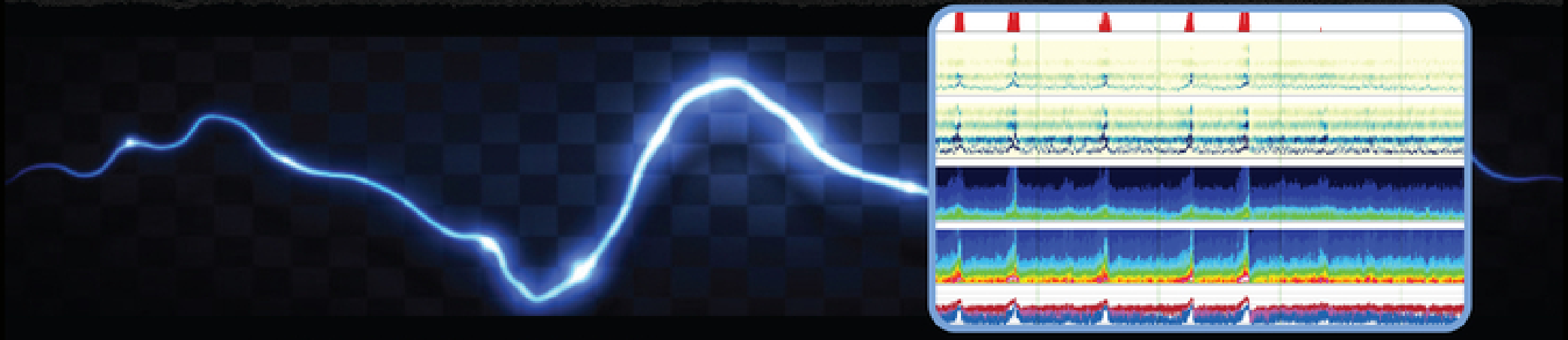
Second Edition

Hirsch and Brenner's

Atlas of EEG in CRITICAL CARE



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Hirsch and Brenner's Atlas of EEG in Critical Care

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Dr. Hirsch dedicates this atlas to his wife Gaetane; his two sons, Calvin and Toby; and Dr. Brenner for teaching him how entertaining EEG reading and teaching could be, and for putting up with his very long delay in completing this edition.

Dr. Fong dedicates this atlas to his loving wife Katherine and his beautiful daughter, Imogen.

Dr. Brenner dedicates this atlas to his wife Elizabeth.

All authors thank their families for putting up with the many hours of work, including at odd hours, required to complete this.

Contents

Preface

The utilization of continuous EEG (cEEG) in critically ill patients has markedly expanded since the first edition of this atlas just over a decade ago. Multicenter collaborative efforts have determined that increases in seizure burden (including nonconvulsive seizures) are independent predictors of worse outcome in many different types of patients, as measured in many ways, including long-term functional outcome, cognition and later epilepsy. These efforts have also shown that even highly epileptiform patterns that do not qualify as seizures are sometimes sufficient to cause progressive neuronal injury, especially in the setting of an acute brain insult. For the vast majority of patients there is little clinical suggestion at the bedside that these patterns or seizures are present (other than impaired alertness), and thus cEEG has a crucial role in patient care. Centers have responded by incorporating new technology and designing highly specialized neuro-intensive care units with the capacity to record EEG at any time of the day, to detect seizures or potentially injurious EEG patterns, and rapidly feed this information back to treating clinicians to best inform management decisions. Continuous EEG has since become a routine part of caring for critically ill patients in many institutions around the world. As a result, neurologists and intensivists need to become familiar with the use of routine brain monitoring with EEG, or 'neurotelemetry', as they have with routine cardiovascular monitoring.

The atlas begins with a section on the basics of EEG interpretation geared towards someone with minimal if any EEG experience (Chapters 1–2). The atlas follows with chapters on: EEG patterns seen in encephalopathy and coma – both nonspecific and specific (Chapter 3); focal abnormalities (Chapter 4); rhythmic and periodic patterns (RPPs), including detailed explanation of the recent American Clinical Neurophysiology Society (ACNS) standardized critical care EEG terminology guideline that was extensively updated in 2021 (Chapter 5); seizures and status epilepticus, including new definitions of electrographic and electroclinical seizures/status epilepticus (Chapter 6), and controversial patterns such as those on the ictal-interictal continuum (now defined); confusing artifacts, including ones that are often misinterpreted or that mimic seizures (Chapter 7); and patterns that are commonly seen post cardiac arrest (Chapter 8).

After the above sections on raw EEG patterns from both a basic and advanced viewpoint, there is an extensive color section on prolonged continuous digital EEG monitoring, including quantitative EEG techniques to assist with interpretation of prolonged recordings (Chapters 9–10). These techniques can aid in efficient recognition of seizures, ischemia and other neurological events, and can help visualize long-term trends. This chapter also contains examples of multimodal brain monitoring in the neurocritical care setting.

Throughout the atlas, EEG findings are highlighted and labeled in detail within the tracings themselves. Each chapter begins with a short section of text and a list of the most important references as suggested reading. In general, the chapters progress from very basic material at the start of the chapter to more advanced. An appendix summarizing the 2021 ACNS terminology is included as well. There is an extensive index as well to help the reader rapidly find what they need.

Who should use this atlas?

This atlas is geared towards all health care professionals involved in critical care medicine, including all clinicians, fellows, residents, EEG technologists and researchers. Although it may be of particular interest to those in neurology, epilepsy and clinical neurophysiology, it is also appropriate for intensivists with an interest in maintaining brain health during critical illness of any etiology. It covers the basics as well as advanced material.

What's new in this edition?

As the volume and variety of patients undergoing cEEG has increased, new patterns of significance have been observed and defined. As a result, the ACNS standardized critical care EEG terminology underwent a major update in 2021. The definition of many of these patterns was established and the definitions of prior patterns refined when necessary. This atlas contains real-world examples of all the terms, past and newly introduced, included in the ACNS terminology. There are extensive new examples of EEGs in all chapters, and the EEGs that were already in the prior version are now re-labeled with the 2021 terminology.

In addition to new electrographic patterns, there have also been new conditions and toxicities since the prior edition. COVID-19-related encephalopathy, anti-checkpoint inhibitor encephalopathy and specific medication effects such as ketamine are all included. New technologies have allowed for rapid-response EEG and examples of using a limited montage as part of a very rapid EEG to triage patients is discussed.

An approach to tackling the cEEG has been introduced, complete with illustrative diagrams to help the reader understand the difference between terms. Quantitative EEG has also progressed drastically since the last edition, and some of these tools are introduced in the QEEG chapter.

Due to the need for expansion of several of the chapters, especially the quantitative EEG ones, and in order to keep the atlas at a reasonable size, we have removed the chapter on evoked potentials.

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Dr. Brenner would like to thank those neurologists, EEG technologists, neurophysiology fellows and neurology residents, at the University of Pittsburgh Medical Center, who have helped over many years in this endeavor. Special thanks to Drs. Mark L. Scheuer and Anne C. Van Cott and EEG technologists Susan Burkett and Cheryl Plummer.

1 EEG basics

1.1 Electrode nomenclature, polarity and montages

Electroencephalography is a technique that measures the spatial distribution of voltage fields on the scalp and their variation over time. The origin of this activity is thought to be due to the fluctuating sum of the excitatory postsynaptic potentials and inhibitory postsynaptic potentials. These potentials arise primarily from the apical dendrites of pyramidal cells in the outer (superficial) layer of the cerebral cortex and are modified by input from subcortical structures, particularly the thalamus and ascending projections of the ascending reticular activating system. Structures in the thalamus serve as a 'pacemaker'. This produces widespread synchronization and rhythmicity of cortical activity over the cerebral hemispheres.

