DISCOVERY OF PROCESSING STAGES: EXTENSIONS OF DONDERS' METHOD

SAUL STERNBERG [1]

Bell Telephone Laboratories, Murray Hill, N.J., U.S.A.

ABSTRACT

A new method is proposed for using reaction-time (RT) measurements to study stages of information processing. It overcomes limitations of Donders' and more recent methods, and permits the discovery of stages, assessment of their properties, and separate testing of the additivity and stochastic independence of stage durations. The main feature of the *additive-factor method* is the search for non-interacting effects of experimental factors on mean RT. The method is applied to several binary-classification experiments, where it leads to a four-stage model, and to an identification experiment, where it distinguishes two stages. The sets of stages inferred from both these and other data are shown to carry substantive implications. It is demonstrated that stage-durations may be additive without being stochastically independent, a result that is relevant to the formulation of mathematical models of RT.

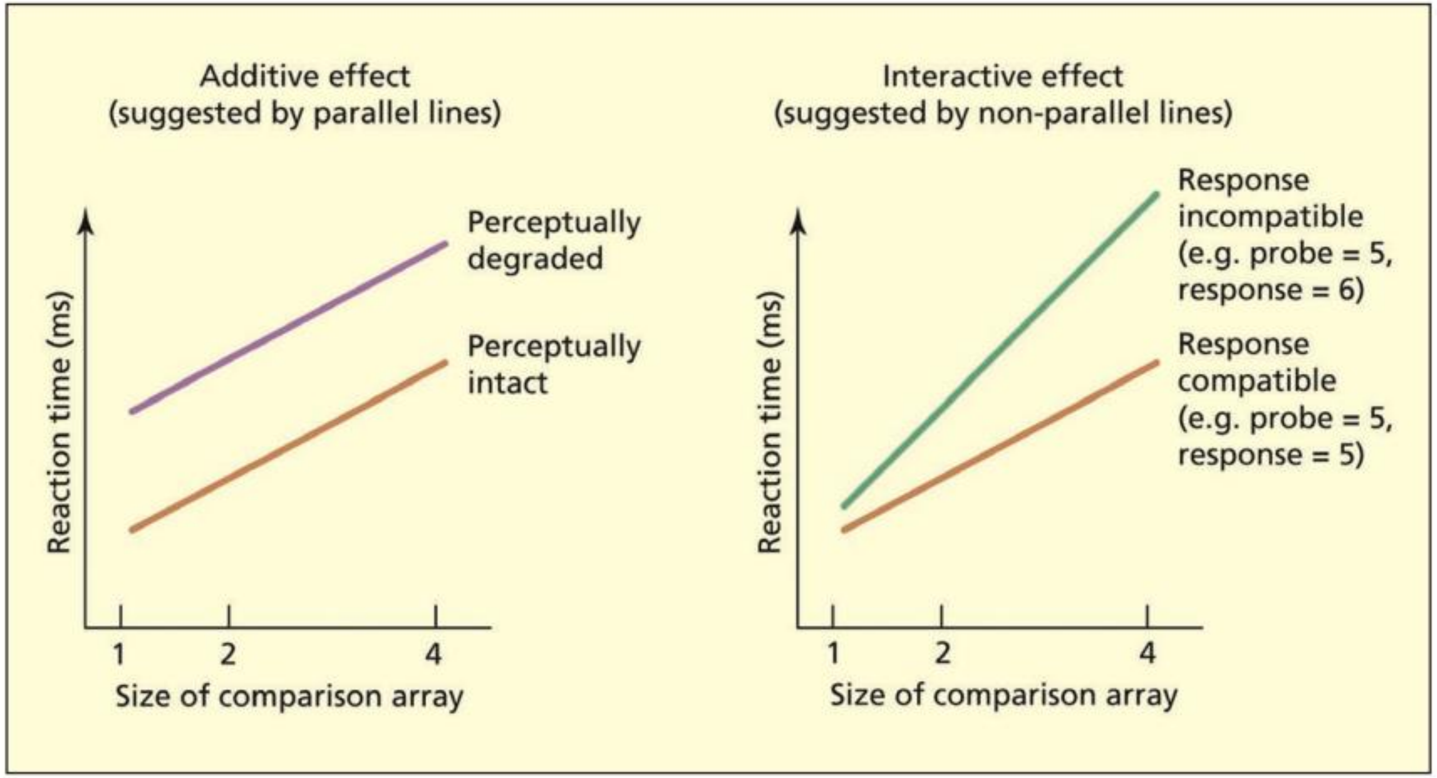
https://www.sciencedirect.com/science/article/pii/0001691869900559

