

A Primer on EEG Reading

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ABSTRACT

Visual EEG analysis remains an indispensable clinical skill, yet its systematic foundations are rarely taught explicitly. This primer conveys the core principles of EEG description and interpretation for clinicians and researchers entering the field. The emphasis throughout is on the physical and physiological basis of the signals. Foundational topics include the structure of an EEG report, the role of age and vigilance, the differential amplifier as the basis of all EEG recording, and the principles of referential and bipolar montages. Beyond the conventional descriptors of amplitude and frequency, the primer introduces *shape* as a third descriptive axis. Two simple symmetries — up/down and temporal — capture it, and their breaking is often what is clinically informative. Such symmetry-breaking can in turn be read as the visible trace of the brain’s nonlinear computation. A short physical detour follows. It traces EEG oscillations to the excitation–inhibition balance from which they arise, and their propagation across the cortex to the local connectivity imposed by evolutionary wiring economy. The cortical sheet thus becomes a medium in which travelling waves act as a real-time carrier of spatiotemporal context. Particular attention is then given to phase reversal — arguably the most important concept in visual EEG localisation — including its four subtypes and their clinical significance. The primer concludes with an outlook toward quantitative EEG analysis. The spatial organisation of cortical signals, understood through cortical eigenmodes, carries clinically relevant information that visual analysis alone cannot access. The text is intended as a companion to independent EEG study, not a substitute for it, and will be updated as the field develops.

Keywords: *electroencephalography; visual EEG analysis; waveform shape; cortical travelling waves; excitation–inhibition balance; cortical eigenmodes; phase reversal; epileptiform signals; referential and bipolar montages*

1 Why This Primer?

Reading and visually analysing EEGs combines systematic methodology with pattern recognition. In the beginning, the systematic approach dominates; as experience grows, automatic pattern recognition gradually takes over. There is no shortcut to developing this pattern recognition: it emerges from independently studying a large number of EEG recordings — including long-term EEGs covering different states of vigilance.

Since experience is irreplaceable, it is all the more worthwhile to internalise the learnable, systematic aspects early. Equally important is an understanding of the physiological and physical principles underlying EEG signal generation. For this, I recommend the classic work of Nunez and Srinivasan (Nunez and Srinivasan 2006) and the newly published book by Halmes et al. (Halmes et al. 2024). Without this foundation, visual EEG analysis quickly degenerates into mere “wiggle-ology” — which is ultimately unsatisfying. A solid grounding in the fundamentals also makes it easier to appreciate quantitative EEG methods later on.

This primer conveys the most important principles and concepts for EEG description and visual analysis — without claiming to be exhaustive. As supplementary reading, I recommend the books by Greenfield et al. ([Greenfield 2021](#)) and Ebersole et al. ([Ebersole 2014](#)), as well as an EEG atlas ([Zumsteg 2004](#); [Rossetti 2008](#); [Stern 2013](#)). For modern accounts of the neurophysiology of the central nervous system, the books by Fröhlich ([Fröhlich 2016](#)) and Buzsáki ([Buzsáki 2019](#)) are highly recommended; for further and more speculative ideas, those by Nicolelis ([Nicolelis 2020](#)) and Cicurel/Nicolelis ([Cicurel and Nicolelis 2015](#)). The neurophysiological basis of the EEG signal is further illuminated by Buzsáki et al. ([Buzsáki, Anastassiou, and Koch 2012](#)), Fröhlich et al. ([Fröhlich and McCormick 2010](#)), and Beenhakker et al. ([Beenhakker and Huguenard 2009](#)). The fundamental role of neuronal oscillations in cortical networks is laid out in an influential review by Buzsáki and Draguhn ([Buzsáki and Draguhn 2004](#)).

A note on navigation: key technical terms appear as clickable links on first use in each section, jumping to the Glossary at the end of the document. To return to where you were reading, use your PDF viewer's back navigation — Alt+- in most viewers, ⌘+[on Mac. Glossary entries link forward to the section that treats each term in depth.

2 Structure of an EEG Report

An EEG report — like many other medical reports — is organised into three parts. The first part lists the most relevant clinical information: in particular, the level of vigilance and any centrally active medications. It should also include a clearly formulated clinical question that the recording is intended to answer. If the referring clinician has not posed a question, it is worth asking — or formulating one yourself, for example: “Query: [epileptiform signals](#).” An explicit clinical question makes it easier to write a focused conclusion in the third part.

The second part contains the description of the EEG signals. One central principle applies here: **description and interpretation must be kept separate**. Terms such as “[spike](#)” or “[sharp wave](#)” have no place in the descriptive section — they are already interpretations. Instead, the observable features are listed, for example: “sharply contoured, rising more steeply than falling, approximately 90 ms duration between the first zero-crossings, surface-negative, followed by a slow wave at approximately 1 Hz.” The interpretation — for instance as “epileptiform” — belongs only in the third part.

The third part is the conclusion: a brief, interpretive answer to the clinical question of part one, grounded in the descriptive findings of part two. The reasoning that links observation to interpretation should be transparent — a colleague reading the report should be able to see how the description supports the conclusion.

The sections that follow take up the most important elements of EEG reading in turn.

3 Before You Look: Age and Vigilance

When first looking at an EEG recording, it helps to know only two things: the patient's age and their level of [vigilance](#) — that is, where they sit on the wakefulness–sleep–coma continuum. Neither can be determined from the EEG itself with certainty.

Additional clinical details should be deliberately withheld at first, to avoid unconscious bias.

A telling example: knowing that a patient has a tumour in the left temporal lobe increases the likelihood of “seeing” a focal slowing in that region — regardless of whether it is actually present. Such subtle patterns that only become apparent through prior knowledge are often a sign of “over-reading,” or over-interpretation.

