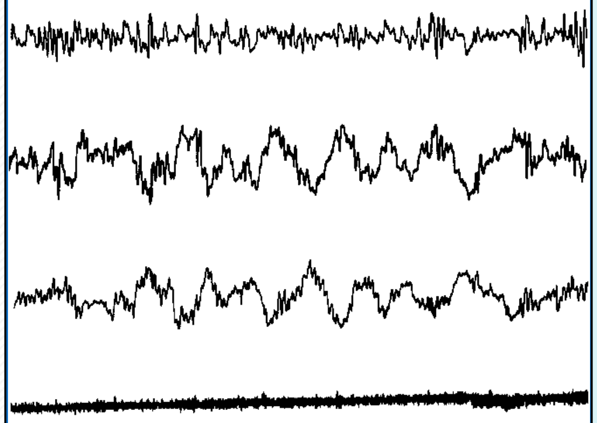
Scoring Sleep Stages: Wake

Sleep Stage Data Reduction

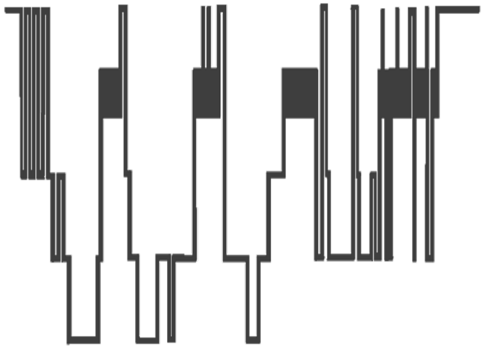
- In the polysomnographic study of sleep, we start by recording the underlying physiological activity.
- Specific EEG, EOG, or EMG activity patterns occur. These polysomnographic events represent the smallest meaningful unit of electrophysiological activity in the study of sleep.
- Sleep data summarization typically involves sleep stage scoring. This consists of dividing the polysomnogram into successive epochs or time intervals. Most commonly, epochs are 30 seconds in duration. Each epoch is then classified as stage N1, N2, N3, REM, or Wake, according to the polysomnographic events and activities present.

Sleep Stage Data Reduction

Raw Data



Sleep Staging



Summary Patterns

1. Total Procedure Time
2. Time Out of Bed

Polysomnographic Events

- Multi-channel recordings made during sleep, commonly referred to as the polysomnogram (PSG), contain a variety of events of interest.
- The first generally accepted manual for scoring sleep was developed by Rechtschaffen and Kales in 1968. This scoring manual was in use for many years. However, it became clear that there was a need for some modifications and additions to these initial scoring rules. In 2007, the American Academy of Sleep Medicine Manual for the Scoring of Sleep and Associated Events was developed, representing an attempt to combine the best available evidence with the opinion of experts in sleep science and medicine. This scoring manual describes and defines many of these events observed during sleep.

Polysomnographic Events

Event descriptions, examples, and data reduction summarization approaches (as appropriate) are organized into the following subsections:

A. EEG Activity and Waveforms
B. Eye Movements
C. Sleep Onset and Microsleep
D. Arousals and Awakenings

EEG Activity and Waveforms

- The EEG leads recommended by the AASM Manual for the Scoring of Sleep and Associated Events were chosen to optimize the ability to accurately identify and stage sleep. Identifying the characteristic waveforms of NREM sleep are optimized by using different EEG derivations – sleep spindle activity is optimally recorded in central electrodes, while K-complexes and delta activity are optimized by frontal electrodes.
- The scoring manual also recommends using a monopolar referential derivation utilizing a reference electrode to the opposite mastoid, although back-up electrodes should be placed in the case that there is any electrode malfunction.

EEG Activity and Waveforms

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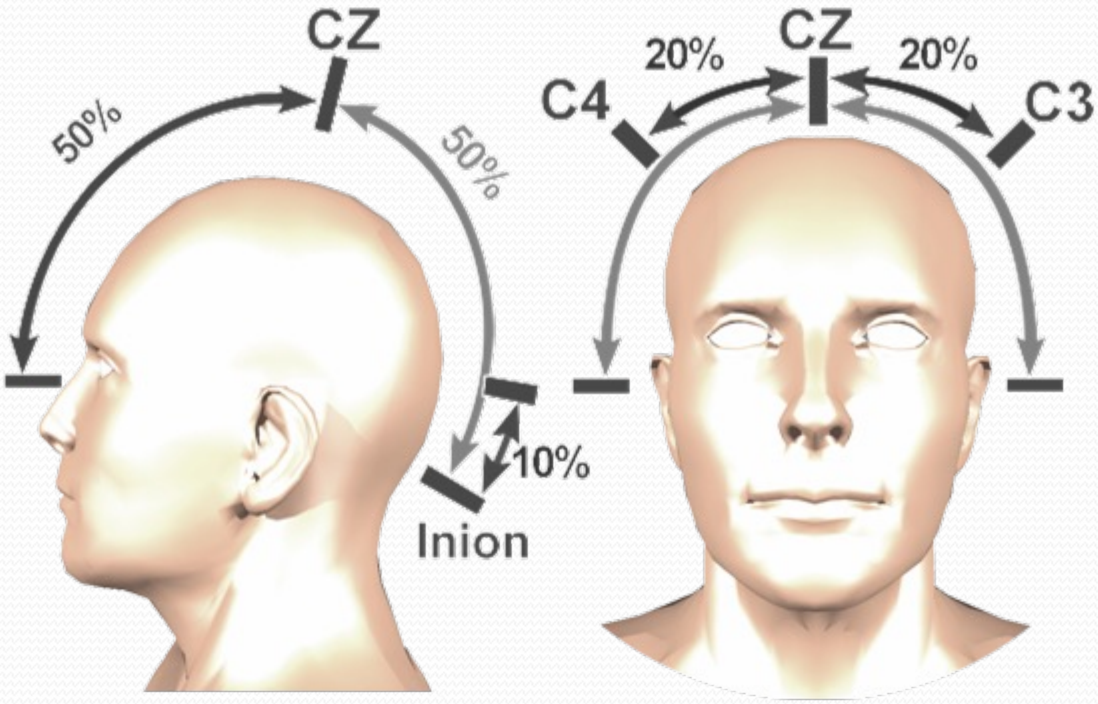


Preauricular Point

Electrode Placement for Sleep Studies

Sleep Stages: Epoch Classification

- Once sleep researchers overcame the incredible difficulties involved with continuously recording overnight PSGs, they faced another major task: data reduction. Counting and measuring each relevant waveform seemed a lengthy task without the assistance of automated digital processing. Therefore, scoring systems were devised to summarize each page of recording based on common electrophysiological activity. This time frame, epoch-based approach led to the eventual creation and adoption of the standardized system for classification of sleep stages that we still use today. The system provided a common terminology for investigators which enabled the field to progress.