Sternberg's experiment involved a **working memory task** in which participants were **given an array of one, two or four digits to hold in mind** (e.g., 5, 9, 3, 2). They were then **shown a single probe digit** (e.g., 9) and asked to **press one of two buttons** (labeled "yes" and "no") to indicate whether **this item had been in the previous array.**

Sternberg proposed that the task could be divided into a number of **separate stages**, including:

1. **Encoding** the probe digit.
2. **Comparing** the probe digit with the items held in memory.
3. **Deciding** which response to make.
4. **Responding** by executing the button press.

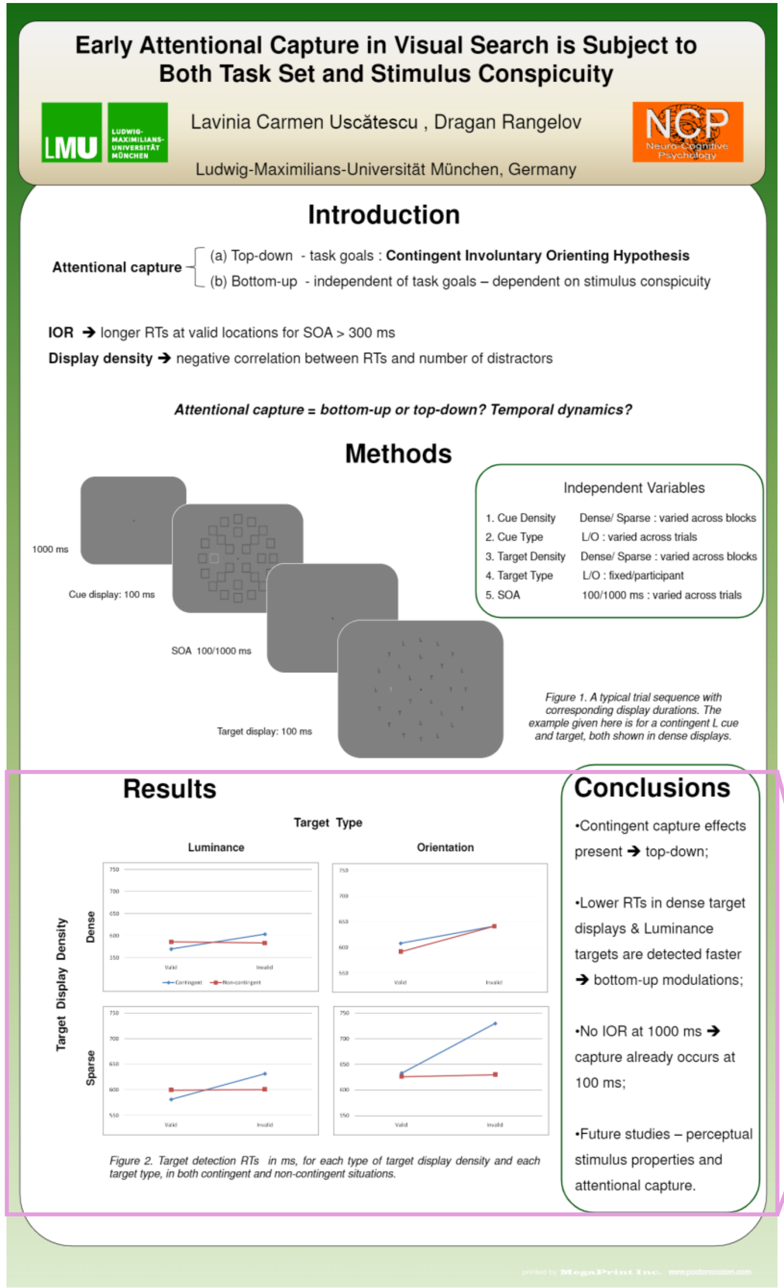
Therefore, **if different factors affect different stages of processing, then the effects should have additive effects on the overall reaction time**, **whereas if they affect the same processing stage, they should have interactive effects.** The strength of this method is that one could then **take an unknown factor** (e.g., sleep deprivation) and **determine whether this has an interactive effect on stimulus perceptibility** (implying that the new factor affects perceptual encoding) **or whether it has an interactive effect with the number of items in the array** (implying the new factor affects the comparison stage) **or both** (implying the new factor has effects at multiple levels).