Misinterpretation of EEG signals can have serious consequences. If epileptiform signals are described where none exist, this may lead to unnecessary treatment with anti-seizure medications — along with their side effects. Compounding the problem is the fact that earlier reports cannot easily be corrected. In typical clinical practice, only the written report of a previous EEG is available; the raw recording is rarely re-examined, even when archived. A subsequent normal EEG cannot then retroactively cancel an earlier abnormal report. The EEG is a dynamic signal that depends strongly on vigilance, medications, and other state-dependent factors. In epilepsy, this dynamism extends further still: chronic EEG recordings have revealed that epileptic brain activity follows cycles at multiple timescales — circadian, multidiurnal (over days), and even circannual — which modulate seizure risk over time (Baud et al. 2020). A normal recording today is fully compatible with a genuinely pathological one weeks earlier. In this respect, a misinterpreted EEG report carries more weight than a misinterpreted MRI report. A follow-up MRI that is structurally normal provides much stronger reassurance, because the MRI is anchored to largely stable anatomy: no lesion now strongly suggests no lesion before. The EEG offers no such structural anchor.

4 Background Activity

A systematic approach helps greatly in visual EEG analysis. The first step is typically to describe the so-called “background activity”: the dominant frequency and the peak-to-peak amplitude of the signals over the occipital regions in a waking patient with eyes closed.

If the patient is comatose rather than awake, “background activity” is no longer apt; a neutral phrase like “predominant frequency and amplitude” is preferable. In general, frequency is more informative than amplitude — unlike amplitude, it is not affected by electrode or skin contact impedance.

5 A Note on the Word “Activity”

The term “activity” is firmly established in the EEG community — for instance in compounds such as “background activity.” It is not, however, uncontested. Paul Nunez, one of the pioneers of quantitative EEG research, has pointed out that the term has never been clearly defined and therefore remains imprecise.

As an alternative, I prefer the term “EEG signal.” It is more neutral and more precise — and can be clearly defined. The English-language Wikipedia puts it as follows:

*In signal processing, a **signal** is a function that conveys information about a phenomenon. In electronics and telecommunications, it refers to any time-varying voltage, current or electromagnetic wave that carries information.*

Some authors put it even more succinctly:

To put it very generally, a signal is any time-varying physical quantity. (Sinha 2014)

6 The Shape of EEG Signals

The previous sections introduced two basic descriptive parameters: amplitude and frequency. A third — *shape* — is implicit in everything we’ve discussed but rarely named as a primary descriptive axis. It deserves to be.

Beyond the familiar symmetry between hemispheres, EEG signals also have symmetries of shape — between excursions above and below the baseline, between rising and falling slopes, between the leading and trailing parts of an event — and the breaking of these symmetries is often what’s clinically informative (Schindler et al. 2011).

The simplest possible signal is a pure sine wave, which has two symmetries that come for free. *Up/down symmetry* is the property that the wave’s peaks above baseline match its troughs below baseline in magnitude — equivalently, the largest positive excursion equals the largest negative excursion in size. The distinction matters: up/down symmetry is about *amplitudes*, not about the wave being identical when flipped vertically. Flipping a sine wave vertically simply gives back a shifted sine wave (since $-\sin(t) = \sin(t + \pi)$), with peak magnitudes preserved — and that preservation is what up/down symmetry names. *Temporal symmetry* (or *left/right symmetry*, if you imagine the trace running across the page) is the property that each peak and trough has matching rising and falling slopes — locally, the wave looks the same near a peak or trough whether traversed forward or backward in time. Most EEG signals — and all the clinically interesting ones — depart from sine-wave shape by breaking one or both of these symmetries (Cole and Voytek 2017).

The four combinations are visible at a glance (Figure 1): a pure sine, each symmetry broken alone, and both broken in the canonical epileptiform morphology. Real clinical events tend to live in the “both broken” cell.

When you next look at a trace, two perceptual habits will let you read its shape rather than just its amplitude and frequency. First, scan for asymmetric excursions around the baseline — sharper one way than the other. Second, scan for asymmetric morphologies in time — events whose rising slope differs in shape from their falling slope. The characteristic features of epileptiform signals (steep rise, slower fall, asymmetric slow after-wave) are special cases of both checks at once.

Naming the two symmetries also sharpens description. “Sharp upgoing transient with a slower downgoing limb” picks out a specific pattern of broken symmetries; so does “rhythmic alpha with preserved up/down balance.” Trading vague impressions for an explicit shape vocabulary makes findings easier to compare across readers, easier to dictate into reports, and easier to revisit weeks later when the trace itself is no

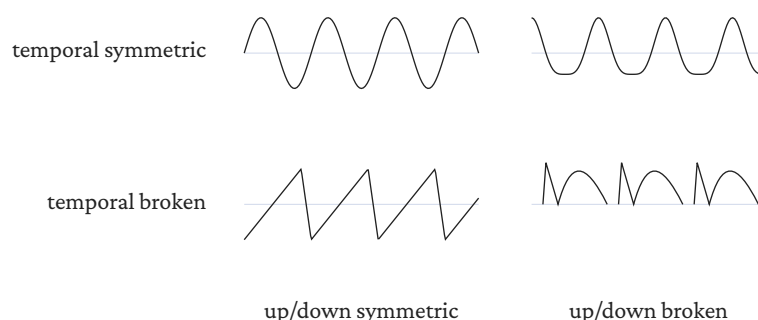


Figure 1. Two ways the shape of an EEG signal can depart from a pure sine wave. *Top-left:* a pure sine has both up/down symmetry (peaks above baseline match troughs below in magnitude) and temporal symmetry (each peak and trough has matching rising and falling slopes). *Top-right:* sharper positive peaks with broader, shallower negative troughs break up/down symmetry; each individual excursion is still mirror-symmetric in time. *Bottom-left:* slow rise with fast fall — a morphology often seen at seizure onset — breaks temporal symmetry; the up and down excursions remain equal in magnitude. *Bottom-right:* a brief run of three spike-and-wave signals breaks both symmetries — steep rise and slower fall of each spike (temporal), each followed by a smaller slow wave in the same upward direction (up/down).

longer in front of you. The language one has for what one sees becomes part of what one sees.