Sleep Stages: Epoch Classification

- The weaknesses of the system are inherent in the tradeoff made when any generalization is adopted. Much of the microarchitecture is rendered invisible once an epoch is classified. Therefore, an epoch scored as sleep stage N2 may have one sleep spindle, 10 sleep spindles, three K-complexes, 19% slow waves, or no high amplitude waveforms at all. Sensitivity to these differences is lost in such a system. Obviously, waveforms can still be summarized separately.

Sleep Stages: Epoch Classification

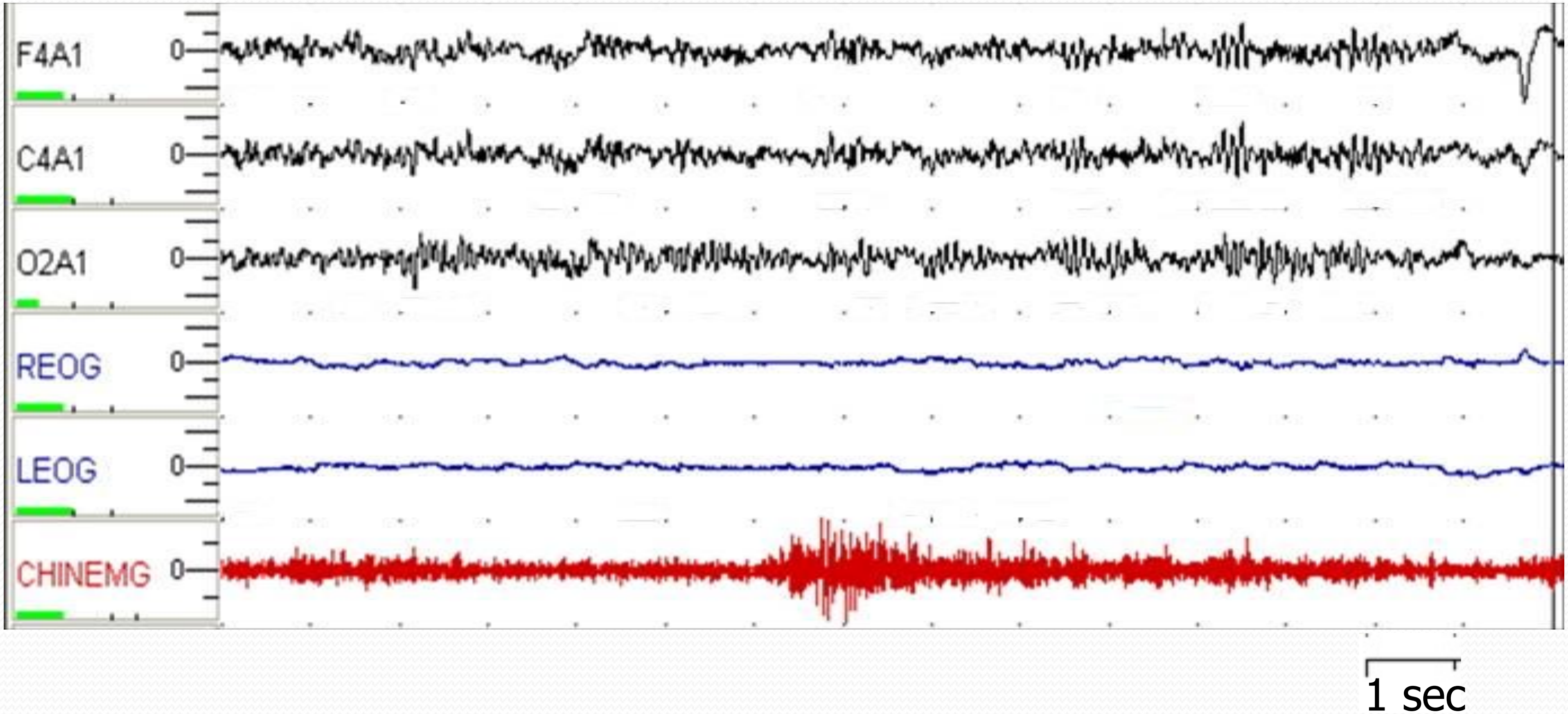
- Nonetheless, the sleep stage scoring system remains, and for good reason. We can characterize sleep macroarchitecture, examine the progression of sleep across the night, determine changes in response to experimental manipulation, and compare the patterns to those derived from normal individuals. Moreover, it is a system that can be learned and applied reliably. Most importantly, it has proven tremendously useful.

Sleep Stages: Epoch Classification

In summary:

1. Need for data reduction led to creation of scoring system
2. Standardized system for classification of sleep
3. Microarchitecture is lost
4. Useful to characterize macroarchitecture across the night

Alpha EEG Rhythm

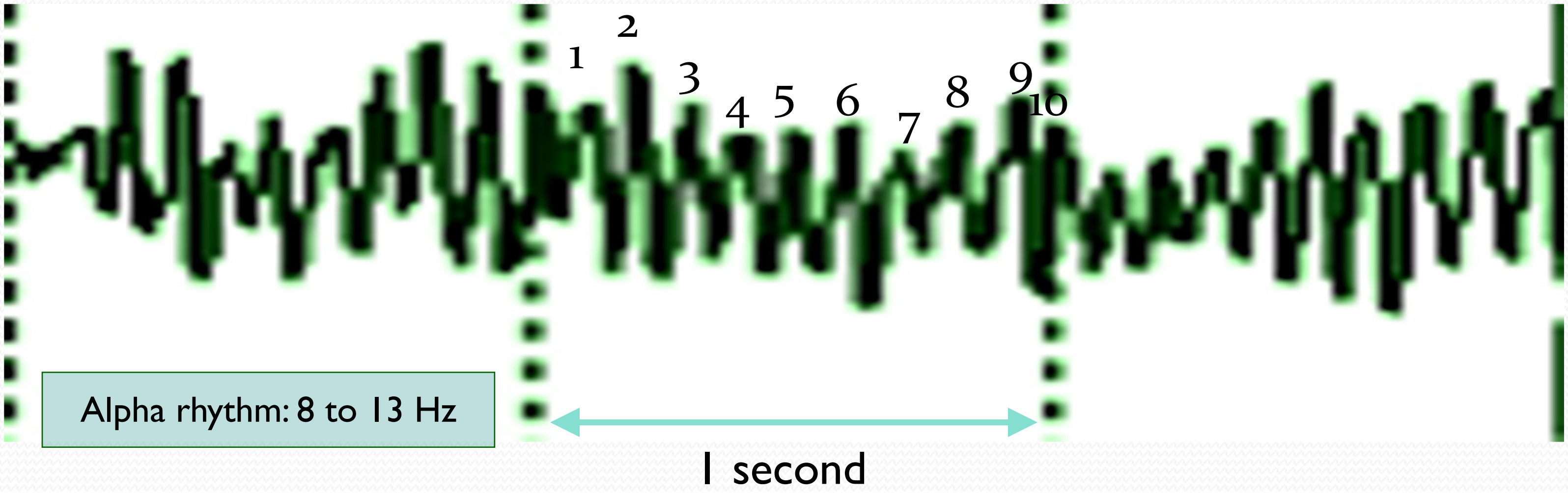


Alpha EEG Rhythm

- Alpha rhythm, first recognized by Hans Berger in 1928, is 8 to 13 Hz sinusoidal activity that is at maximum amplitude in the occipital area. Frequency, expressed in Hz, is measured by counting the number of peaks in a one second recording.