When dendritic generators are aligned, they form a dipole. Dipoles are sources of electrical current consisting of two charges of opposite polarity (one positive [current source], and one negative [current sink]), separated by relatively small distances. The easiest way to conceptualize a dipole is by considering the example of a battery; there is one positive end and one negative end that allows current to flow if the ends are connected. In the cortex these dipoles are mostly radially oriented, which means that they are aligned in a way that projects one end of the dipole towards the scalp, and hence can be recorded with EEG. In general, approximately 10 cm^2 of cortex needs to be discharging synchronously for the signal to be appreciated on scalp EEG.

The hardware necessary to record the EEG employs differential amplifiers. Each amplifier records the potential difference between two scalp electrodes (the electrode pair is referred to as a derivation or channel). Each amplifier has two inputs connected to scalp electrodes. By convention, when input 1 (historically referred to as grid 1, or G1) is relatively negative compared to input 2 (grid 2, or G2) there is an upward deflection; when input 1 is relatively more positive than input 2 there is a downward deflection. It is the relationship between the two inputs that determines the direction and amplitude, not the absolute values. Simply put, the tracing at each channel (derivation) displays G1 minus G2, with negative values causing upward deflections. Listed below are some examples to help further demonstrate these principles.

TABLE 1.1 Polarity

Channel	Input 1	Input 2	Difference	Deflection direction
A	+50	+10	+40	Down
B	+50	+50	0	—
C	+50	+70	−20	Up
D	+50	−50	+100	Down

In the following four examples inputs 1 and 2 have been switched. i.e., channel E is the same as channel A in Table 1.1 with input 1 and input 2 switched and the resultant differences shown.

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TABLE 1.2 Polarity

Channel	Input 1	Input 2	Difference	Deflection direction
E	+10	+50	−40	Up
F	+50	+50	0	—
G	+70	+50	+20	Down
H	−50	+50	−100	Up

The EEG is the graphical representation of these differences over time. If taking the timepoint that the above tables were generated, a graphical presentation of this data can be constructed (Figure 1.1).

As can be seen from the above examples, there are no true 'positive' or 'negative' deflections; there are only upward or downward deflections. When there is no deflection, the inputs are equipotential and are either equally active or inactive. For example, taking channel B, if both the inputs were made −50 μV (as opposed to +50 μV) there would still be no resultant deflection as there would remain no difference between input 1 and 2.

When looking at only a single derivation (a one-channel recording of the potential difference between an electrode pair) one can only state the relationship of input 1 to input 2, i.e., it is either more or less negative or positive. However, it is not possible to localize cerebral activity or determine its polarity without further derivations/channels. Understanding polarity, as well as accurately assessing other factors such as the frequency of the activity being evaluated (cycles/second), its morphology, location, voltage, reactivity and symmetry in conjunction with the age and state of the patient, is necessary for proper interpretation of the EEG. In order to adequately represent the topography of the voltage, additional amplifiers and channels are needed for the sequential display of the EEG data, and this display of multiple channels is termed a *montage*. A montage refers to a collection of derivations for multiple channels recorded simultaneously and arranged in a specific order. Montages enable the technologist and electroencephalographer to systematically visualize the field of electrical activity of the brain.

Electrodes are applied to the scalp in accordance with the International 10-20 System. Different regions of the brain are identified as Fp (frontopolar),

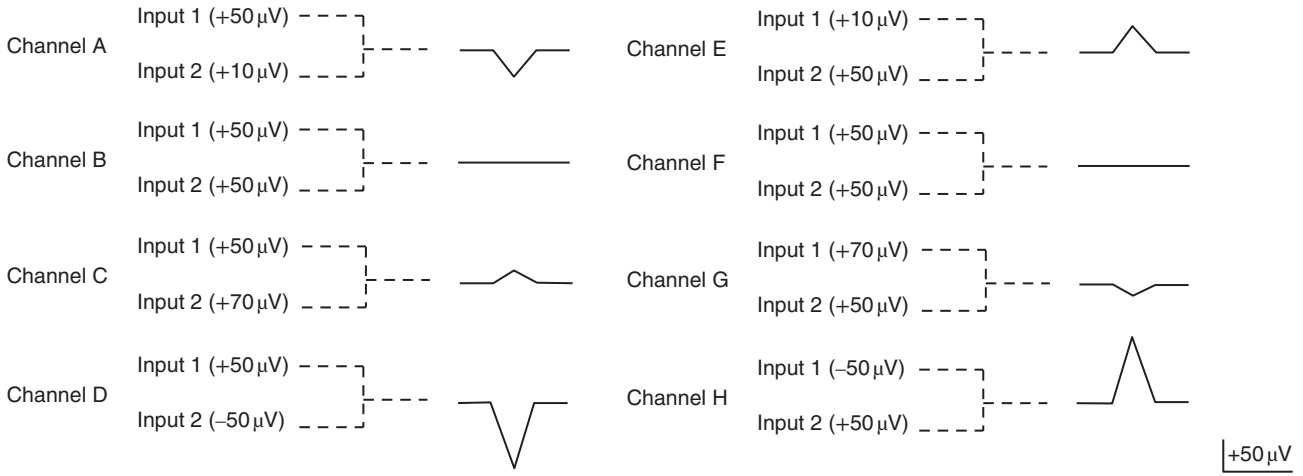

Figure 1.1. Schematic representation of channel inputs. The figure demonstrates how the pen deflections would appear if the voltage inputs from Tables 1.1 and 1.2 were put into an EEG machine. Channels A-D show the resultant inputs from Table 1.1, whereas channels E-H show the deflections if input 1 and input 2 were 'flipped' for each channel, as shown in Table 1.2. The figure exemplifies that if the relative polarity between input 1 and input 2 is flipped from positive to negative, then the resultant waveform is flipped. However, if there is the same relative difference between the two input voltages the height or amplitude of the deflection remains unchanged.

F (frontal), C (central), P (parietal), O (occipital) and T (temporal). Odd numbers refer to the left side, even to the right and z to midline placements. 'A' signifies an ear channel (A1 for left ear, A2 for right). Electrode placement has been standardized with this system, with electrode sites determined by anatomical skull landmarks. Technologists measure the distance from the nasion to the inion and the head circumference, marking precise electrode locations based on 10 or 20% intervals of those distances: hence the name '10-20'. For completeness' sake, a diagram depicting the 10-10 system has been included, this spaces electrodes in 10% intervals from each other (Figure 1.2). The 10-10 system and the 10-20 system use the same electrode labels, just not all electrodes of the 10-10 system are included in the 10-20 system for practical purposes.

Montages may be viewed as software that enhances the use of the EEG machine (hardware) to function as a form of brain imaging. There are two basic types of montages – bipolar and referential. A referential montage compares each individual electrode potential to the potential of a user determined 'referential point'. For this, input 1 (G1) is the electrode position and input 2 (G2) is always the selected referential point. Common referential points include the ear(s), the vertex (Cz) or an average of all electrodes (termed a 'common average reference'). With a bipolar sequential recording, scalp electrodes are linked in straight lines (either anterior-posterior or transverse), and each channel records the difference in potential between electrode pairs.

An analogy that assists with understanding the concept of referential and bipolar montages is to consider a series of buoys floating on waves of the ocean. A bipolar montage is analogous to comparing the relative height of each buoy to that immediately neighboring it. A referential montage is like measuring the absolute height (or altitude) of each buoy in relation to a determined referential point (for example the seabed). This analogy assists with understanding the strengths and weaknesses of the two montage types. A bipolar montage eliminates the signal that is common between two points. This means that when considering a small wave in a deep ocean, the bipolar recording is very sensitive at detecting small differences in height (or potential). The bipolar montage, however, tells you nothing about the depth of the ocean or the actual altitude of the two buoys, merely the height of the small wave. Conversely, a referential montage provides information of the absolute height/altitude (absolute potential) of a waveform.