7 Why Shape Matters: A Glimpse of Computation

Shape is clinically informative, but why should it be informative at all? A short detour into what shape implies about the underlying machinery is worth making, both because it sharpens reading intuition and because it points to a deeper reason the EEG looks the way it does.

A pure sine wave is the signature of a *linear* system — one whose output scales smoothly with its input and in which separate frequencies pass through without interacting. Linear systems are useful — the cables and amplifiers in the recording chain are deliberately built to be as linear as possible — but they cannot do much computationally: whatever frequencies enter, the same frequencies come out, just at different sizes. A brain that worked like that could mirror its inputs, or filter them, but could not combine them into anything new.

Real neural tissue is not linear. Neurons and neuronal assemblies threshold, saturate, fatigue, and interact in many small ways that all amount to the same thing: when two signals enter together, the response is not just their sum. Frequencies mix and produce new frequencies — sums, differences, and harmonics that were not there before. This mixing is precisely what the brain needs in order to do non-trivial computation: to take separate streams of information and combine them into something whose meaning depends on *how* they combine, not just on what is present in isolation. A linear brain could not distinguish a melody from its scrambled notes; a nonlinear brain can, because in a nonlinear system the combination of inputs leaves a different signature in the output than the inputs themselves do (Khaner 2009).

The relevance for clinical reading is direct. The very departures from sine-wave shape that we have just learned to look for — asymmetric peaks, asymmetric slopes, sharp transients followed by slower waves — are the visible trace of the brain's nonlinear machinery doing something. When that machinery is working, the EEG is full of these

shape signatures. When it is constrained — as in some forms of [hypersynchronous activity](#) seen in certain phases of epileptic seizures, in deep anaesthesia, or in some encephalopathies — part of what is being lost is precisely the shape complexity that nonlinear computation generates. Seizures in particular are highly heterogeneous and non-stationary, and few traces ever approach the mathematical limit of a pure sinusoid; but the broad direction of travel toward simpler, more symmetric, more redundant patterns is itself a visible signature of reduced computational complexity ([Schindler et al. 2007](#)).

This raises an apparent paradox. Epileptiform signals are among the most asymmetric features in any EEG — strongly broken in both the up/down and the temporal sense. If symmetry-breaking is the visible trace of nonlinear computation, would they not then be the hallmark of cortical computation at its richest? They are not, and seeing why points at something deeper. What computation requires is not nonlinearity in the absolute, but nonlinearity in a particular regime — rich enough to mix and recombine inputs, but not so dominant that the system collapses into a few stereotyped patterns. Epileptiform signals break symmetry powerfully, but they break it the same way every time. Normal cortical activity breaks it differently every moment, and that constant variation is what carries information forward. There is, in this sense, an optimal range of nonlinearity ([Beggs and Plenz 2003](#)); the EEG signs of operating outside it run in both directions — too quiet (deep anaesthesia, burst suppression) and too uniform (hypersynchrony) are equally hostile to computation.

You do not need any of this physics to read an EEG well. But it can help to remember, when a wave looks unusual, that “unusual shape” and “the brain is doing something computationally interesting” are often two descriptions of the same fact. The next section asks where the oscillations themselves come from — and what they carry once they begin to travel across the cortex.

8 Where Waves Come From, and What They Carry

We have looked at shape and at the nonlinear computation it hints at. Two questions are still open. Why does the cortex produce waves at all? And once it produces them, do those waves do anything beyond what we can read off a single channel?

A restoring force, inertia, and an oscillation. Waves require three ingredients: a medium that can be displaced from its resting state, a *restoring force* that pulls the displaced medium back, and *inertia* — the property that makes the medium overshoot equilibrium rather than relaxing smoothly to it. A guitar string oscillates because string tension restores it when plucked, and its mass carries it past the resting position. A pendulum oscillates because gravity pulls it back when pushed, and the bob’s inertia keeps it swinging through. A mass on a spring oscillates because the spring restores it, and the mass keeps moving when the spring is at rest length. Without inertia, displacement would simply relax to equilibrium — no oscillation. With it, the system overshoots, and displacement is converted into the cyclic exchange between potential and kinetic energy that we call an oscillation.

The cortex has both. Its restoring force is the *excitation–inhibition balance*: when excitatory pyramidal neurons grow more active, they recruit local inhibitory interneurons, which dampen the excitation. As inhibition takes hold, excitation is released to rise again. This balance has long been suspected on theoretical grounds; it is now

directly demonstrated in ensemble recordings from human and monkey neocortex, where excitatory and inhibitory populations track each other across all states of the wake–sleep cycle, with only small instantaneous deviations from balance. Strikingly, the only state in which the balance collapses is the epileptic seizure (Dehghani et al. 2016). The cortical analogue of inertia is more subtle but just as essential: excitation and inhibition operate on different time constants, with inhibition lagging behind excitation. By the time inhibitory interneurons have built up enough to suppress excitation, excitation has already grown past the level that triggered the response; inhibition then overshoots in turn, suppressing excitation below its resting level. This delay plays the same mathematical role that inertia plays in mechanical systems: it prevents excitation and inhibition from settling into a static balance and forces them to oscillate around it instead.

From balance to waves

Excitation and inhibition pull against each other like two opposing springs — but inhibition acts on a slower clock. Excitation overshoots before inhibition can catch up, and inhibition overshoots in turn. The result is not a static standoff but an oscillation — and oscillation is the substrate of every rhythm visible in the EEG.