Alpha EEG Rhythm

In the example, there are ten peaks in one second – a 10 Hz waveform.



Alpha EEG Rhythm

- You will notice in the example in the previous slide that the waveforms are not smooth but are instead “choppy” and irregular. This is due to the sampling rate of the recording equipment. A low sample rate provides the advantage of a smaller amount of data to store but can render some of the key EEG information difficult to detect. The *AASM Manual* recommends a minimum of 200 Hz sampling rate for EEG (≥500 Hz is desirable). At 200 Hz each wave in the alpha rhythm in the sample is defined by 20 points; at 500 Hz each wave has 50 points. The display is just like “connect the dots.” If you have 20 points, there will be a lot of straight lines between points. At 50 points, the waves become much smoother.

Alpha EEG Rhythm

- The amplitude of alpha rhythm is variable but typically is below 50 uV in the adult. The rhythm is blocked by eye opening or other arousing stimuli. It is indicative of the awake state in most, but not all, normal individuals. It is most consistent and predominant during relaxed wakefulness, particularly with reduction of visual input.
- Not everyone has alpha rhythm. As many as 10% of subjects may not have any alpha frequency activity greater than 20 uV. Special scoring rules apply for sleep onset in these subjects.

Alpha EEG Rhythm

- The alpha rhythm of an individual usually slows by 0.5 to 1.5 Hz (cps) and becomes more diffuse during drowsiness. The frequency range also varies with age; it is slower in children and older age groups, relative to young and middle-aged adults.
- Alpha EEG activity can also occur during sleep intermixed with other waveforms (as in alpha-delta sleep), or it can occur in cyclic bursts. Such alpha intrusions into sleep may have clinical implications. So essentially alpha activity can be seen in any stage of sleep with alpha intrusion. Alpha intrusion can be a sign the patient has chronic pain.

Wake Definitions

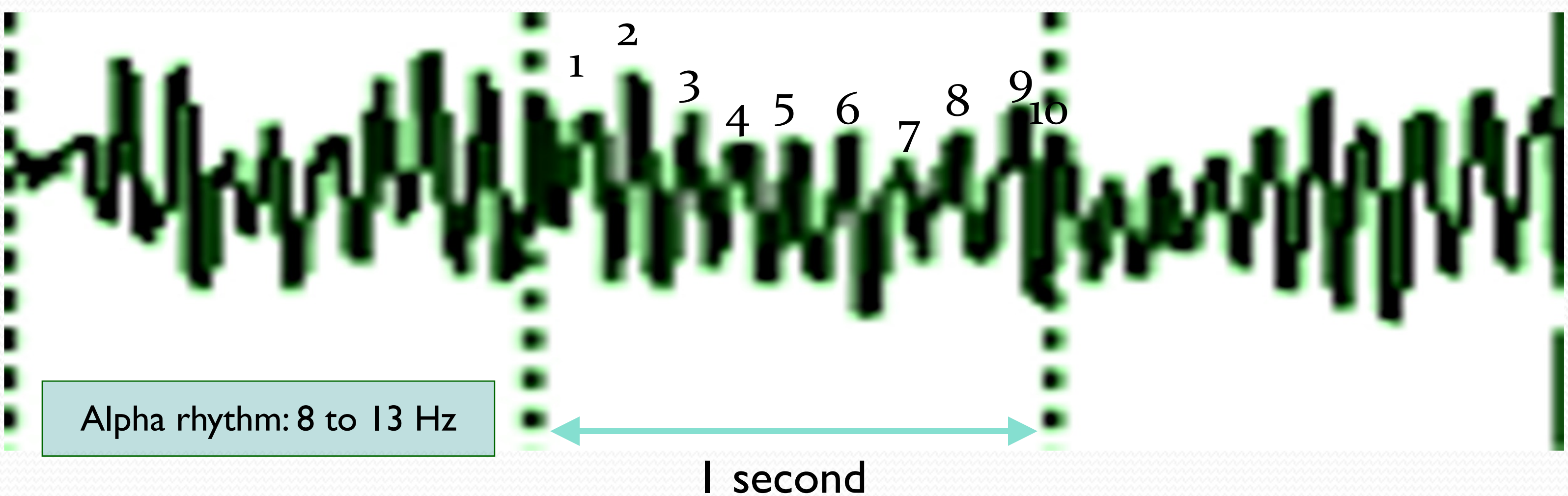
- Posterior dominant rhythm (also known as alpha rhythm): EEG pattern consisting of trains of sinusoidal 8-13 Hz activity recorded over the occipital region with eye closure and attenuating with eye opening.
- Eye blinks: Conjugate vertical eye movements at a frequency of 0.5-2 Hz present in wakefulness with the eyes open or closed
- Reading eye movements: Trains of conjugate eye movements consisting of a slow phase followed by a rapid phase in the opposite direction as the individual reads