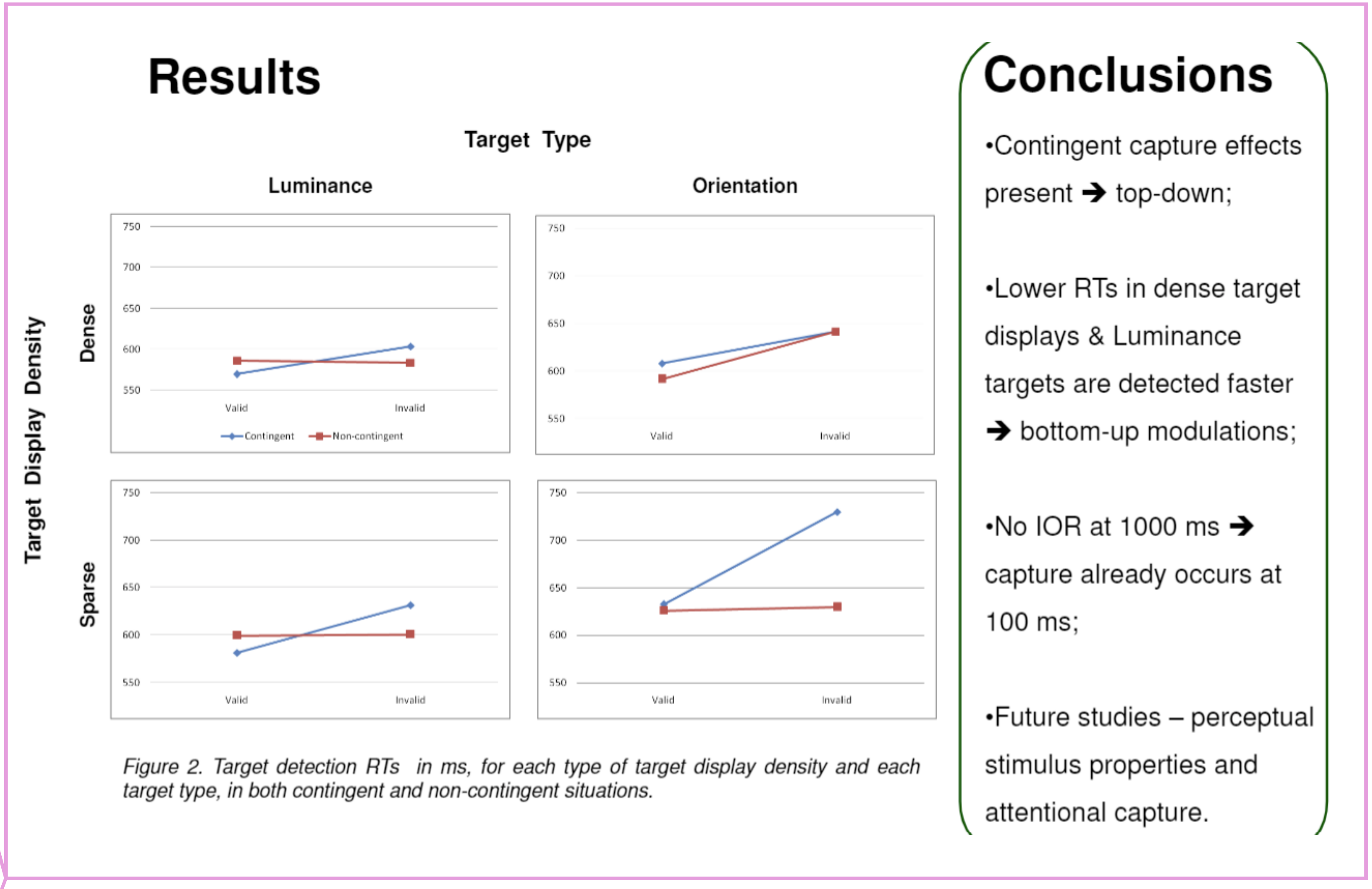


Ward, (2020), p. 47

FIGURE 3.11: Sternberg's additive factors method assumes that if two variables affect different stages of processing then they should have an additive effect on the overall reaction time (left), but if two variables affect the same stage of processing then the factors should have an interactive effect (right). His task involved comparing a probe digit (e.g., 5) with an array of one, two or four digits held in mind.

example of interactive effect in a modern psychophysics experiment





Franciscus Donders
(1818 – 1889)

the subtraction method

inferring the speed of higher mental processes from reaction time (RT)

pure insertion (also pure deletion)

the assumption that adding a different component to a task does not change the operation of other components

the A-task
(or simple RT)