Consider Figure 1.3, which demonstrates a series of four buoys spaced at equal (predetermined) distances from each other. The height of each buoy measured from a referential point (in this case the seabed) has been provided in units for each buoy. These inputs can be entered into an EEG machine that would generate a series of deflections that cumulatively make up a montage. The resultant deflections for a bipolar and referential montage are shown in Figure 1.4.

There are several points that should be highlighted:

(1) The waveform being measured has not changed in any way when the montage has been changed. The only thing that has changed is how the information from that waveform has been visually displayed.

(2) The reproduction of a wave is limited by the number of sampling points, in this case buoys. The buoys at position 2 and 3 have the same depth (7 units). However, as can be seen by the depiction, neither buoy (despite both having the greatest number of units) sits at the crest of the wave. If two sequential buoys have the same number of units, they could both be positioned at the crest of a very broad wave, but it is possible (as in this case) they both sit an equal difference from the true crest of the wave. It is useful to remember this concept when 'localizing' based on surface EEG. There will always be some spatial limitation. Some of this can be overcome by adding more sampling points. In the case of the buoys, doubling the number buoys would increase the chances that a buoy is positioned at the true crest. In EEG a greater number of electrodes can be applied, for example a 10-10 montage where an electrode is placed every 10% rather than 20% of head measurement, or even a high-density array consisting of 256 or 512 channels. Although this would provide greater spatial resolution it comes at a practical cost.

(3) The vertical scale units of the referential montage are double that of the bipolar; because bipolar montages compare neighboring electrodes, they reject all of the activity that is common between these two points. This means that even very small differences can be more easily

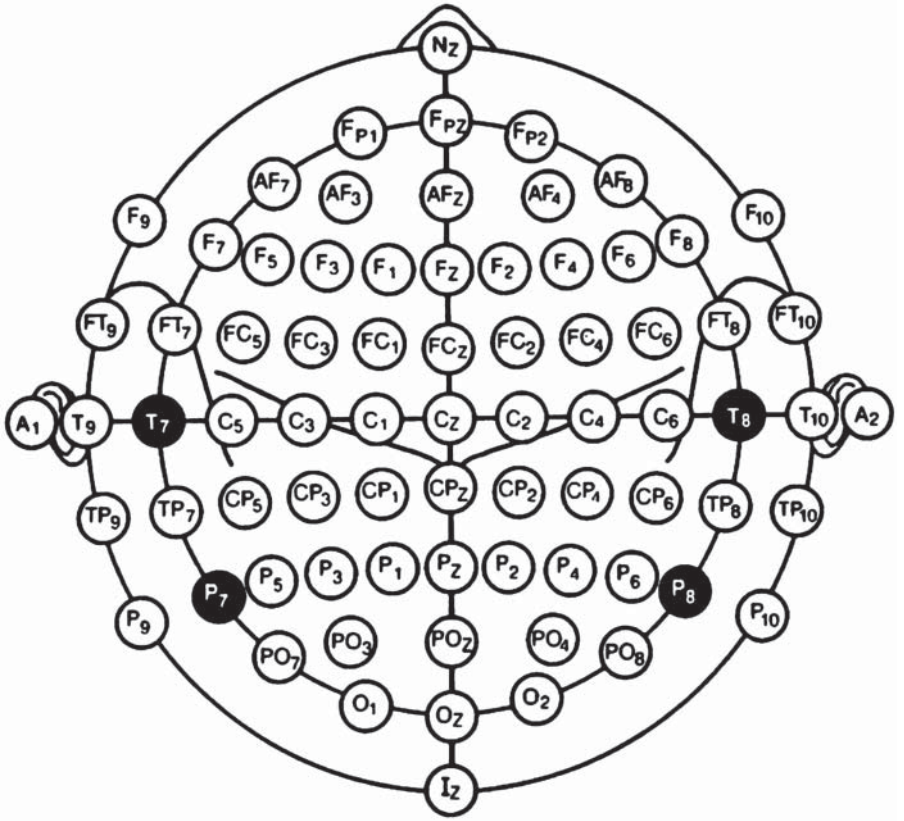

Figure 1.2. International 10-10 system for electrode placement. The figure depicts the standardized international 10-10 system for electrode placement. This system places electrodes at pre-defined positions of the head, relative to the patient's own head measurements (so the positions remain relatively constant between patients, irrespective of head size). In the anterior-posterior (front to back) direction a measurement is taken from the nasion to the inion. This distance forms 100% of a patient's A-P head dimension, and so 10% represents 1/10th of this distance. In the transverse or coronal plane (side to side, or left to right) measurement is taken from the tragus of one ear, across the top of the head, to the tragus of the other ear (tragus to tragus). This distance forms 100% of the head dimensions in the transverse plane. Cz is situated at the approximate vertex (more specifically the intersection between 50% of the nasion-inion distance and 50% of the tragus-tragus distance). Electrodes are then spaced at 10% intervals, so FCz is 10% of the AP distance in front of Cz, and C2 is 10% of the tragus-tragus distance to the right of Cz. All electrodes on the right are assigned even numbers, and all electrodes on the left are assigned odd numbers, with electrodes in the midline allocated a z (for zero). By this nomenclature FC2 is 10% A-P distance in front of Cz, and 10% the tragus-tragus distance to the right. The 10-10 system is presented mostly for reference, with most 'standard' EEG using the modified 10-20 system. This system uses the same electrode naming nomenclature, but mostly only utilizes the electrodes spaced at 20% intervals. Doing so provides a compromise between adequate scalp coverage and the practical application of recording electrodes. The EEG in this book is for the most part recorded using a 10-20 system. The electrodes in bold are those with an historical alternate name (i.e., T7 previously referred to as T3, P7 as T5, T8 as T4 and P8 as T6); these names are still used in some centers.

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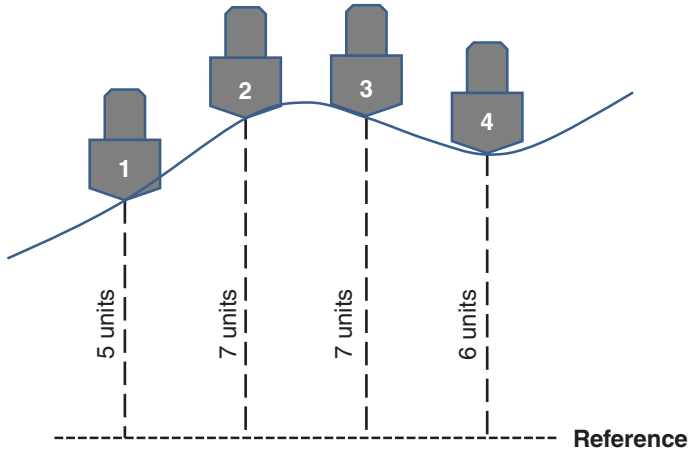

Figure 1.3. Analogy depicting the crest of a wave. In order to conceptually appreciate the difference between bipolar and referential montages, the figure presents an analogy of buoys floating on the surface of an ocean. The waves of an ocean form multiple crests and troughs and this is depicted by the wavy line. Four buoys (numbered 1–4) have been placed at equal distances from each other (similar to how EEG electrodes are placed at predetermined points mostly equidistant from their neighboring electrode). Each buoy has been assigned an arbitrary 'height' or unit (that correlates to amplitude/voltage in EEG). There are two ways of gaining information about the wave.

(1) Compare each buoys height to that of its neighboring buoy (1 compared to 2, 2 compared to 3, etc.). This is equivalent to a bipolar montage.