Waves that travel. So far we have spoken as if the wave lived at one electrode. But waves in a coupled medium *travel*: a pluck on a string does not stay where it was made, it propagates. The cortex is such a medium, and it is worth pausing on why. Most cortical connections are short, only a few millimetres long — long-range axons are metabolically expensive both to build and to drive with action potentials, and the brain has been under strong evolutionary pressure to economise on wiring and traffic (Laughlin and Sejnowski 2003). And as vertebrate brains grew larger over evolutionary time, this pressure became sharper still: preserving uniform connectivity in a bigger brain would have made wiring and energy costs scale explosively, forcing larger brains to become progressively more locally and modularly wired (Striedter 2006). The activity of any small patch is therefore shaped above all by how it compares to its immediate surroundings. This is the same kind of local coupling that lets a drumhead vibrate: each point is tugged toward the average of its neighbours, and the resulting tug-of-war propagates as a wave. A familiar consequence is that slow rhythms, having time to recruit larger cortical areas, engage large patches and reach correspondingly large amplitudes, while faster rhythms tend to stay more local (Buzsáki and Draguhn 2004). A deeper consequence is structural: a medium of this kind has its own preferred patterns of motion — its resonant modes — set jointly by the local connectivity and the geometry of the cortical sheet. A drum has its modes; the cortex has them too. We will meet these *cortical eigenmodes* again in the closing section.

Once one looks for travelling waves on this medium, one finds them: in visual, motor, and prefrontal cortex; in the hippocampus during exploration and sleep; in scalp and intracranial recordings of the human brain across waking and sleep states (Muller et al. 2018). They are not pathological signs. They are part of normal cortical processing.

Waves as context. Why should the cortex bother to send waves across itself? A useful contemporary analogy comes from the machine-learning systems behind today's large language models. A *transformer* handles a sentence by taking the entire sequence of words at once and mapping it into a single high-dimensional encoding vector —

the temporal structure of the input becomes a spatial pattern, and an operation called *self-attention* then reads out relations across that pattern. Sensory inputs to the brain, however, arrive one fixation, one syllable at a time. How could the cortex implement anything similar in real time?

The proposal is that travelling waves do exactly this. Each input creates a wave that fans out across the cortical surface; subsequent inputs create waves of their own. The state of the cortex at any moment is therefore not just a snapshot of the present input — it carries the recent past, written into space as a pattern of overlapping wave fronts. A downstream region looking at this pattern can read off what arrived, where, and in what order: the same *spatiotemporal context* a transformer extracts from its encoding vector (Muller, Churchland, and Sejnowski 2024).

This idea fits a broader theoretical framework. The cortex’s dense recurrent connectivity makes the entire network a high-dimensional, non-linear dynamical system: an input does not just produce a brief response, it perturbs an ongoing dynamics, and that perturbation lingers. Like ripples on a pond struck by successive raindrops, the state of the medium at any moment carries a fading trace of recent inputs. Singer and Lazar (Singer and Lazar 2016) have argued that the cortex exploits this high-dimensional state space directly — stimuli that are difficult to tell apart on arrival become easy to separate once projected into it, and sequences are integrated by the medium itself. Travelling waves are one visible expression of this dynamics; the transformer analogy names one thing it is good for.

For the EEG reader, the consequence is concrete. The squiggles on the screen are not a cacophony to be tolerated until the next epileptiform signal. They are the surface expression of a medium in which the brain is actively computing — and that computation is partly carried by where, in space, the activity sits and how it propagates. Phase reversal, taken up next, is the first concrete tool for reading that spatial dimension — symmetry-breaking across electrodes rather than within a single channel.

9 Phase Reversal

“Phase reversal” is one of the most important concepts in visual EEG interpretation. Understanding it requires a brief detour.

Correctly localising epileptiform signals matters clinically. Such signals typically exhibit the following features — though in practice, not all need to be present simultaneously:

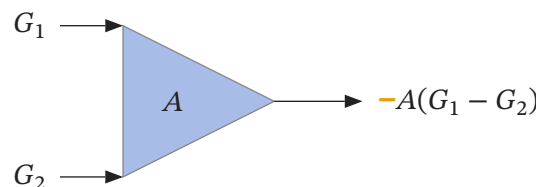


Figure 2. The differential amplifier — the basic element of every EEG channel. Each amplifier takes two inputs (G_1 and G_2) and outputs their difference scaled by the gain A . The leading minus sign (orange) is the EEG polarity convention: when G_1 is more negative than G_2 , the output deflects upward. Subtracting the inputs also rejects common-mode interference — mains hum, distant muscle activity, and other artefacts that appear nearly identically at both electrodes cancel, leaving only the small brain-electrical signal.

Characteristics of Epileptiform Signals

1. High amplitude relative to the surrounding signal
2. Surface-negative
3. Sharply contoured
4. Asymmetric: steep rising, slower falling slope
5. Bi- or polyphasic
6. Followed by a slow after-wave
7. Brief duration: 20–200 ms

First, a word on “phase”: in the context of visual EEG analysis, it refers to a signal deflection in one direction — either upward or downward. Informally, a phase can be thought of as the portion of a signal between two zero-crossings, or between two inflection points that bracket a peak or trough. A “phase reversal” then refers to two opposing, anticorrelated deflections occurring simultaneously in adjacent channels.

The typical [surface-negativity](#) of epileptiform signals is explained by the dipole model: when many cortical pyramidal neurons fire synchronously, positive ions (Na^+ , Ca^{2+}) flow into the [apical dendrites](#). To compensate, positive ions exit the cell in the region of the cell bodies, which lie deeper in the cortical layers. This creates an extra-cellular charge dipole: a negative pole near the scalp electrodes, and a positive pole at depth. This accounts for the surface-negativity.

An important caveat

Epileptiform signals are characteristically surface-negative — but not every surface-negative signal is epileptiform.