ex: press a button when a picture is presented

stimulus input time → processing/ decision time → motor response time

the B-task
(or choice RT)

ex: press the green button when a picture of a dog is presented, and a red button when a picture of a pig is presented

stimulus input time → processing/ decision time → discrimination time → motor choice time → motor response time

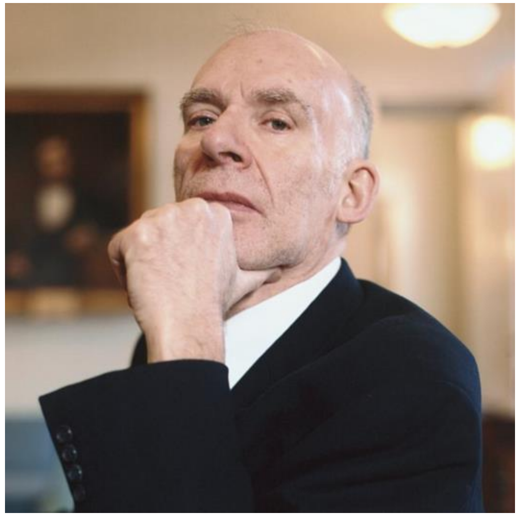
the C-task
(or go/no-go task)

ex: press the green button when a picture of a dog is presented (go), but don't press any button when a picture of a pig is presented (no-go)

stimulus input time → processing/ decision time → discrimination time → motor response time

See Ulrich et al., (1999), https://psycnet.apa.org/record/1999-03234-004, for more on this topic

Prominent event-related potential (ERP) components



Risto Näätänen
(1939 – 2023)