(2) Compare each buoys height to a set point (reference point) (1 compared to reference, 2 compared to reference, etc.). In this case the reference point has been set as the seabed, but as for the case of any referential montage the set point can be any point determined by the user.

detected, which can be harder to appreciate in a referential montage. The example is the 1-unit difference between buoy 3 and 4. Channel C of the bipolar montage easily shows this difference with a 1-unit deflection, however, to gain this information from the referential montage one would have to compare the height of channel C and D (often done visually).

The above analogy depicts the crest (maximal positivity) of a wave. However, in many cases the activity of interest is oriented so that the resultant radial dipole projects its negative end towards the scalp, therefore in EEG the maximal negativity (trough of a wave) is often the most of interest. This can be conceptualized by flipping the analogy of the waveform on its head (Figure 1.5). When this information is inputted to a bipolar and referential montage, the result has been shown in Figure 1.6.

These figures highlight the advantages and disadvantages of bipolar vs. referential montages. The bipolar montage is very sensitive for detecting the location of maximal activity, with the deflections of a montage either pointing toward the region of maximal negativity ('negative phase reversal') or away from the region of maximal positivity ('positive phase reversal'). However, the resultant deflections of a referential montage more closely represent the shape (or field) of the waveform being measured, which makes it easier to conceptualize its distribution and potential brain regions involved. Bipolar and referential montages are not used in isolation and should be considered complementary ways of viewing information to (1) detect abnormality,

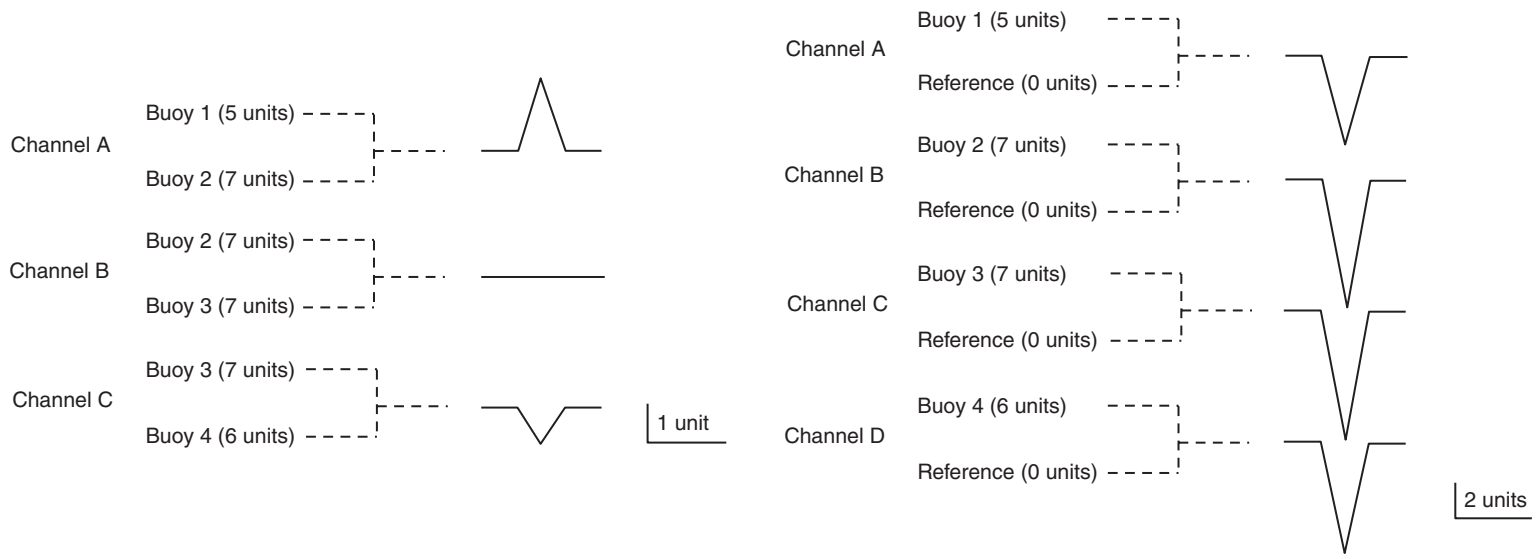

Figure 1.4. Bipolar vs. referential representation of a crest or maximal positivity. The information gained from Figure 1.3 can be represented in bipolar and referential formats/montages. A bipolar montage is shown on the left and referential on the right.

Bipolar montage: each channel of a bipolar montage represents a pair of neighboring buoys. Channel A, input 1 is the height (or altitude) of buoy 1 and input 2 is the height of buoy 2. The resultant deflection for each channel is given by subtracting input 2 from input 1 (5 units − 7 units = −2 units). The resultant deflection is therefore −2 units, which by convention is an upward deflection of 2 units height. Channel B then consists of input 1 (buoy 2 [which was previously input 2 of the prior channel]) and input 2 (buoy 3). In this case buoy 2 (7 units) minus buoy 3 (also 7 units) results in zero, so there is no deflection for that channel; and so on.

Referential montage: each channel of a referential montage represents that buoy compared to a set/referential point. Taking the referential point as zero units: Channel A, input 1 height of buoy 1 (5 units) and input 2 height of the reference point (zero units). Therefore, the deflection of channel A will be positive 5 units (5 units − 0 units = 5 units), which by convention is a downward deflection of 5 units height. Channel B then carries no information about buoy 1, instead channel B is input 1 (buoy 2) compared to input 2 (same referential point), which equates to 7 units minus 0 units, resulting in a positive 7-unit deflection (i.e., a downward deflection of 7 units), and so on.

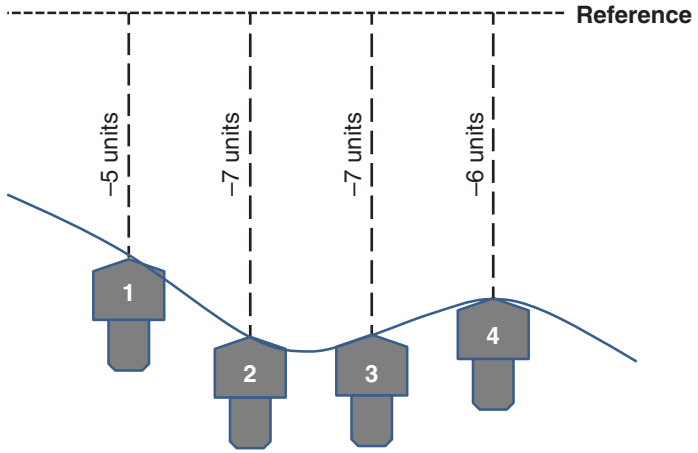

Figure 1.5. Inverse wave analogy. In order to highlight the bipolar and referential depiction of a trough of a wave, the analogy in Figure 1.3 has been inverted (flipped on its head). Here the previous crest of the wave (maximal positivity) now appears as a trough (maximal negativity). Considering these would be theoretically below the seabed the assigned values have become negative.