How are such signals localised in the EEG? This depends on the montage used. As a general principle: voltage can only ever be measured between two electrodes — analogous to hydrostatic pressure, which is always expressed relative to a reference level. In a [referential montage](#), the second electrode is placed outside the signal field; in a [bipolar montage](#), both electrodes lie over the region of interest.

Key principle — referential montages

In referential montages, maxima of the electric field appear as large amplitudes.

The situation is different for bipolar montages: both electrodes lie over the signal-generating region, and localisation is achieved by identifying a phase reversal.

Key principle — bipolar montages

In bipolar montages, maxima of the electric field appear as phase reversals.

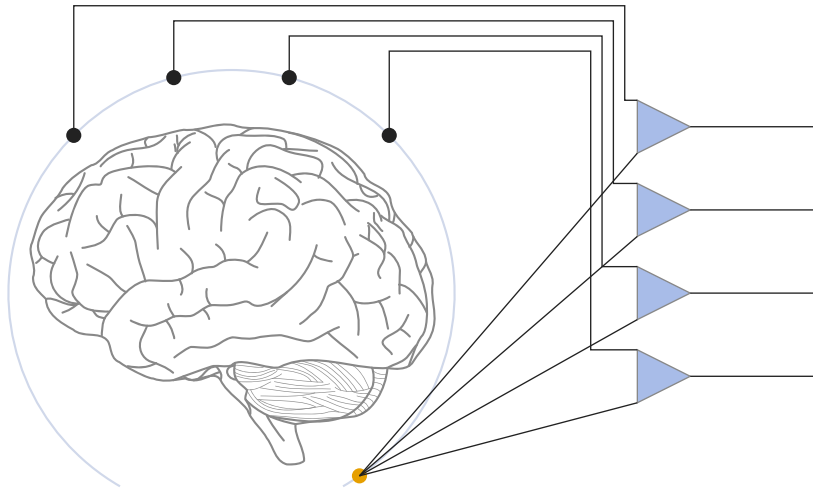


Figure 3. The referential montage. Each scalp electrode is amplified against a single common reference (orange), here at a nape position (mastoid or earlobe are equally common). Each amplifier output is the potential difference between its scalp electrode and the reference.

A reminder

Epileptiform signals characteristically produce a narrow negative phase reversal in bipolar montages — but not every narrow negative phase reversal is epileptiform.

The positive pole of a dipole generates a positive phase reversal. This is usually not recorded in scalp EEG, as no electrodes are placed over the corresponding region (face, chin). In intracranial recordings, however, both types of phase reversal are frequently seen — as in the example shown in [Figure 8](#), with depth electrodes from a region of cortical dysplasia.

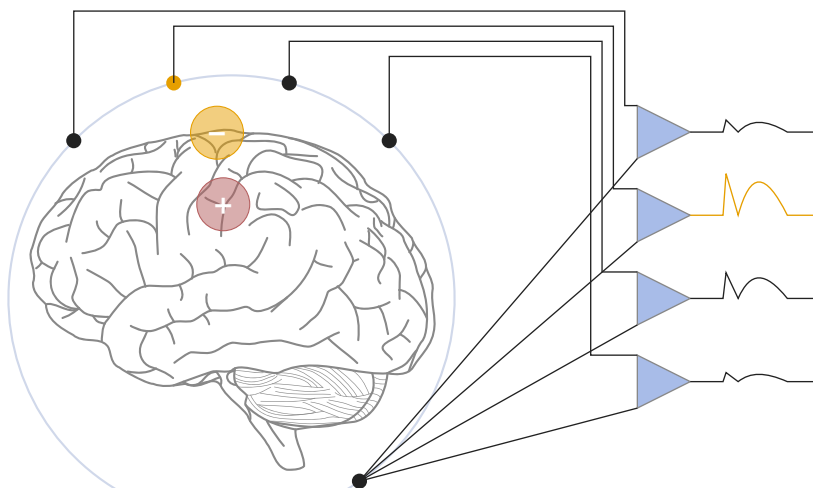


Figure 4. Recording with a referential montage in the presence of a cortical dipole. The dipole's negative pole (orange) sits just under the scalp, oriented toward the surface; its positive pole lies deeper in cortex. The channel whose electrode (orange) sits closest to the negative pole records the largest amplitude deflection (orange spike); deflections at other channels scale with proximity to the field maximum. Each output shows a sharp spike followed by a rounder, slower wave — a stylised focal epileptiform signal.

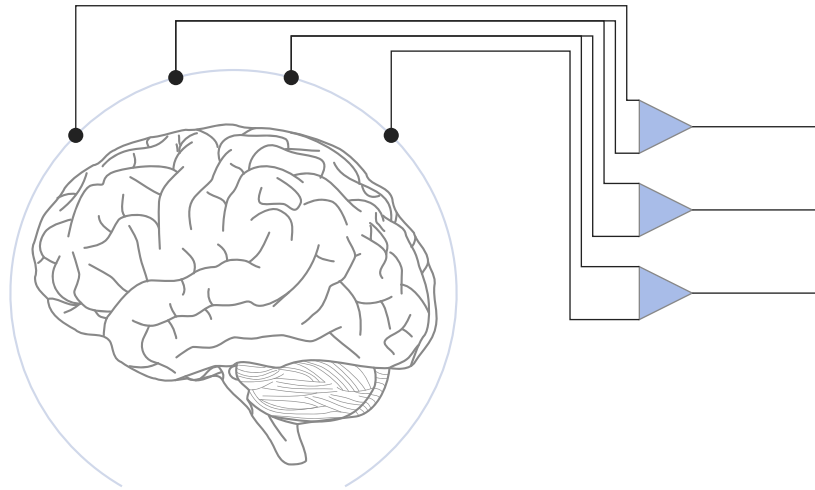


Figure 5. The bipolar montage. Each amplifier takes its two inputs from adjacent scalp electrodes; interior electrodes are shared between successive amplifiers, forming a chain along the head. Unlike the referential montage, all electrodes lie over the region of interest — there is no distant reference. The output channels are flat at rest.