Wake Definitions

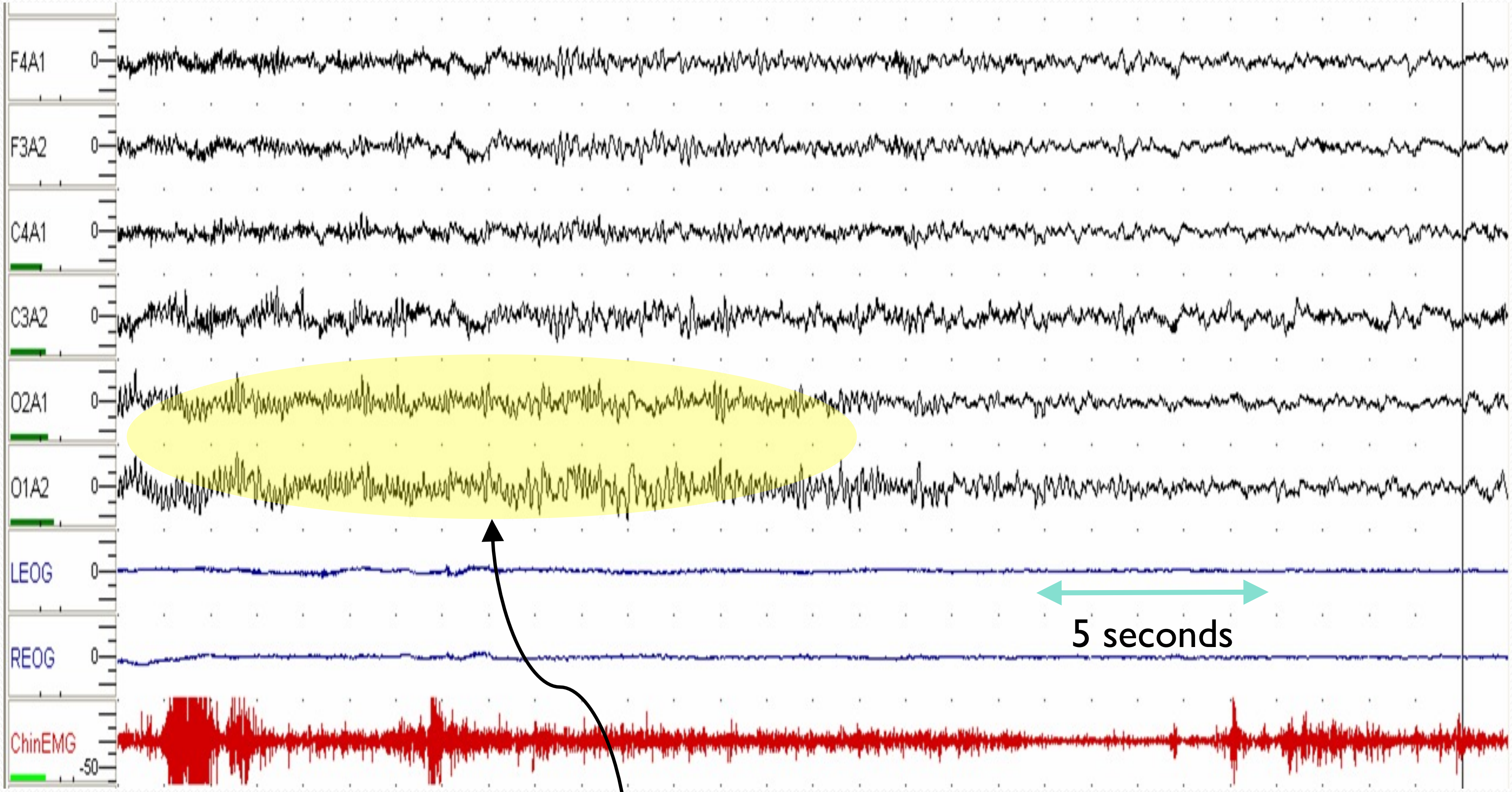
- Rapid eye movements (REMs): Eye movements recorded in the EOG derivations consisting of conjugate, irregular, sharply peaked eye movements with an initial deflection usually lasting <500 msec.
- Slow eye movements (SEM): Conjugate, reasonably regular, sinusoidal eye movements with an initial deflection that usually lasts >500 msec.

Stage Scoring Rules - Wake

A. Score epochs as stage W when more than 50% of the epoch has posterior dominant rhythm (alpha rhythm) over the occipital region.