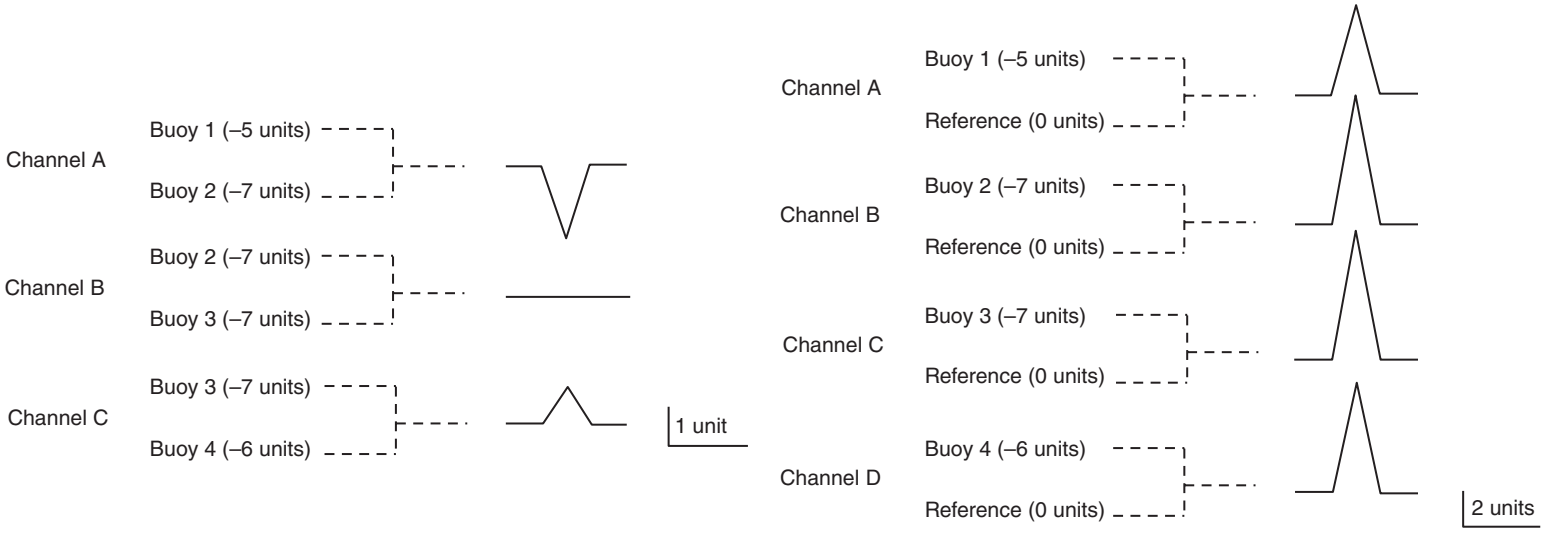

Figure 1.6. Bipolar vs. referential representation of a trough or maximal negativity. The bipolar representation is again shown on the left and referential on the right.
Bipolar montage: considering the reformatted analogy, Channel A, input 1 (buoy 1) is now −5 units and input 2 (buoy 2) is −7 units. Channel A is therefore −5 units − −7 units (with the double negative being equivalent of a +), this results in −5 units + 7 units = +2 units. Hence the 2 unit positive or downward deflection in channel A.
Referential montage: with input 1 of each channel being negative and each compared to input 2, which is zero, the resultant deflections of all channels of the referential montage are negative (upgoing).

(2) identify the region/s most affected, and (3) conceptualize the volume of parenchyma involved.

Listed below are some advantages and disadvantages of each type of recording.

Short distance bipolar recording

Advantages

(1) Value of phase reversal in localization – particularly when this occurs at the same electrode in two montages run at right angles to each other. Phase reversal in a sequential bipolar montage refers to the opposite simultaneous deflection of pens in the channels that contain a common electrode. It is important to realize that a phase reversal does not imply normality or abnormality. This instrumental phase reversal usually, but not always, indicates that the potential field is maximal at or near the common electrode. To be certain that one has accurately defined the site of maximal involvement it is necessary to use an additional bipolar montage at right angles to the first, or a referential recording.

(2) Bipolar montages will usually display local abnormalities well since a phase reversal is often present. The exception occurs when the discharge is maximal at either the beginning or end of the sequential chain and there is no phase reversal.

(3) Can help resolve ambiguous findings on referential montages due to an active reference.

Disadvantages

(1) Amplitudes can be misleading; in any given channel higher amplitude indicates a greater potential difference, not necessarily the most active site, while low amplitude could be due to the two electrodes being equally active and canceling, or to both electrodes being inactive. A flat line in a bipolar pair of electrodes does not mean those channels are not involved, it infers they are equally involved.

(2) Diffuse potentials with relatively flat gradients are not detected well.

(3) Waveforms and frequencies may be distorted.

Referential recording

Advantages

(1) Amplitude can be used to localize site of maximal involvement if the reference is inactive. With referential recordings, when the reference is inactive (or is the least active electrode), the site of maximal involvement is identified as the one having the greatest voltage (i.e., greatest amplitude of deflection).

(2) Little distortion of frequency or waveforms.

(3) Diffuse patterns with flat gradients can be detected. In contrast to focal abnormalities, diffuse discharges are frequently better appreciated on referential montages, particularly when there is a flat gradient.

(4) Can help resolve difficulties in bipolar recordings due to equipotential areas, horizontal dipoles or unevenly sloping gradients.

Disadvantages

(1) The reference electrode may not be inactive or the least active electrode – it may be very active. When the reference electrode is active, because it is located near the peak of the potential being studied, interpretation can be more difficult. A major problem with the use of referential montages is that it is often difficult to use an inactive reference or to realize that the reference is active.
A reference may be active because of artifact, or it may be within the cerebral field under study. With an active reference there often appears to be a 'phase reversal' on a referential montage, i.e., some electrodes are more negative than the reference, while others are more positive. One has to look at relative polarity, as well as amplitude, to decide which is the most active site. For those electrodes that are

more active than the reference, the greatest amplitude indicates the site of maximal involvement. In contrast, for sites less active than the reference, the largest amplitude indicates the least active area. The deflection of the maximal and minimal sites will be in opposite directions. When the reference is the most active site the deflections in all channels are in the same direction i.e., there is no phase reversal. Furthermore, the largest amplitudes occur at those sites which are the least active. This type of situation can be confusing since one cannot be sure if the reference is uninvolved or is the most active of all scalp electrodes.

(2) Greater problem with artifact – depending on the reference employed. No single reference electrode is ideal for all situations. The ear electrodes frequently are contaminated by temporal lobe spikes as well as EKG and/or muscle artifact. The Cz electrode, which is often a very good choice in helping to display focal temporal abnormalities, has the least muscle artifact but is very active during sleep. Other midline reference electrodes, such as Fz or Pz, also have limitations: during wakefulness Fz is in the field of vertical eye movements, while Pz may be in the field of the posterior dominant 'alpha' rhythm; thus, these references are often active.

The American Clinical Neurophysiology Society (ACNS) published suggestions for standard montages to be used in clinical electroencephalography. The suggested montages include:

(1) longitudinal bipolar (LB) montages

(2) transverse bipolar (TB) montages

(3) referential (R) montages (such as ipsilateral ear, or Cz reference).

The montages listed are not intended for some purposes, such as neonatal EEG, all-night sleep recordings or for verification of electrocerebral inactivity. Additional guidelines for these specific indications can also be found at www.acns.org/practice/guidelines.

1.2 Normal EEG: awake and asleep

EEGs can be performed on patients of all ages, including neonates. There are marked maturational changes that occur in infancy and early childhood, while in adults, between the ages of 20–60 years, the EEG is relatively stable. Further fairly subtle changes occur in the elderly. Thus, in different age groups different patterns characterize wakefulness, drowsiness and sleep.

The normal adult EEG contains a number of different background rhythms and frequencies. These include alpha, beta, delta, mu, theta and normal sleep activity, such as vertex waves (V waves), spindles, K-complexes and positive occipital sharp transients of sleep (POSTS). EEG activity is conventionally divided into the following frequencies (number of waveforms/second, or hertz [Hz]):

Delta – refers to frequencies under 4 Hz (and $\geq$0.1 Hz). Delta activity, which is the slowest of the standard waveforms, is normal when present in adults during sleep. In asymptomatic elderly subjects, delta activity is sometimes seen intermittently in the temporal regions during wakefulness, and in a generalized distribution, maximal anteriorly, during drowsiness. It is usually abnormal under other circumstances.