Clin Neurophysiol. 2009 Mar; 120(3): 453–463.
doi: 10.1016/j.clinph.2008.11.029

The mismatch negativity: A review of underlying mechanisms

Marta I. Garrido,* James M. Kilner, Klaas E. Stephan, and Karl J. Friston

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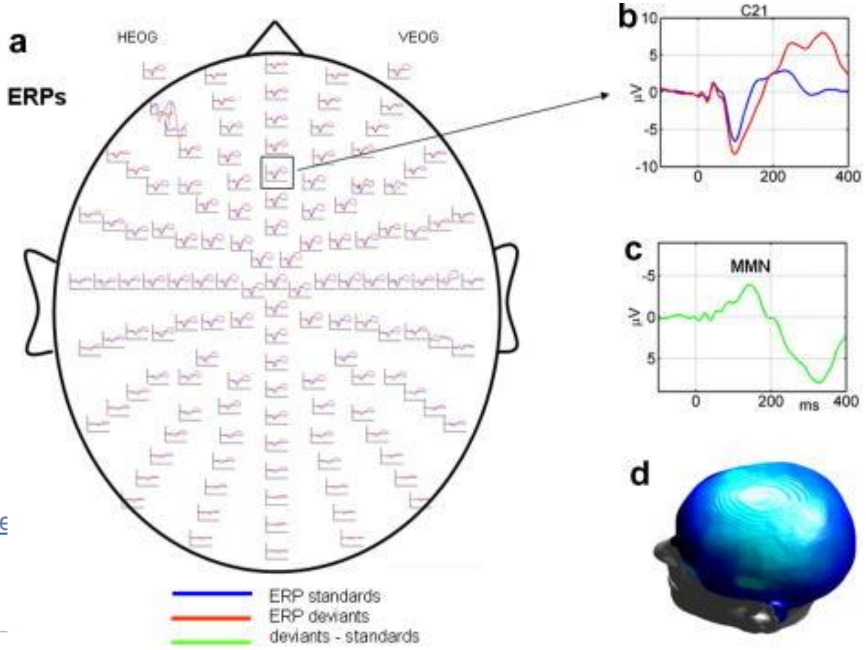
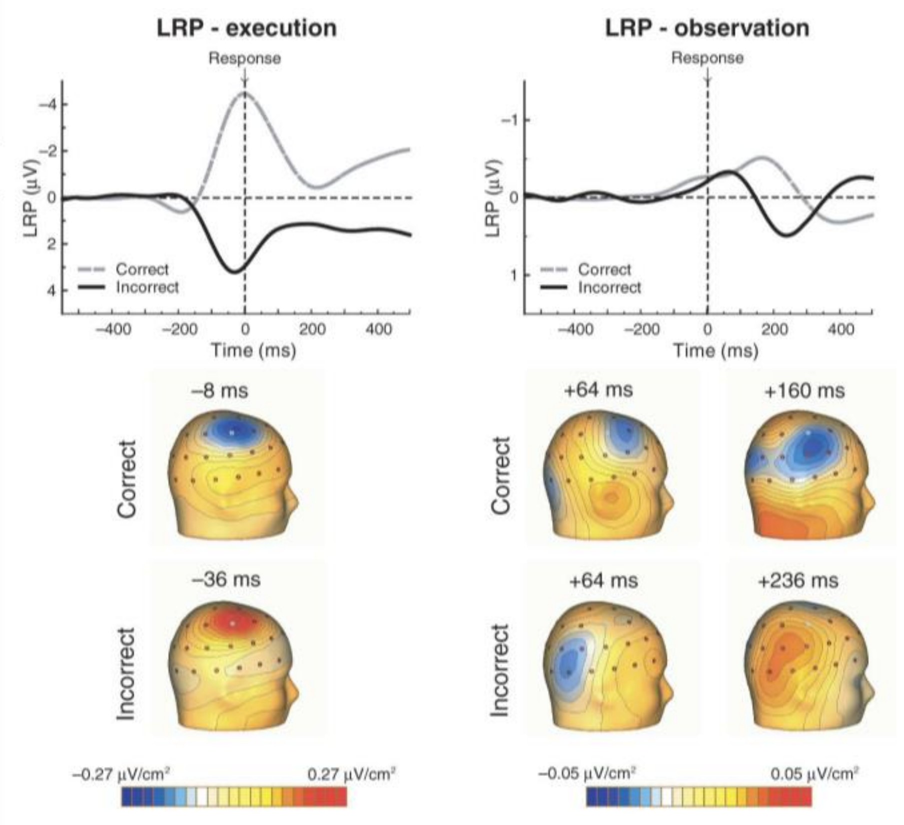