10 Two Less Common Phase Reversal Patterns

Two further patterns extend the basic picture sketched so far. Each is less common than the canonical narrow negative phase reversal in a bipolar montage, but each is worth recognising.

The first is phase reversal in a referential montage, which can arise for two distinct reasons. The most common is a poorly chosen reference electrode: if the reference is not positioned outside the signal field, it will pick up the signal of interest — violating the basic assumption of the referential montage and producing an apparent phase reversal where the underlying dipole geometry alone would not have generated one. The second reason is the geometry of the source itself. A dipole oriented horizontally

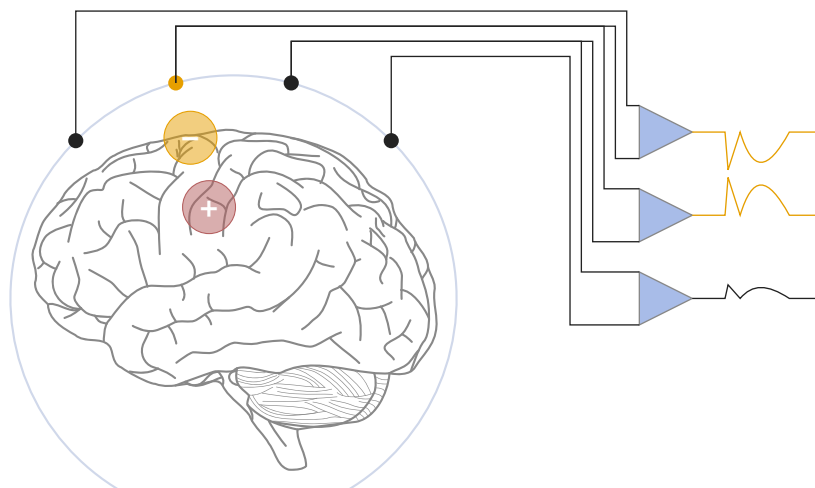


Figure 6. The bipolar montage during a focal epileptiform signal — a narrow negative phase reversal. The dipole's negative pole (orange) sits just under e2 (orange); the field maximum is therefore at e2. Because e2 is the (–) input of amp1 and the (+) input of amp2, those two channels deflect in opposite directions at equal amplitude (both orange), pointing at each other across e2 — and that is what localises the maximum. Amp3 carries a smaller residual gradient between e3 and e4.

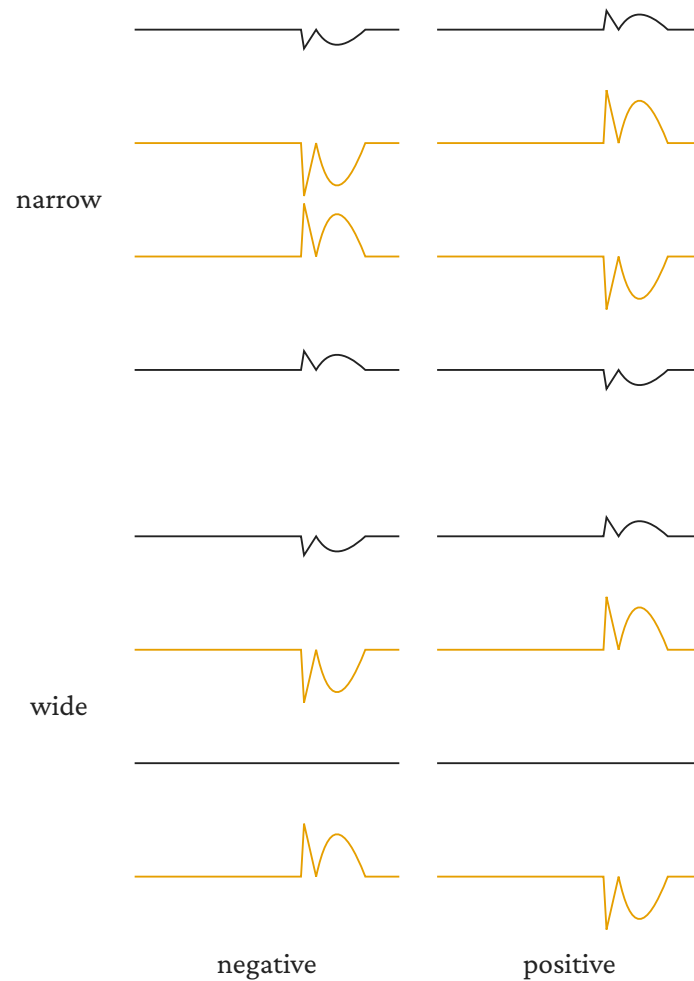


Figure 7. The four types of phase reversals — narrow vs wide (rows) and negative vs positive (columns). The two orange channels in each cell form the reversal pair. In narrow reversals (top row), the field maximum is at a single electrode that the orange channels share; their deflections point toward (negative) or away from (positive) each other across that electrode. In wide reversals (bottom row), the maximum lies between two electrodes — the channel comparing them is silent, and the reversing pair flanks that silent channel. Clinically the most significant pattern is the narrow negative phase reversal (top left) — the canonical signature of a focal cortical signal with surface negativity.