Theta – ranges from 4 Hz to under 8 Hz. It is often present diffusely in young children during wakefulness, whereas in adults it occurs predominantly during drowsiness. Like delta activity, theta activity may occur in the temporal regions in asymptomatic elderly adults during wakefulness.

Alpha – ranges from 8–13 Hz, inclusive.

Beta – ranges from >13 Hz to under 30 Hz. This activity is usually low voltage, most prominent anteriorly, and often increased during drowsiness and in patients receiving sedating medication, particularly barbiturates or benzodiazepines.

In the analysis of the EEG the following need to be evaluated:

(1) frequency

(2) voltage
(3) location
(4) morphology
(5) polarity
(6) state
(7) reactivity
(8) symmetry
(9) artifact.

An important feature of the normal awake EEG is the frequency of the *alpha rhythm*, also known as the *posterior dominant rhythm*. During wakefulness, the alpha rhythm is present over the posterior regions of the head, maximal with the subject relaxed and eyes closed. It attenuates with eye opening. Its frequency ranges from 8.5–13 Hz in normal adults and it is typically sinusoidal. Some normal individuals do not have an alpha rhythm during wakefulness. By itself, this is not abnormal. There is often a mild asymmetry of the alpha rhythm with the right side being of higher voltage. A consistent asymmetry of the alpha rhythm of 50% or more (expressed as a percentage of the higher side) is considered abnormal. Since the right is often somewhat higher in voltage, an asymmetry of 35–50% may be significant and is considered abnormal when the right is the lower amplitude side. Slowing of the alpha rhythm unilaterally is rare and a difference of 1 Hz or greater is significant. An asymmetry of reactivity or frequency is a better indicator of a focal abnormality than is a voltage asymmetry.

Low voltage beta activity is usually present in the normal EEG. Beta activity can show a mild (35%) asymmetry; however, a consistent asymmetry, particularly when associated with other findings, is a sensitive indicator of a cortical abnormality on the lower amplitude side, assuming that there is not an extra-axial collection on that side or a skull defect on the opposite side.

Theta and delta activity are classified as rhythmic (also known as monomorphic) versus arrhythmic (a.k.a. polymorphic or irregular), intermittent versus continuous, and generalized versus lateralized (with lateralized sometimes divided into hemispheric, regional or focal, each involving a smaller volume of brain than the prior term). Lateralized (including regional or focal) slowing (theta or delta), particularly when persistent and of delta frequency, is often associated with a structural lesion. Arrhythmic slowing is classically seen with lesions affecting white matter, whereas rhythmic slowing is more suggestive of subcortical gray matter dysfunction, especially thalamic or upper brainstem, or an epileptic focus (only if lateralized). Attenuation (decreased amplitude) or loss of faster frequencies suggests either cortical dysfunction or a collection between the cortex and the recording electrodes (including extracranial fluid).

The *mu rhythm* (7–11 Hz) is present in some normal individuals in wakefulness and drowsiness; it arises from the Rolandic cortex (primary sensorimotor cortex) at rest. It is often asynchronous and asymmetric and can be unilateral. The mu rhythm attenuates with voluntary movement of the opposite side, such as clenching a fist, or even thinking about moving the opposite side.

Drowsiness could be considered a transition state between wakefulness and sleep. When a patient becomes drowsy there is a decrease in frequency or persistence of the alpha rhythm, appearance of slow lateral eye movements, decrease in myogenic artifact, increased slower frequencies (theta and delta), and often an increase in beta frequencies anteriorly.

As the patient enters sleep there are a number of physiological hallmarks of each stage of sleep. Sleep is split into non-rapid eye movement (REM) and REM sleep. Non-REM sleep includes stages N1, N2 and N3. N3, also known as slow wave sleep, has replaced the prior terms of stage 3 and 4 sleep.

The physiologic hallmarks of sleep include:

POSTS – Positive occipital sharp transients of sleep. These are common in drowsiness and N1 sleep, less common in N2 sleep, and rare in N3 sleep.

Vertex (V) waves – Sharp potential, maximal at the vertex but with a field extending to bilateral fronto-central regions, surface negative, appears at the end of N1 and can persist in deeper stages of sleep.

Sleep spindles – Usually paroxysmal, sinusoidal, low-medium amplitude, 11–15 Hz activity lasting 0.5–2 seconds, and maximal at the vertex and

fronto-central regions. Spindles (and K-complexes) mark the beginning of N2 sleep.

K-complexes – High voltage, diphasic slow waves (duration at least 0.5 seconds) frequently associated with a sleep spindle. They are related to the arousal process, usually maximal at the vertex and can occur spontaneously or in response to sudden sensory stimuli.

N3 sleep – Characterized by delta activity ≤2 Hz and >75 μV (peak to peak) occupying at least 20% of the recording.

Stage R, or REM (rapid eye movement) sleep – The EEG is low voltage and there are rapid eye movements. Saw-toothed waves can also be seen in the central regions. Saw-toothed waves are sharply contoured 4–7 Hz theta range activities that resemble the toothed edge of a saw, hence its name.

Figure list

EEGs throughout this atlas have been shown with the following standard recording filters unless otherwise specified: LFF 1 Hz, HFF 70 Hz, notch filter off.

Suggested reading

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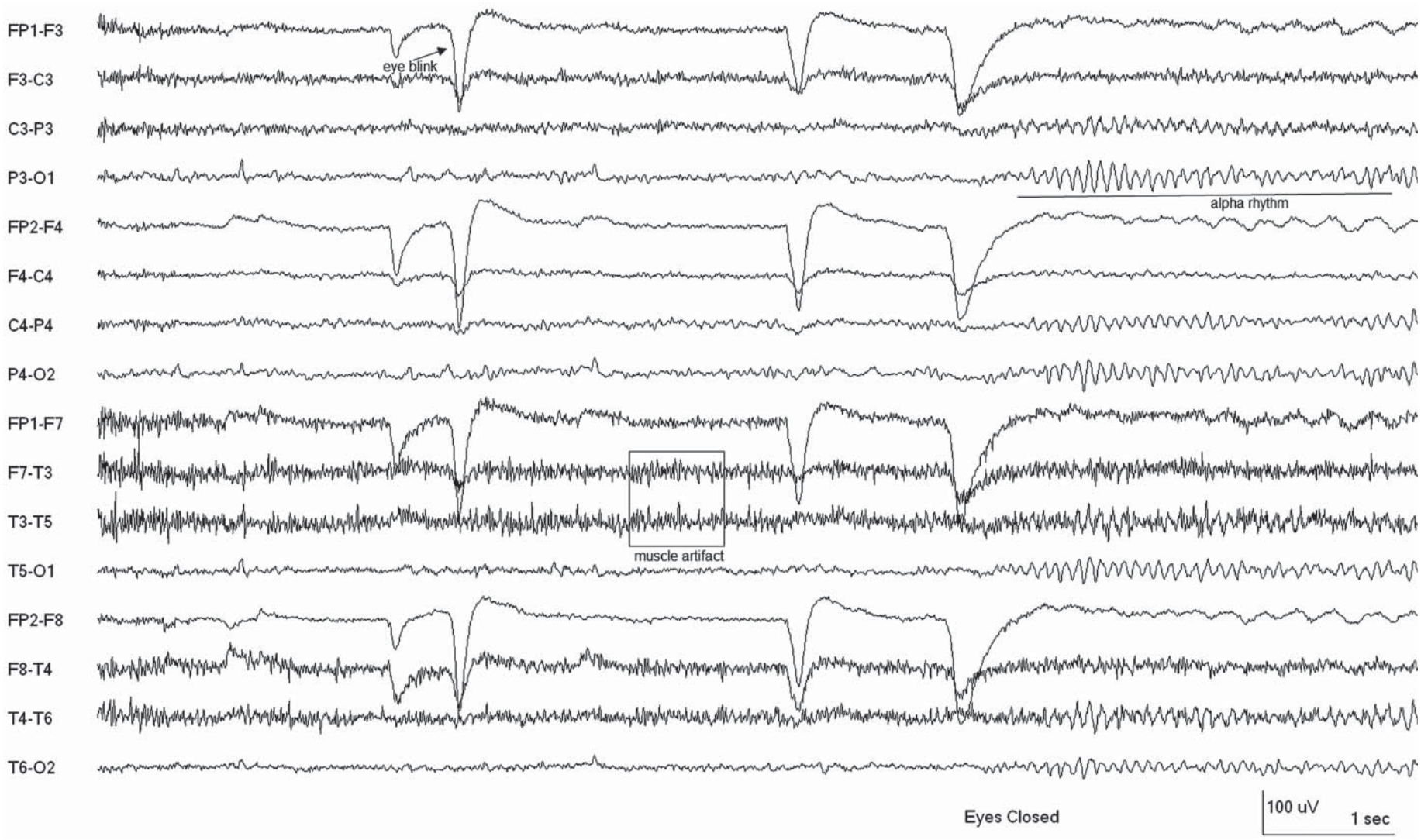