Abstract

The mismatch negativity (MMN) is a brain response to violations of a rule, established by a sequence of sensory stimuli (typically in the auditory domain) [Näätänen R. Attention and brain function. Hillsdale, NJ: Lawrence Erlbaum; 1992]. The MMN reflects the brain's ability to perform automatic comparisons between consecutive stimuli and provides an electrophysiological index of sensory learning and perceptual accuracy. Although the MMN has been studied extensively, the neurophysiological mechanisms underlying the MMN are not well understood. Several hypotheses have been put forward to explain the generation of the MMN; amongst these accounts, the "*adaptation hypothesis*" and the "*model adjustment hypothesis*" have received the most attention. This paper presents a review of studies that focus on neuronal mechanisms underlying the MMN generation, discusses the two major explanatory hypotheses, and proposes predictive coding as a general framework that attempts to unify both.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2671031/

*Participants took part in **two conditions**: an **execution** condition in which they performed a **choice reaction task**, and an **observation** condition in which they observed an experimenter performing the same task.*



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What Is the Readiness Potential?

Aaron Schurger,[1,2,3,4,7,*] Pengbo 'Ben' Hu,[5] Joanna Pak,[2] and Adina L. Roskies[6,7,*]

Abstract

The readiness potential (RP), a slow buildup of electrical potential recorded at the scalp using electroencephalography, has been associated with neural activity involved in movement preparation. It became famous thanks to Benjamin Libet (*Brain* 1983;106:623–642), who used the time difference between the RP and self-reported time of conscious intention to move to argue that we lack free will. The RP's informativeness about self-generated action and derivatively about free will has prompted continued research on this neural phenomenon. Here, we argue that recent advances in our understanding of the RP, including computational modeling of the phenomenon, call for a reassessment of its relevance for understanding volition and the philosophical problem of free will.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8192467/

Benjamin Libet
(1916 – 2007)

***Figure 4 Lateralized readiness potentials**. Top, **response-locked** lateralized readiness potentials in the **execution condition (left)** and the **observation condition (right).** LRPs recorded to correct response trials are indicated by dashed lines in gray, and LRPs to incorrect trials by solid lines in black. Bottom, current source density (CSD) maps of LRP effects in the execution condition (left) and the observation condition (right), for correct and incorrect responses separately. The **C3/C4 electrode over the lateral motor cortex** is marked in light blue for reference. The relevant time-point (relative to the response) is indicated above each map.*

Schie et al., (2004), *https://www.nature.com/articles/nn1239*

The present paper focuses on ERP data recorded during a number of different speeded response tasks, including the [...] color Stroop task, and the ***Go/NoGo task****.*

› Clin Psychol Rev. 2008 Dec;28(8):1343-54. doi: 10.1016/j.cpr.2008.07.003. Epub 2008 Jul 9.

The error-related negativity (ERN) and psychopathology: toward an endophenotype

Doreen M Olvet [1], Greg Hajcak

Affiliations + expand

PMID: 18694617 PMCID: PMC2615243 DOI: 10.1016/j.cpr.2008.07.003

Free PMC article

Abstract

The ERN is a negative deflection in the event-related potential that peaks approximately 50 ms after the commission of an error. The ERN is thought to reflect early error-processing activity of the anterior cingulate cortex (ACC). First, we review current functional, neurobiological, and developmental data on the ERN. Next, the ERN is discussed in terms of three psychiatric disorders characterized by abnormal response monitoring: anxiety disorders, depression, and substance abuse. These data indicate that increased and decreased error-related brain activity is associated with the internalizing and externalizing dimensions of psychopathology, respectively. Recent data further suggest that abnormal error-processing indexed by the ERN indexes trait- but not state-related symptoms, especially related to anxiety. Overall, these data point to utility of ERN in studying risk for psychiatric disorders, and are discussed in terms of the endophenotype construct.