— its axis parallel to the cortical surface rather than radial — places its negative and positive poles under different scalp regions, so anterior and posterior electrodes lie over different polarities even with a perfectly chosen reference. The deflections

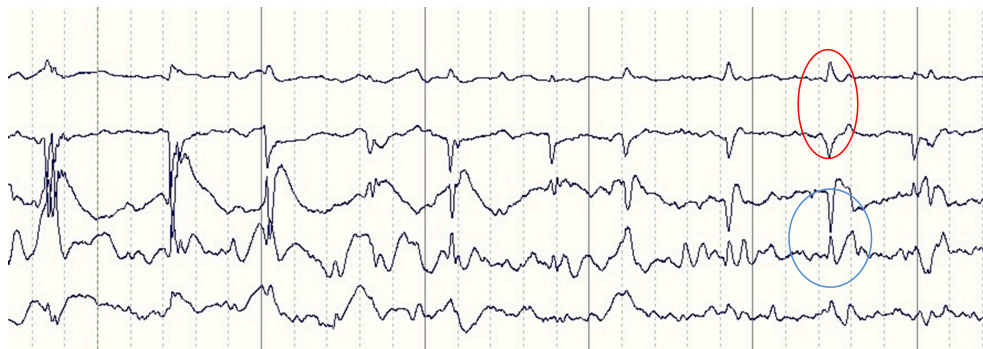


Figure 8. Narrow positive (red) and negative (blue) phase reversals in close proximity — indicating a spatially very focal dipole.

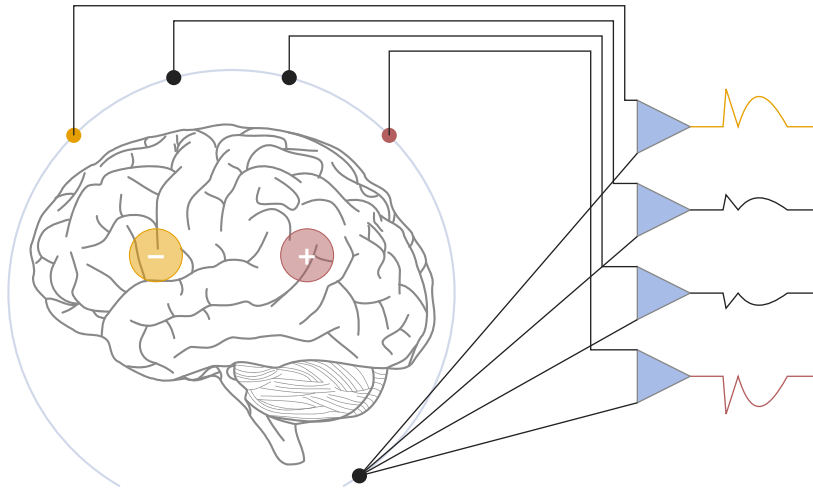


Figure 9. A horizontally oriented dipole — its axis parallel to the cortical surface rather than radial — produces an apparent phase reversal even in a referential montage. The anterior electrode (orange) lies over the negative pole and its channel deflects upward; the posterior electrode (red) lies over the positive pole and its channel deflects downward. The two middle channels carry the field gradient in between. This pattern occurs, for example, in Rolandic epilepsy (cf. [Figure 8](#)).

oppose each other, producing a phase reversal that is not an artefact of the wiring but a real consequence of source geometry ([Figure 9](#)).

The second pattern is the rare positive phase reversal at the scalp in a bipolar montage. As noted earlier, every cortical dipole has both a negative and a positive pole, but scalp recordings typically capture only the negative pole — because no electrodes are placed over the regions onto which the positive pole projects (face, chin). Orbitofrontal cortex is a clinically important exception: its surface faces caudally, so the cortical dipole is inverted relative to convex cortex — the positive pole points toward the scalp electrodes, the negative pole away from them. In a bipolar chain over the anterior frontal region, an orbitofrontal spike then appears as a *positive* phase reversal, the deflections pointing away from each other across the field maximum ([Figure 10](#)) — mirror image of the canonical negative case. It is the only common scalp manifestation of the positive phase reversal phenomenon that is otherwise visible mainly in intracranial recordings (cf. [Figure 8](#)).

11 Reading from Large to Small

A practical tip for difficult recordings: work from the “large to the small.” First, survey the entire EEG and divide it broadly into meaningful segments — both in time and space. With lateralised changes, it can help to describe left- and right-sided signals as separate groups. With temporally heterogeneous recordings — for example, during emergence from pharmacological coma, or before and after administration of anti-seizure medication in non-convulsive status epilepticus — dividing the recording into distinct time periods is a useful strategy.

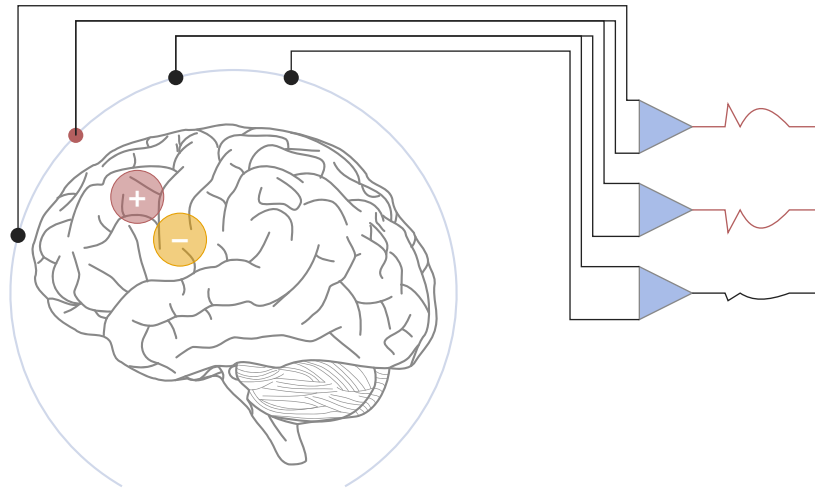


Figure 10. The bipolar montage during a focal orbitofrontal epileptiform signal — a positive phase reversal. Because the orbitofrontal cortex faces caudally toward the orbital floor, its cortical dipole is inverted relative to convex cortex: along the radial line through e2, the positive pole (red) sits at the outer end (toward the scalp), while the negative pole (orange) sits deeper on the same radial line and is not picked up at the scalp. The field maximum at scalp is therefore positive and sits at e2 (red). Because e2 is the (−) input of amp1 and the (+) input of amp2, those two channels deflect in opposite directions at equal amplitude (both red), pointing away from each other across e2 — the mirror image of the canonical negative phase reversal in [Figure 6](#). Amp3 carries a smaller residual gradient between e3 and e4. Amplitudes are smaller than in [Figure 6](#) because the orbitofrontal generator lies further from the recording electrodes than a typical convex-cortex generator.

