# Nox SAS Detailed Scoring Commentary

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The Nox SAS solution is a new, flexible way to record EEG, ECG and EMG data during polysomnography sleep studies conducted with the Nox A1s PSG system. The solution comes with disposable EEG electrodes that are secured to the patient's forehead, a head cable, and body cables. The Nox SAS aims to make the hookup process simple and comfortable for clinicians and patients alike.

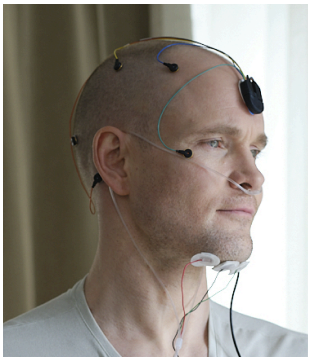
The Nox SAS solution will be familiar to physicians and technicians experienced with the AASM rules for sleep analysis, and these guidelines can be broadly followed with a few considerations.

### Nox SAS solution compared to conventional PSG:

- Nox SAS features frontal-only EEG.
- Nox SAS uses EOG instead of mastoid (M1 & M2) references.
- Nox SAS EMG is derived from the EOG channels on the forehead (frontalis muscle), between the auricular and orbital region, rather than the conventional chin EMG.

### Conventional AASM - EEG

- 8 EEG channels
- 2 EOG channels
- 2 EMG chin channels



### Nox SAS - Frontal EEG

- 9 channels
- Recording EEG and EOG (incl. EMG measures)

### Nox SAS Analysis Considerations:

- Nox SAS sleep data can look both familiar and slightly different depending on the epoch. Feedback from the field recommends reviewing a few studies to familiarise yourself with the sleep stage patterns of Nox SAS.
- The EEG signals available for analysis with Nox SAS are limited to frontal channels. This requires adjusting your analysis approach compared to the AASM standard configuration. A key consideration is that the absence of occipital channels means you will not observe posterior-dominant rhythm (alpha), which is typically used to score sleep onset and arousals from sleep. As a result, you will need to use alternative indicators within the frontal EEG to accurately score these events.
- Nox SAS EEG features lower amplitude and power compared to conventional PSG. To help with this, the Nox Medical team has developed a SAS Frontal Filter (Noxturnal 7.1) that amplifies waveforms in the analysis range to be more like their PSG counterparts. If you decide not to use the Frontal Filter, consider adjusting your requirement for sleep staging based on amplitude (e.g. N3)[1,5].
- Nox SAS PSG can introduce eye movement artefact into the EEG channels due to the location of the reference electrodes. This EOG bleed can be misinterpreted for sleep physiology if not considered in context. A solution is to adjust the low-frequency filter when required to reduce the EOG bleed or sway artefact. When analysing Nox SAS studies, be careful not to mistake slow eyes movements for delta waves and REMs for N2 waveforms.

- Feedback from the field suggests Nox SAS EMG derived from EOG is not as responsive to changes in sleep stage (e.g. REM atonia). Other REM physiology should be taken into consideration[2]. If you have difficulty staging REM, work backwards from a definitive epoch.

With these points, the scoring of Nox SAS studies is expected to have a quick adaptation period and can be scored with the same rules as the AASM Manual for the Scoring of Sleep and Associated Events (Version 3, Feb 2023)[2]. What follows is a consideration for scoring Nox SAS studies with the established AASM rules.

## Nox SAS Background

The Nox SAS solution differs from conventional PSG in a few ways.

### Nox SAS is Frontal EEG only.

- For sleep staging purposes, the Nox SAS channels AF4-E3E4 and AF3-E3E4 are similar to PSG channels F4-M1 and F3-M2, though they use different references (see below). The backup derivatives are AF7-E3E4 and AF8-E3E4.

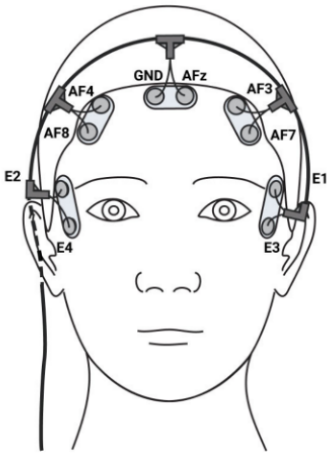
### Nox SAS replaces conventional mastoid (M1M2) with EOG reference (E3E4).

- Each of the AF-leads from the frontal montage is referenced to the average of E3 and E4 electrodes to reduce eye movement artefacts in the EEG.