https://pubmed.ncbi.nlm.nih.gov/18694617/

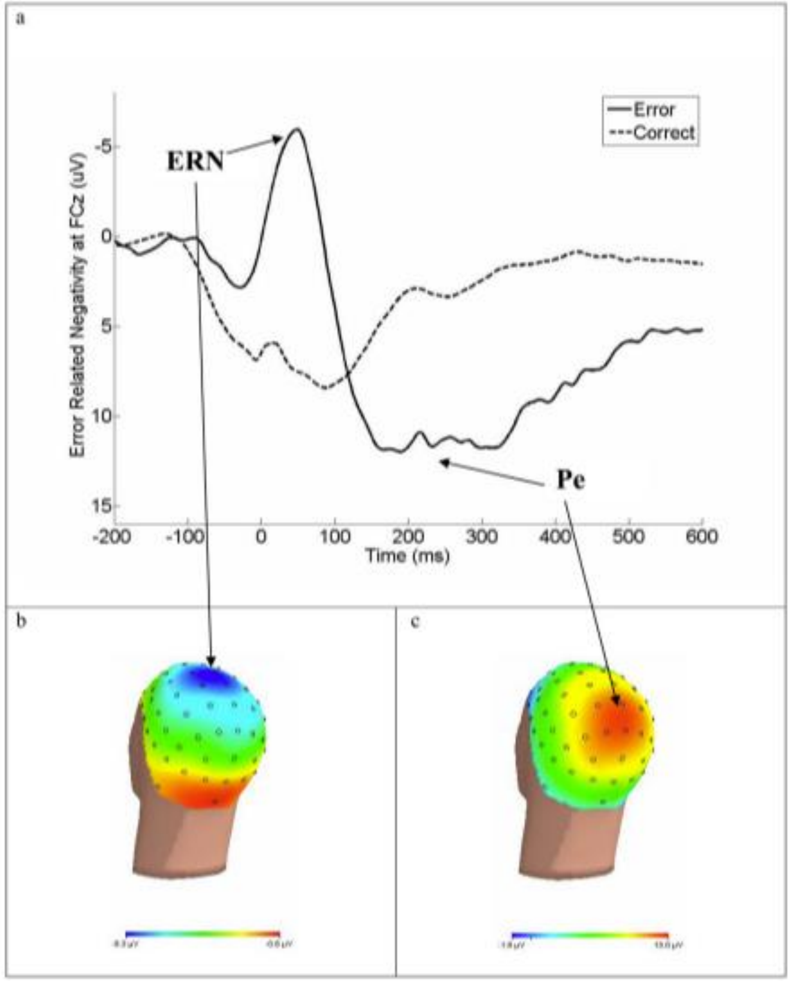


Figure 1.
The response locked ERPs for error and correct trials at FCz, where the ERN was maximal (a). The response onset occurred at 0 msec and negative is plotted up. Scalp topography of error-related brain activity from 0 to 100 msec post-response (b). Scalp topography of error positivity from 200 to 400 msec post-response (c).

J Neurosci. 2011 Apr 20; 31(16): 5891–5892.
doi: 10.1523/JNEUROSCI.0279-11.2011

The Role of the Error Positivity in the Conscious Perception of Errors

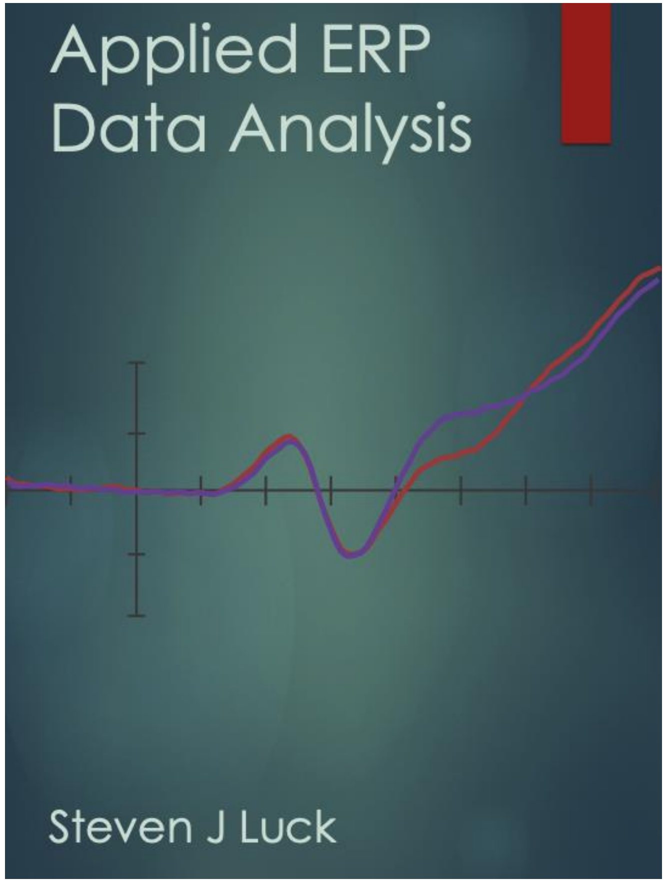
Joseph M. Orr[1] and Melisa Carrasco[2]