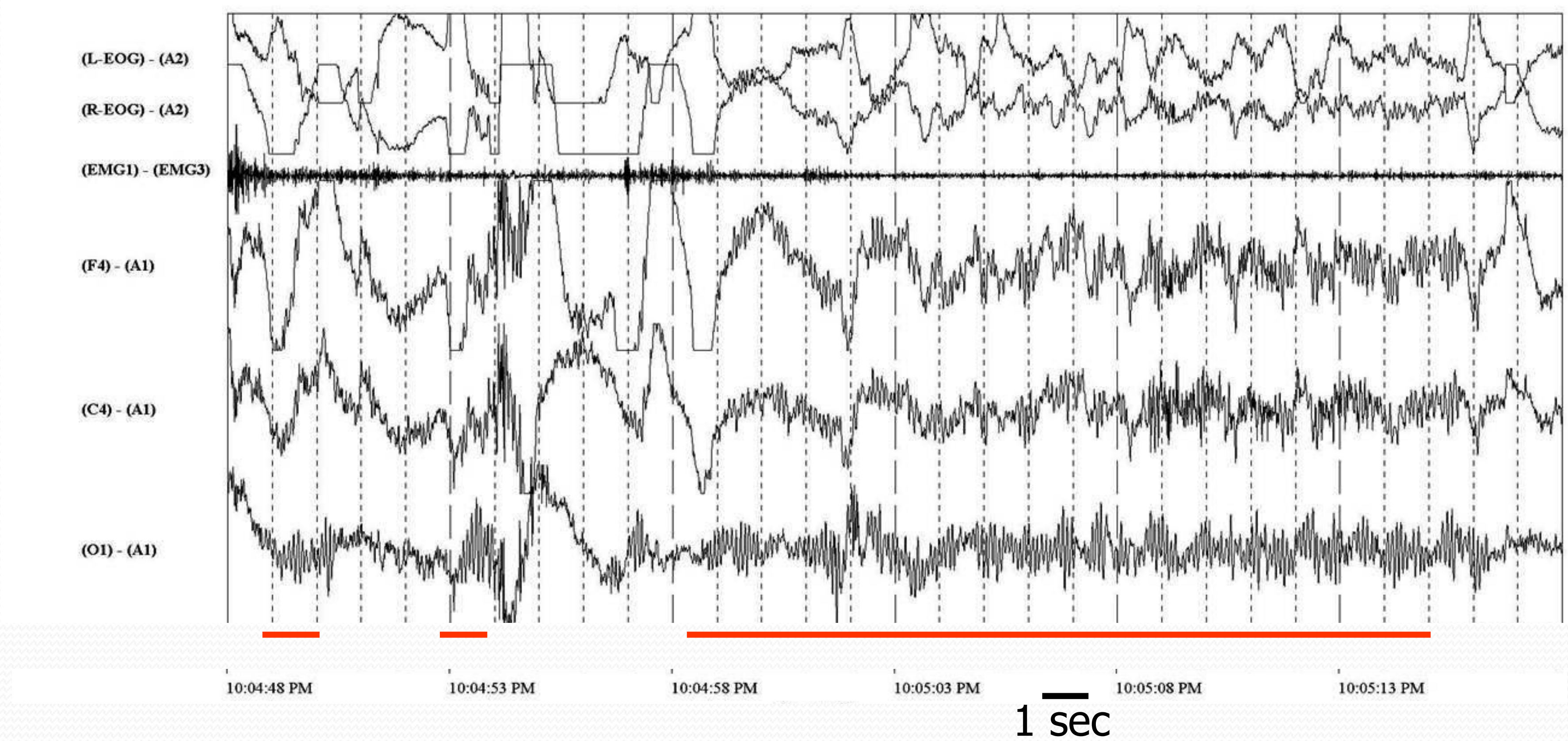


Stage W – Rule A



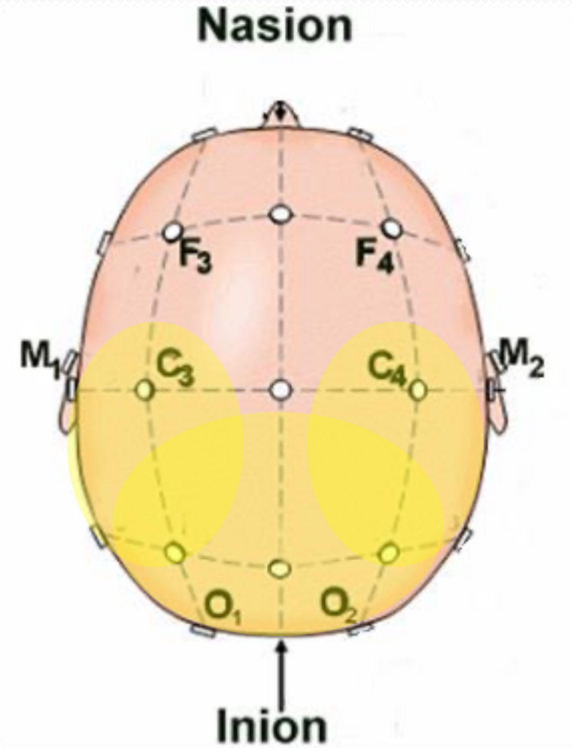
Alpha rhythm in more than half of the epoch in occipital channels

Stage W (Awake)



This slide illustrates a 30-second polysomnographic epoch scored as stage W. More than 50% of the epoch contains alpha EEG activity, especially prominent in the occipital derivation (underlined in red). Submentalis electromyographic activity is high, and there are blinking eye movements. The subject was reclining with eyes closed in a darkened room.

Distribution of Alpha Rhythm

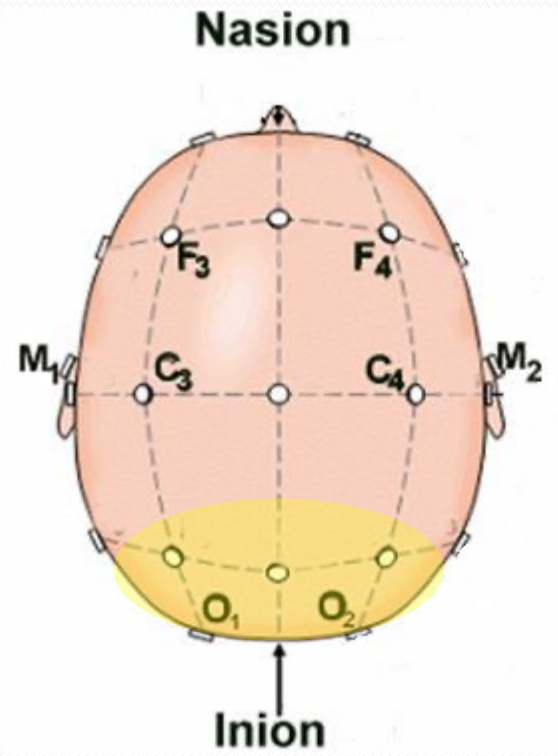


A

The distribution of alpha rhythm across the scalp varies from person to person. In individual A, the alpha generators extend forward to include the mastoid area (yellow). This means that the reference electrode (M1) is "active" – it also records alpha rhythm. Since there is alpha rhythm in M1 and alpha activity in O2, the differential amplifier that has these two leads as inputs will cancel out some of the alpha rhythm. The F4 – M1 channel will display alpha rhythm because there is alpha at the M1 electrode and not in F4.

Distribution of Alpha Rhythm

Individual B has alpha activity confined primarily to the occipital cortex. During relaxed wakefulness, central and frontal channels should show low voltage mixed frequency activity. The activity will be largest in the O2 channel. Some alpha activity will be seen in the C4 channel due to volume conduction of the brain. The reference electrodes will not pick up alpha activity because they are distant from the source, and the differential amplification of the occipital and central channels will allow a high amplitude signal.