### Nox SAS utilises EMG derived from the EOG signals to replace the conventional chin EMG.

- Nox SAS measures EMG derived from the muscles of the forehead.
- The design allows patients with facial hair to easily achieve good-quality EMG signals.

The table below outlines the signals available for sleep staging. Nox SAS also features ECG, nasal flow, respiratory effort (RIP), and dual limb EMG.

| Nox SAS Sleep Staging Signals | | |
|---|---|---|
| AFz | Reference | |
| AF3-E3E4<br>AF4-E3E4<br>AF7-E3E4<br>AF8-E3E4 | Frontal EEG | |
| E2-AFZ<br>E3-AFZ | EOG | |
| EMG.Frontalis-Left: Corresponds to the E1-E3 signal<br>EMG.Frontalis-Right: Corresponds to the E2-E4 signal | EMG derivation via EOG electrodes |  |

## Nox SAS Sleep Staging Considerations

Nox SAS has already been used for research purposes involving thousands of subjects in the field[1,3].

With this in mind, we will consider details and methods clinician can use to aid Nox SAS scoring. Feedback from technicians and physicians analysing Nox SAS studies, as well as research from the Nox Medical team, has found a few important considerations for sleep staging with Nox SAS. These include:

- Nox SAS is frontal EEG only
- Nox SAS EEG has been shown to feature lower amplitude and power across the analysed frequency range[1]. Nox Medical has developed an EEG filter (Noxturnal 7.1) which digitally amplifies the EEG signals to better mimic conventional PSG.
- The EOG-based reference for the frontal EEG can add artefact and EOG bleed into the EEG. It is possible to adjust the low-frequency filter (LFF) to reduce or remove this EOG bleed into the EEG.
- The Nox SAS EMG derived from EOG can perform differently to the conventional chin EMG of PSG. Other aspects of sleep physiology should be considered when staging, particularly REM, and scoring arousals.

These will all be explored in detail below.

## Nox SAS Frontal EEG

Results from a study comparing manual scoring of simultaneously recorded standard PSG and Nox SAS show areas where clinicians should focus on when learning to score with Nox SAS. The table below compares sleep stage classifications between the Nox SAS system and the AASM A1s Montage (EEG, EOG, chin EMG).

The results show high agreement in most stages, particularly for N2 (90.7%), N3 (76.4%), REM (83.9%), and Wake (80.9%). However, some discrepancies were noted, especially with N1, where 29.5% of N2 epochs and 7.7% of REM epochs were misclassified as N1 by the Nox SAS. Users should be aware of these potential misclassifications when analysing sleep data, particularly in studies requiring precise stage differentiation.

| | | AASM A1s Montage EEG, EOG, and chin EMG | | | | |
|---|---|---|---|---|---|---|
| | | **N1** | **N2** | **N3** | **REM** | **Wake** |
| **Nox SAS** | **N1** | 59.2 | 2.4 | 0.03 | 2.9 | 7.3 |
| | **N2** | 29.5 | 90.7 | 23.0 | 12.6 | 10.4 |
| | **N3** | 0.1 | 2.4 | 76.4 | 0.03 | 1.2 |
| | **REM** | 7.7 | 4.2 | 0.6 | 83.9 | 1.2 |
| | **Wake** | 3.6 | 0.3 | 0.07 | 0.43 | 80.9 |

## Scoring Guide for N1 Sleep Stage Using Nox SAS

Nox SAS only records frontal EEG. When staging N1, it is important to recognize this limitation in detecting the posterior-dominant rhythm (also known as the alpha rhythm. The alpha rhythm is typically most prominent in the occipital channels during standard PSG, but since Nox SAS focuses on frontal channels, the rhythm might not be as clearly visible or reliable.

To improve N1 scoring accuracy:

- Understand that not all individuals exhibit a strong, easily recognizable alpha rhythm. Given that Nox SAS does not monitor occipital channels, identifying alpha rhythms in the frontal leads may be challenging or unreliable.
- The AASM manual provides guidelines for sleep staging when alpha rhythms are unclear or absent. Consider these alternative criteria, focusing on the overall context of the recording, such as the transition from wakefulness to sleep, and using other available cues like slow eye movements or reductions in chin EMG tone to help identify N1 sleep.

This approach will help mitigate the limitations of the Nox SAS system and improve the reliability of N1 scoring in the absence of robust posterior-dominant rhythms.