Figure 1.7. Alpha rhythm and blinks. (a) Alpha rhythm, longitudinal bipolar. Following eye closure, rhythmic activity of 10 Hz is present posteriorly. This represents a normal alpha rhythm (sometimes referred to as the posterior dominant rhythm). The activity is maximal in the O1 and O2 electrodes and seen to a lesser extent in the parietal (P3/P4) and posterior temporal (T5/T6) regions. The patient is awake with eye blink artifact (arrow), and muscle artifact more prominent in the temporal regions (box). Additional information on determining eye movement artifact from cerebral activity can be found in Chapter 7: Artifacts. The temporal regions are a common location for muscle artifact given these electrodes overly the temporalis muscle (whereas there is relatively little muscle at the vertex).

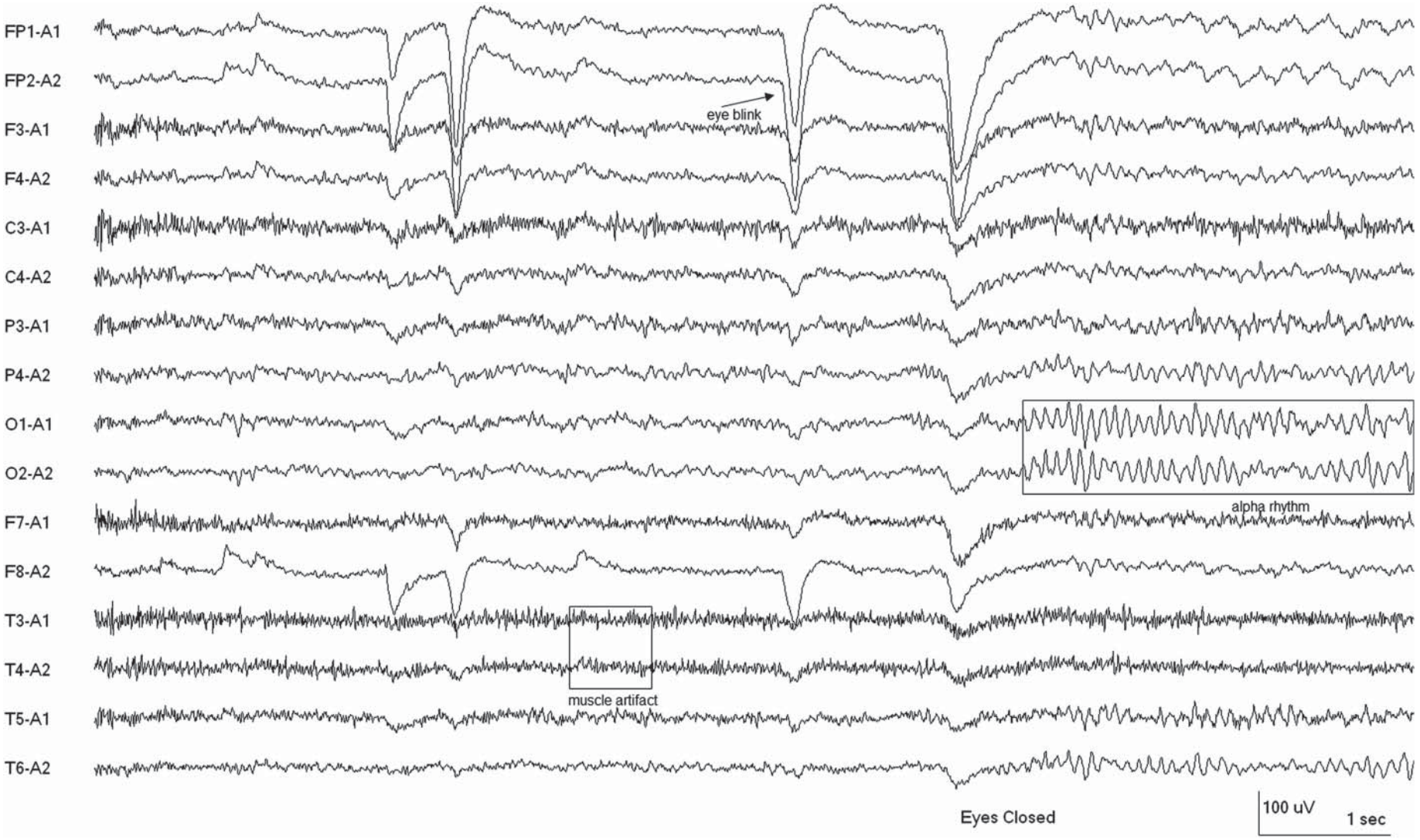

Figure 1.7. (*Continued*) (b) Alpha rhythm, referential. The same epoch in a referential montage, with ipsilateral ear reference. Blinks appear as prominent deflections on the EEG because the eye is a dipole, with the cornea being surface positive and the retina surface negative. During blinks the eyes go upward, due to Bell's phenomenon. This causes the closest electrodes (Fp1 and Fp2) to become relatively positive (as the positive cornea comes into close proximity to these electrodes). As Fp1/Fp2 become grossly positive, a large positive or down-going deflection can be seen in these channels. The opposite occurs if there is a downward movement of the eyes.