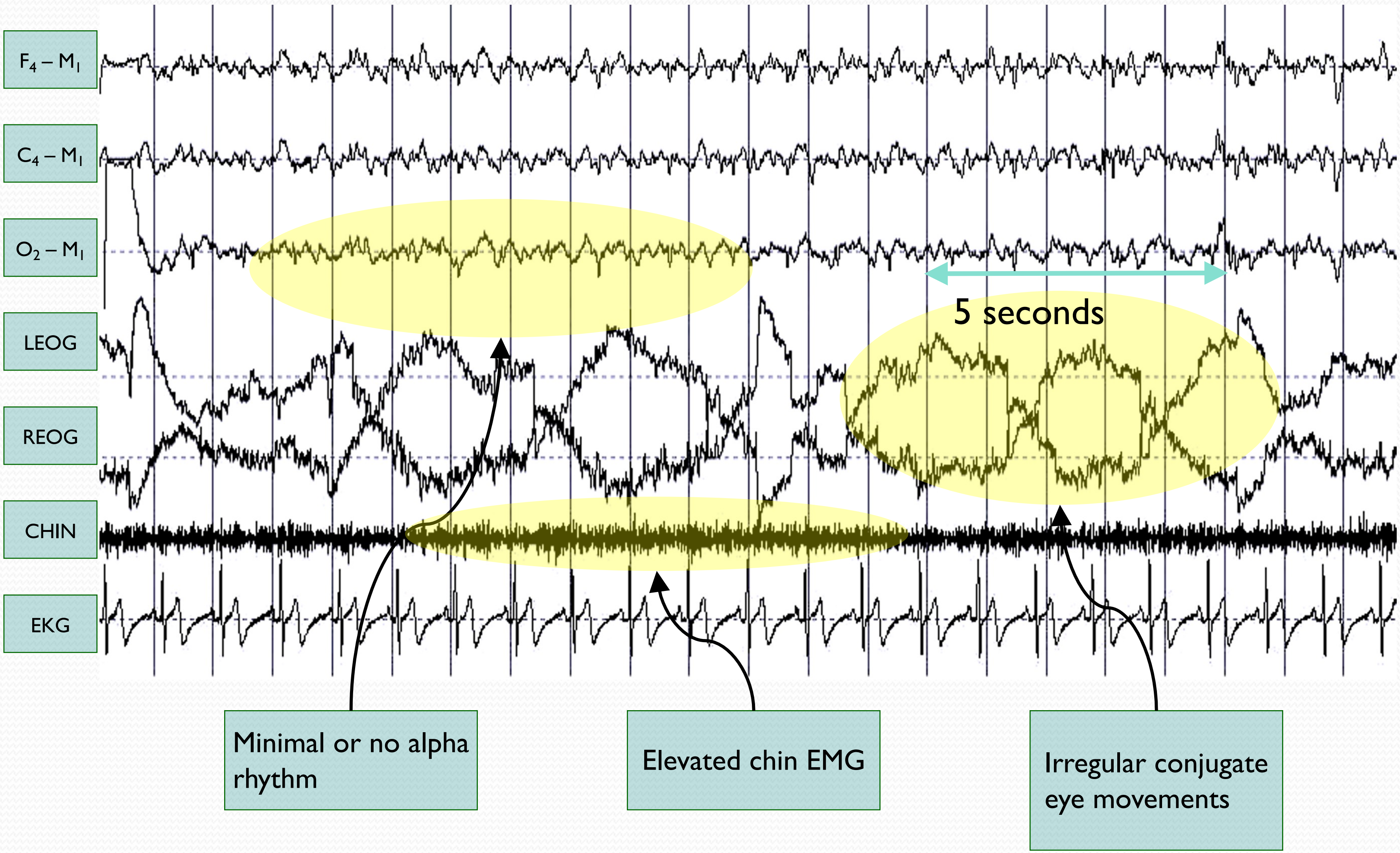
B

The paradox in this situation is that the subject with widespread alpha will have a lower amplitude signal than the subject with alpha activity confined to a smaller portion of the brain.

Stage Scoring Rules – Wake

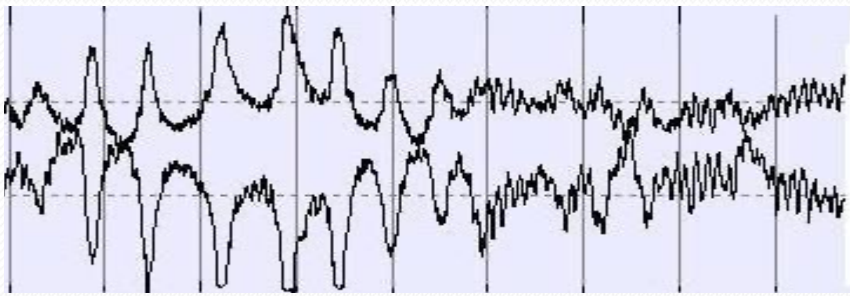
B. Other findings consistent with stage W:
   1. Eye blinks are present at a frequency of 0.5-2 Hz
   2. Rapid eye movements are present associated with normal or high chin muscle tone
   3. Reading eye movements are present

Stage W – Rule B

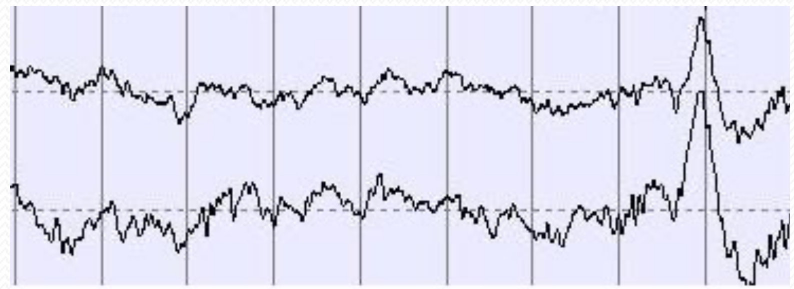


Types of Eye Movements

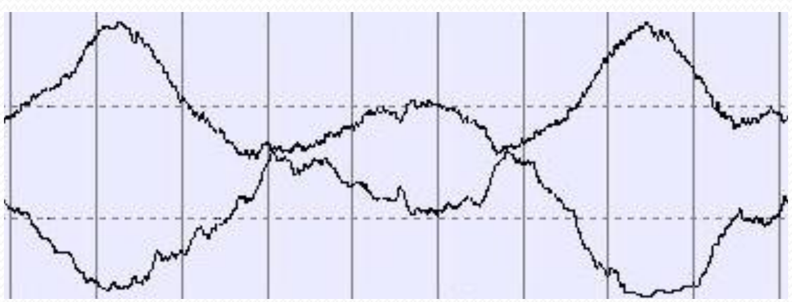
Blinks -- Stage W



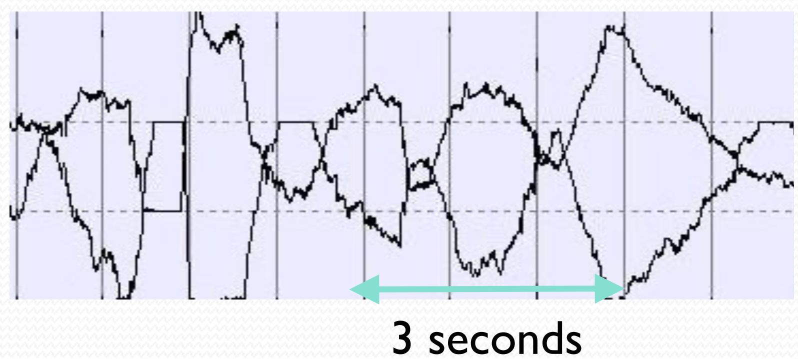
No Eye Movements -- Stage N2



Slow Eye Movements -- Stage N1



Rapid Eye Movements – Stage R



Eye Movements

- A reflex causes the eyes to roll upward when they are closed. This is called Bell's phenomenon, named after the Scottish physician, Sir Charles Bell. It is visible in some patients with Bell's palsy because their eyelids become weak, and the eyes do not close completely. When a person with Bell's palsy tries to close the weak eyelid, the eyeball rotates upward. This phenomenon occurs in about 75% of normal people but is not visible because the eye closes. Due to Bell's phenomenon, blinking produces an easily recognizable pattern of activity in eye movement channels. The eye movement channels use the mastoid electrodes as a reference. In some patients, alpha activity can be recorded from the mastoid electrodes.

Eye Movements

- Slow eye movements look like gently rolling hills – smooth ups and downs lasting several seconds. It is possible to create these movements by having someone watch a slowly moving object, but it is not possible to voluntarily produce slow eye movements without a stimulus. Sleep onset may occur without slow eye movements, but slow eye movements are rarely seen except at sleep onset.
- The retina is negative, and the cornea is positive. When the eyes move right, the left channel becomes more negative (the retina at the back of the eye get closer) and the right eye channel becomes more positive (the cornea gets closer).