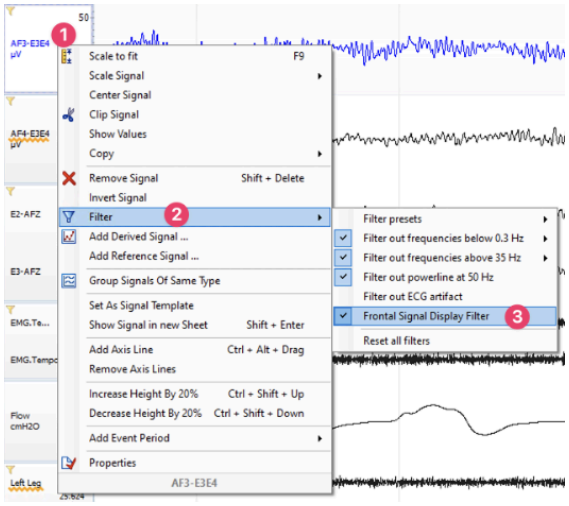
## Nox SAS EEG Amplification and Power Considerations

Research performed by the Nox Medical team has shown that Nox SAS EEG features lower amplitude and power across the analysed frequency range of 0.3-35Hz[1]. A Frontal filter has been developed which digitally amplifies the SAS EEG signals to better mimic those from PSG.

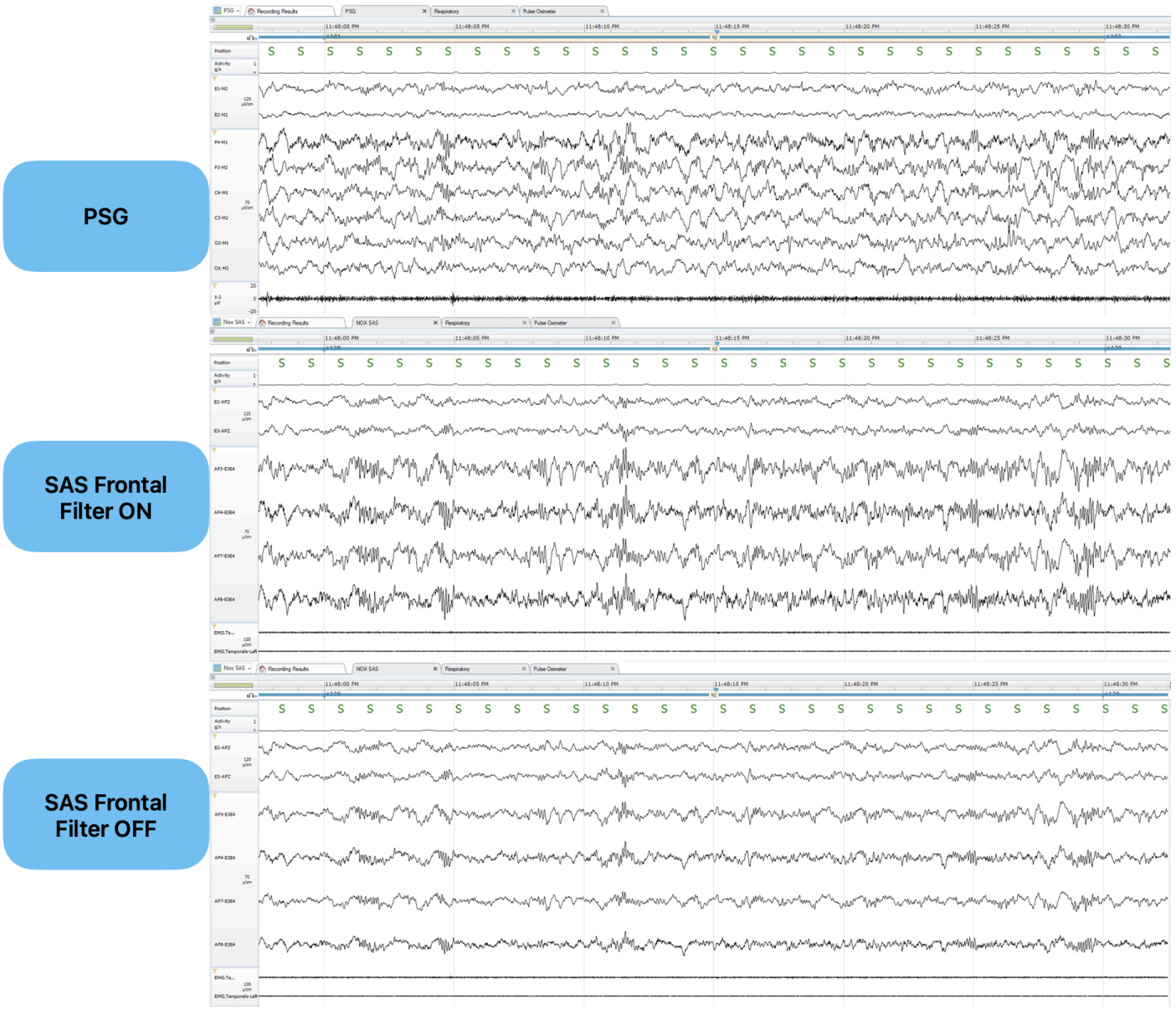
### Scoring with the Nox SAS Frontal Filter recommendations:

- Familiarise yourself with the EEG pattern by scrolling through and adjusting the epoch time between 30s and 1 minute to get a feel for the amplitude and frequency of the EEG
- The Frontal Filter is *optional* but comes activated as standard in the built in Nox SAS worksheet.
- If using the standard PSG filter with SAS, consider lowering the threshold for delta based on a review of the overall PSG pattern.

The Nox SAS Frontal Signal Display Filter is used in addition to the standard filter settings for EEG. The image below shows the standard AASM EEG filters (LFF 0.3Hz and HFF 35Hz) plus the addition of the frontal filter to amplify the signals. The Nox SAS Frontal filter can be turned on and off for EEG signals in the filter settings.

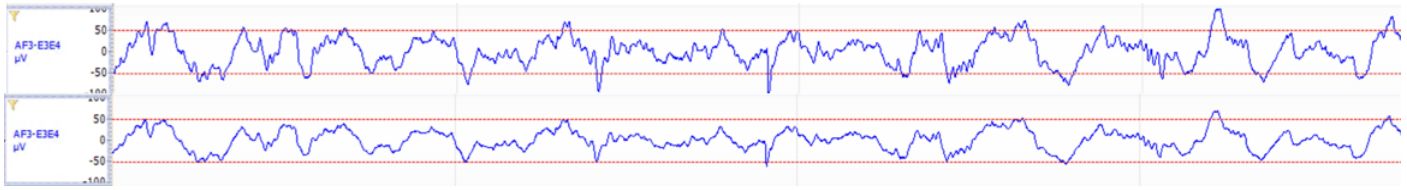



The Nox SAS Frontal Signal Display Filter design focuses on accurately converting signals from the Nox SAS system (specifically AF4-E3E4 and AF3-E3E4) into their equivalent PSG signals, which are essential for accurate sleep staging. The primary goal was to match the frequency response of the SAS signals to the PSG counterparts, particularly for NREM sleep stages.




To achieve this, the design targeted the average of the median frequency responses for NREM. NREM frequency responses were selected because they exhibit a characteristic dip in the alpha band, a feature that is distinctive to NREM and helps differentiate it from wakefulness and REM sleep. Accurately reflecting this dip is crucial for sleep stage classification.

Moreover, the design aimed to ensure that the power levels of the SAS signals align with those of the PSG signals, which is vital for maintaining consistent amplitudes. This consistency is particularly important for correctly applying the thresholding rule used in scoring N3 sleep stages, where specific amplitude thresholds are crucial. The screenshots below compare N3 with and without the frontal signal filter. The top signal is with the frontal filter and the bottom is without. Notice the increased amplitude of the delta waves.