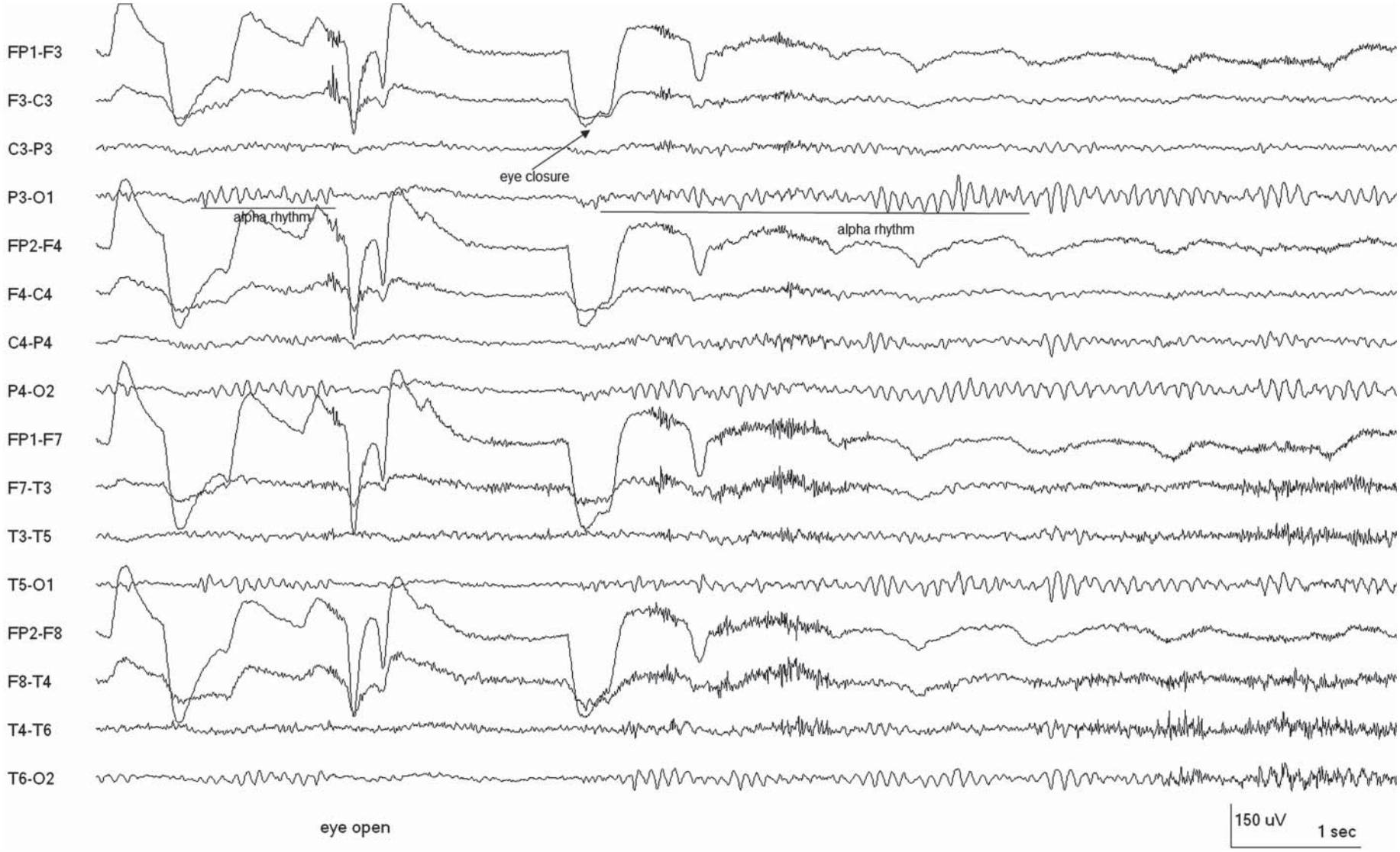

Figure 1.8. Alpha rhythm reactivity. There is an attenuation of the alpha rhythm following eye opening in this 72-year-old man. The alpha rhythm then returns following eye closure, best seen in the channels containing O1 and O2. This feature can be described as 'reactive to eye opening/closure'. Loss of this reactivity can be being an early sign of diffuse dysfunction.

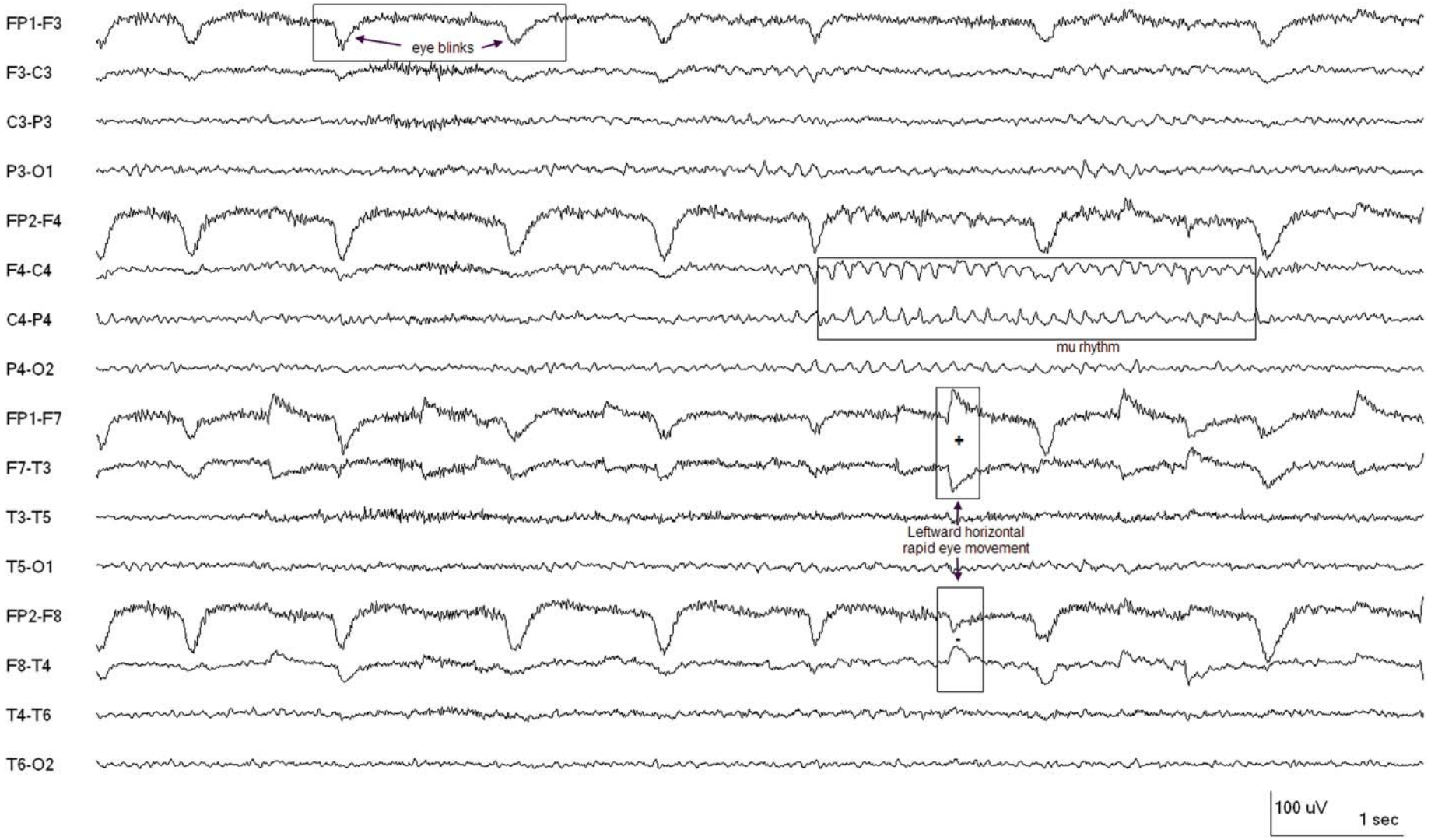

Figure 1.9. Mu rhythm and eye movements. (a) Mu rhythm, longitudinal bipolar. A mu rhythm is prominent in the right parasagittal region (box) in this 45-year-old man. The sharp component is surface negative and maximal at electrode C4, as demonstrated by the phase reversal on this bipolar montage. This morphology, containing a sharp negative component alternating with a blunt positive component, as seen in F4-C4 and C4-P4, resembles the Greek letter mu, giving this rhythm its name. There is also a typical leftward horizontal eye movement shown. Again, consider the cornea is positively charged. Eye movement to the left causes the electrode closest to the corner of the left eye (F7) to become positive. Also consider that the electrode closest to the corner of the right eye (F8) would become less positive (more negative) as the right eye moves away from this electrode. Therefore, on the bipolar montage there is a positive phase reversal at F7 with deflections away from each other, whereas at F8 there is a negative phase reversal with the deflections pointing towards each other.