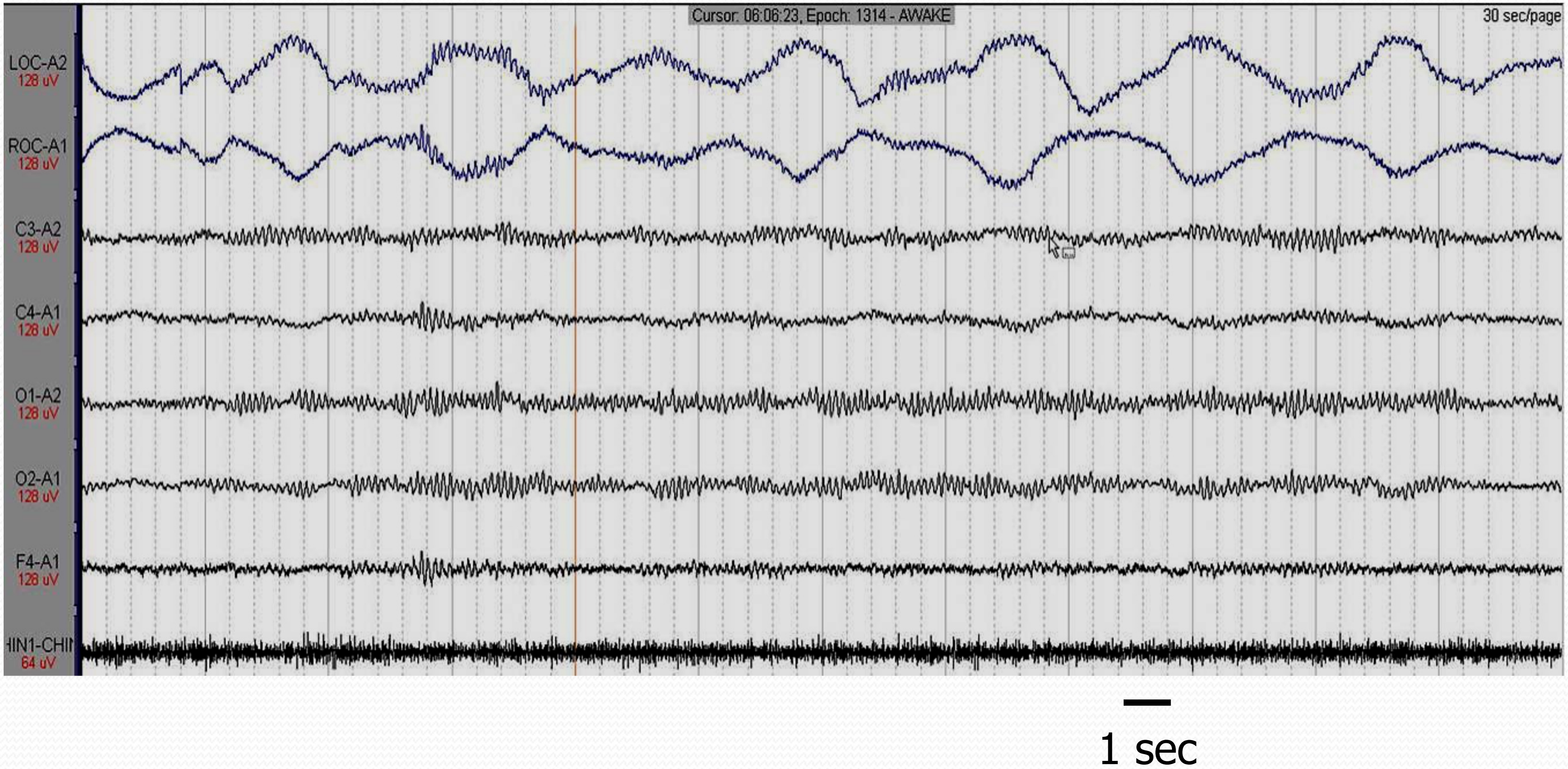
Eye Movements

- In the upper right tracing on the "Types of Eye Movements" slide, eye movements are absent. At the end of the tracing, a high amplitude signal is seen. This is caused by a K-complex that is recorded at the mastoid electrodes. How can one distinguish a vertex wave from an eye movement? K-complexes are "in phase" in both eye movement channels – negative in both channels, whereas eye movements are "out of phase" -- negative in one channel and positive in the other.

Eye Movements

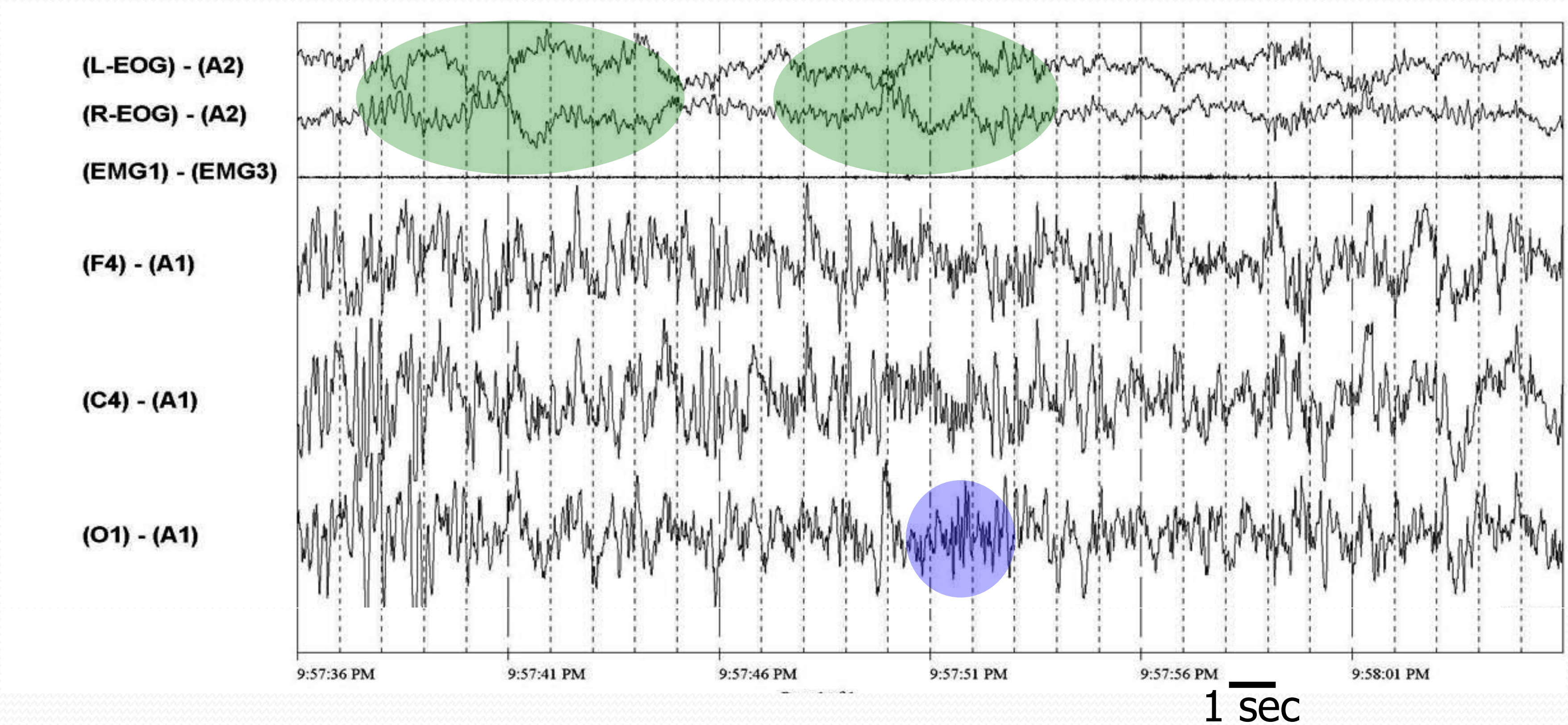
- The lower right channel on the "Types of Eye Movements" slide shows Rapid Eye Movements (REMs) of Stage R. The rapidity of the eye movements causes sharp changes in amplitude. These look like craggy peaks rather than gentle hills. Patients will typically move from Stage N2 to R, making REMs easy to distinguish. REMs often occur in bursts.