12 Outlook

Visual EEG analysis is an indispensable clinical skill — and the necessary first step toward a deeper understanding of brain electricity. It has an inherent limit, though: the eye captures only a small slice of the data at a time — individual channels, brief time windows. Yet no EEG signal at a single electrode can be fully understood in isolation: it is the local expression of a spatially extended cortical field — with [cortical eigenmodes](#) as its physical basis ([Nunez and Srinivasan 2006](#); [Müller et al. 2022](#)). The correlation structure across many channels simultaneously — the spatial organisation of EEG activity — carries clinically important information that visual analysis alone cannot access ([Schindler et al. 2007](#)). Quantitative EEG analysis methods aim to capture precisely this spatial dimension and represent an active field of research. The foundations conveyed here are the first and necessary step along that path.

13 Glossary

Apical dendrite The long, vertical dendrite of a cortical pyramidal neuron, oriented perpendicular to the cortical surface. Synchronous current flow into apical dendrites is what creates the cortical dipole detectable in scalp EEG. See [§ Phase Reversal](#).

Background activity The dominant frequency and peak-to-peak amplitude of the EEG signal over the occipital regions in a waking patient with eyes closed — the starting point of every visual EEG description. See [§ Background Activity](#).

Bipolar montage A wiring scheme in which adjacent electrodes are paired in chains, with both members of each pair lying over the region of interest. Maxima of the electric field appear as phase reversals. See [§ Phase Reversal](#).

Common-mode rejection The property of differential amplification by which signals appearing nearly identically at both inputs (mains hum, distant muscle activity) cancel out, while genuine voltage differences between the two inputs are preserved and amplified. *See § Phase Reversal.*

Cortical dipole The extracellular charge separation produced when many cortical pyramidal neurons fire synchronously: a negative pole near the scalp electrodes and a positive pole at depth. The physiological basis of EEG signal generation. *See § Phase Reversal.*

Cortical eigenmode A spatial pattern that arises naturally from the geometry and connectivity of the cortex, providing a physical basis for understanding spatially extended EEG signals. A framework underpinning quantitative spatial EEG analysis. *See § Outlook.*

Differential amplifier The basic building block of every EEG channel. It receives two input voltages, computes their difference, and amplifies the result, while rejecting signals common to both inputs. *See § Phase Reversal.*

Epileptiform signal A waveform whose constellation of features suggests origin from epileptic neuronal activity: high amplitude, surface-negativity, sharp contour, asymmetric slopes (steep rise, slower fall), bi- or polyphasic, often followed by a slow after-wave, and brief duration (20–200 ms). *See § Phase Reversal.*

Hypersynchronous activity A state in which large populations of neurons fire in step, producing simpler, more rhythmic, and more redundant traces with reduced shape complexity. Can occur in certain phases of epileptic seizures, in deep anaesthesia, and in some encephalopathies. *See § Why Shape Matters: A Glimpse of Computation.*

Phase In visual EEG, a signal deflection in one direction — informally, the part of the signal between two zero-crossings, or between two inflection points that bracket a peak or trough. *See § Phase Reversal.*

Phase reversal Two opposing, anticorrelated deflections occurring simultaneously in adjacent channels. In bipolar montages, this is how maxima of the electric field are localised. *See § Phase Reversal.*

Referential montage A wiring scheme in which each recording electrode is paired with a single common reference electrode placed outside the signal field. Maxima of the electric field appear as large amplitudes. *See § Phase Reversal.*

Sharp wave An epileptiform signal with somewhat longer duration than a spike (70–200 ms). Like *spike*, the term is interpretive and belongs in the conclusion, not the description. *See § Phase Reversal.*

Slow after-wave A slow (typically 1 Hz) deflection that follows an epileptiform spike or sharp wave. Its presence is one of the defining features of epileptiform signals. *See § Phase Reversal.*

Spike An epileptiform signal with very brief duration (typically 20–70 ms). The lower bound helps distinguish spikes from muscle artifacts, which on non-invasive (scalp) EEG are typically shorter than 20 ms. The term is interpretive and belongs in the conclusion, not the description. *See § Phase Reversal.*

Surface-negative A scalp-recorded signal whose voltage is more negative than the reference. Epileptiform signals are characteristically surface-negative — but not every surface-negative signal is epileptiform. *See § Phase Reversal.*

Transformer A neural-network architecture introduced in 2017 that handles sequences — sentences, time series — by taking the whole input in parallel and mapping it into a single

high-dimensional encoding vector, then using *self-attention* to read out relationships between its elements. The temporal structure of the input becomes a spatial pattern. Transformers are the architecture behind contemporary large language models; the proposed analogy with cortical travelling waves, which similarly turn time into space across the cortical surface, is one motivation for taking waves seriously as a medium of cortical computation. See § [Where Waves Come From, and What They Carry](#).

Temporal symmetry A waveform property: each peak and trough has matching rising and falling slopes — locally, the wave looks the same traversed forward or backward in time. Also called *left/right symmetry*. See § [The Shape of EEG Signals](#).

Up/down symmetry A waveform property: the largest positive excursion from baseline equals the largest negative excursion in size. Pure sine waves have it; most clinically interesting EEG signals break it. See § [The Shape of EEG Signals](#).

Vigilance Where the patient sits on the wakefulness–sleep–coma continuum. Knowing this before reading is essential because EEG patterns differ profoundly between states. See § [Before You Look: Age and Vigilance](#).

14 Declaration of AI Use

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