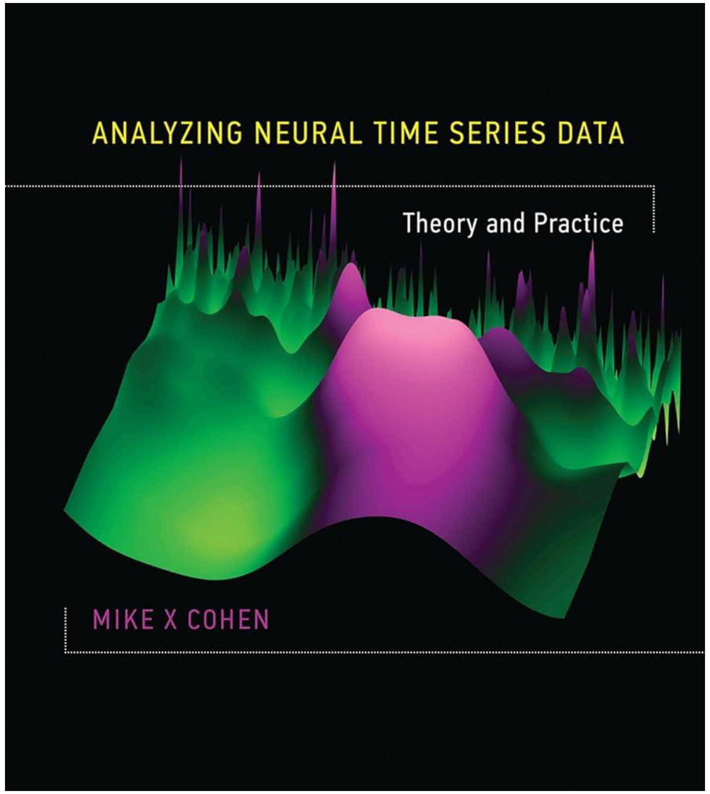
Goal-directed behavior relies on the ability to detect errors and to correct the action(s) that led to the error. Research on error detection really took off with the discovery almost 20 years ago of two event-related potential (ERP) components found within the human EEG: the error-related negativity [ERN; or error negativity (Ne)] and the error positivity (Pe) (Falkenstein et al., 1991; Gehring et al., 1993). The ERN is a negative deflection that peaks ~50–80 ms after an erroneous button press. The Pe is a positive deflection that peaks ~100–200 ms after an erroneous button press. While most research has focused on the role of the ERN in error detection, recent research is beginning to uncover the function of the Pe.

The ERP results indicated that the Pe, but not the ERN, was associated with accumulating evidence of an error. While both ERN and Pe amplitude were larger for detected errors than for undetected errors, only the Pe was larger for correctly signaled errors in the high criterion condition than in the low criterion condition. Thus, only the Pe appeared to reflect the amount of evidence involved in detecting an error. Interestingly, neither component reflected the output of deciding to report that an error was made. Further, Pe amplitude was positively correlated with the extent that participants increased their decision criterion from the low to the high criterion condition. Thus, participants who required more evidence to signal an error in the high (vs low) criterion condition showed a larger Pe on trials where they correctly signaled an error. In addition, the authors modeled Pe data to see how well Pe activity explained error signaling behavior. The model showed that the Pe accurately reflected error signaling accuracy. In addition, the model revealed that, on a single-trial basis, Pe accurately reflected evidence strength.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6632949/

Further resources





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