Slow Eye Movements While Awake



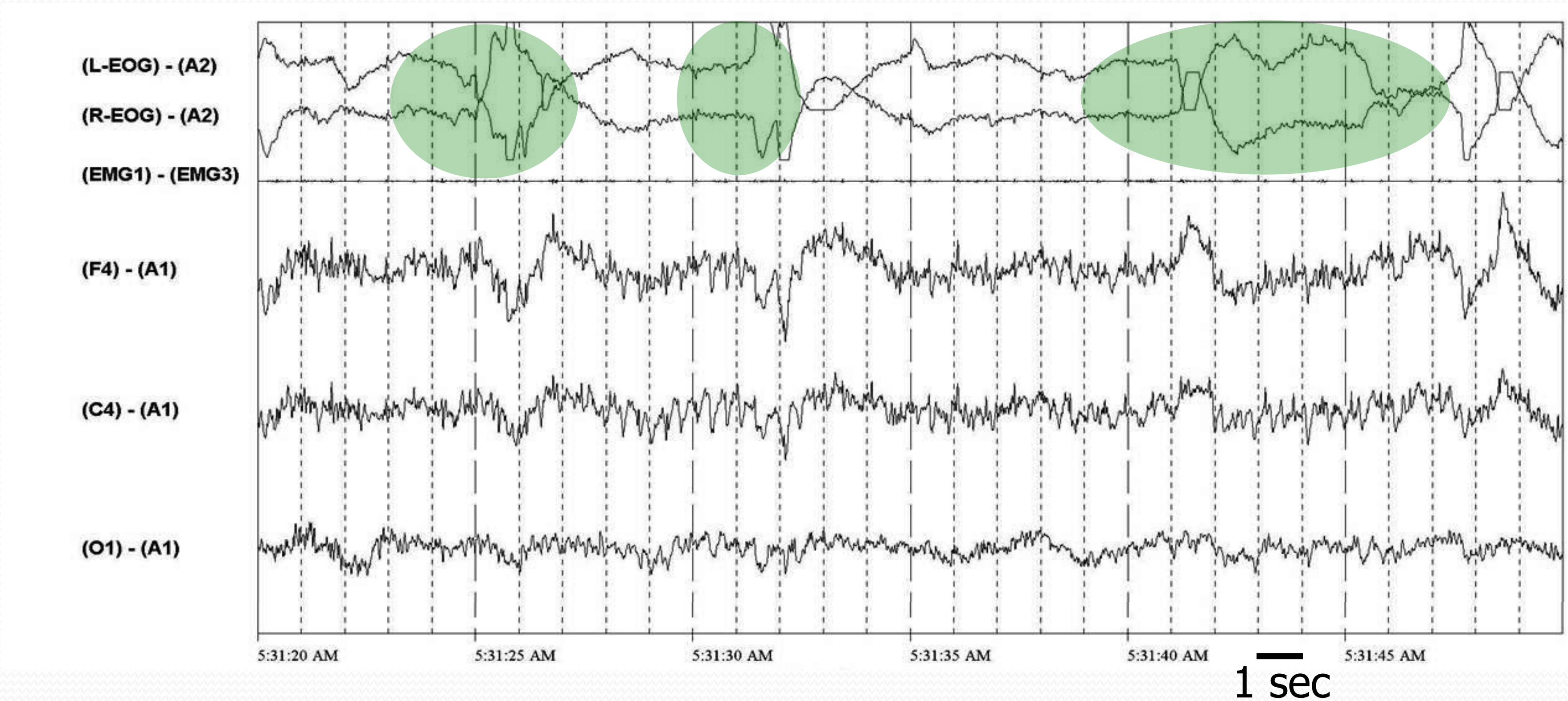
This slide shows the evolution of slow eye movements during the awake state before sleep onset has occurred.

Slow Eye Movements During Sleep



As an individual falls asleep, slow eye movement activity may continue for a while. In the slide shown here, we see rhythmic slow eye movements (highlighted in green) during sleep onset. Note also the brief increase in alpha activity (highlighted in blue).

Rapid Eye Movements (REM)



The rapid eye movement is one characterized by rapid, saccadic movement that may occur individually or in bursts (highlighted in green on this slide). When recordings are made using standard technique, rapid eye movement can be differentiated from slow eye movements. Rapid eye movements are characteristically sharply peaked with an initial deflection usually lasting 0.5 seconds or less, while slow eye movements are more regular and sinusoidal, with an initial deflection usually lasting greater than 0.5 seconds.

Additional Notes on Stage W

- Stage W represents the waking state, which ranges from full alertness to early stages of drowsiness.
- Most people will demonstrate posterior dominant rhythm (alpha) in Stage W when their eyes are closed. When the eyes are open, it is low-amplitude activity. About 10% of people do not generate posterior dominant rhythm (alpha), and another 10% may generate a limited posterior dominant rhythm (alpha) rhythm.
- The EOG during Wake may demonstrate rapid eye blinks at a frequency of about 0.5-2 Hz. The earliest sign of drowsiness is the absence of eye blinks.

Additional Notes on Stage W

- The chin EMG during Wake is of variable amplitude but is usually higher than during sleep stages.
- Time where the patient is disconnected from the recording equipment should be scored as Stage W.
- Posterior dominant rhythm has traditionally been called alpha rhythm; however, the term posterior dominant rhythm is preferred because not all alpha activity is posterior dominant rhythm (PDR). The normal range for PDR in adults is 8.5-13 Hz, and in infants over 6 months and young children, it typically starts in the upper delta and theta frequency and gradually increases in frequency as the child ages.