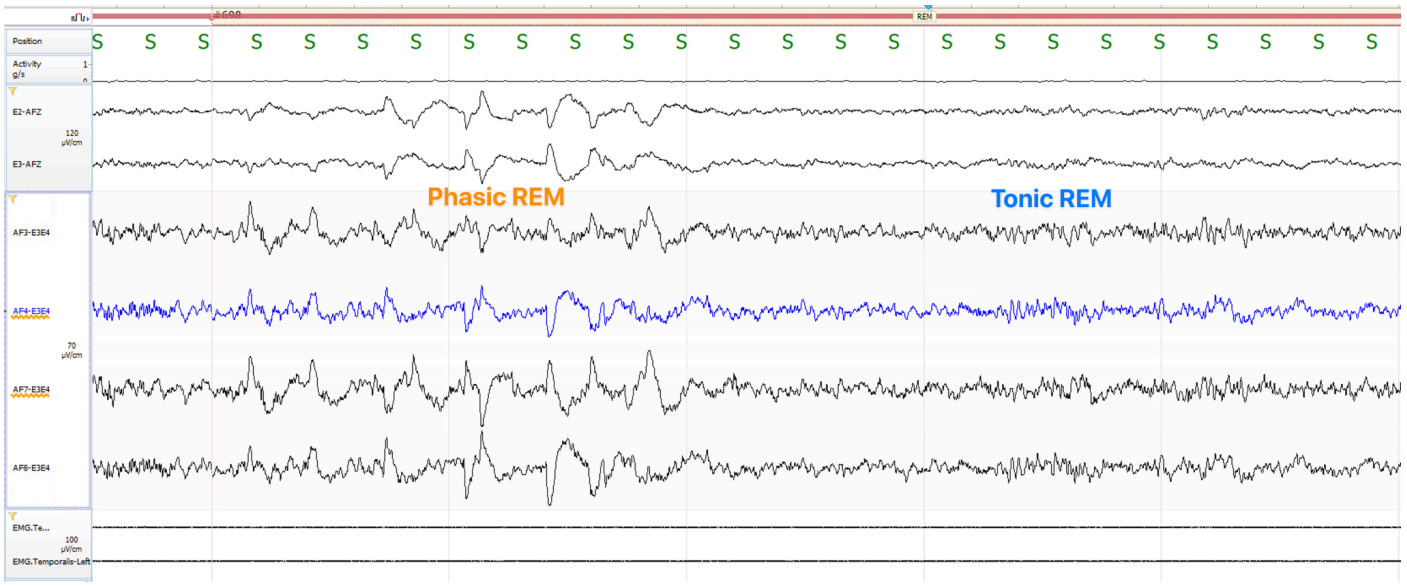

## Nox SAS EOG-based reference considerations

Nox SAS replaces the conventional mastoid reference for the unipolar channels with references derived from EOG. This results in a few changes to the EEG. Nox SAS uses the average E3E4 (voltage) as the reference instead of average M1M2 (voltage). As a result, eye movements can occasionally be seen in the EEG. This EOG bleed should not be misinterpreted for other characteristics of EEG, including:

- Slow eyes movements of sleep as delta waves or N3
- Wake eye movements for delta waves
- REMs for NREM waveforms (k-complexes or delta waves)

Adjustments to the low frequency filter (LFF; also known as high pass filter) can help reduce the EOG bleed into the EEG. Feedback from the field suggests increasing the LFF from 0.3Hz to 0.5Hz for periods of the study that feature EOG bleed can aid analysis. It is important to consider that increasing the LFF will impact the amplitude of the signals. Play around with the filter settings to understand what is best for you without compromising the overall signal quality.

Below shows a Nox SAS with EOG bleed from REMs into the EEG. This waveform deviation should not be considered when staging the EEG. Periods between REMs (Tonic REM) show the low-amplitude, mixed frequency EEG waveform that is characteristic of REM.



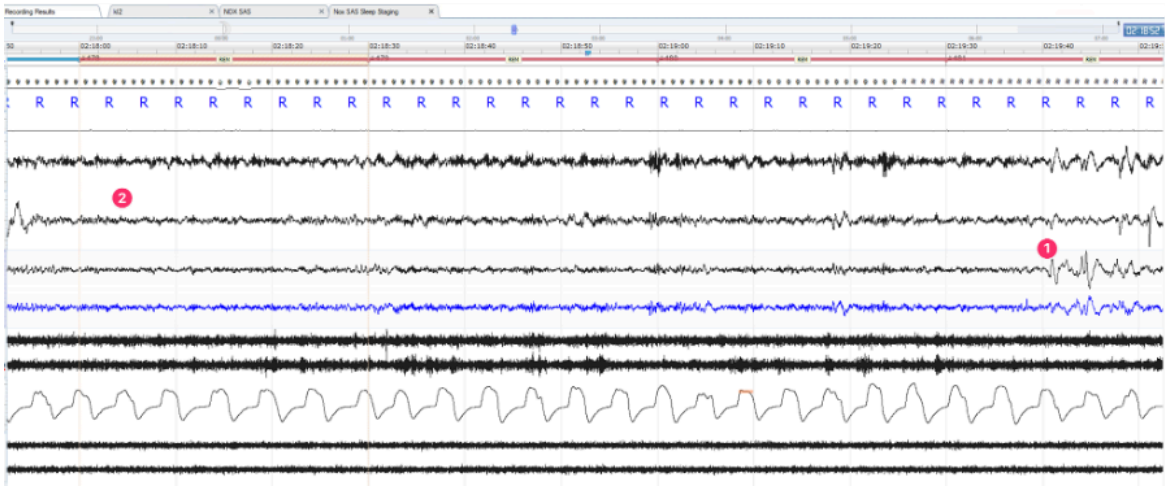
## Nox SAS EMG Considerations

As mentioned, Nox SAS streamlines the PSG set-up and replaces chin EMG with measurements from the facial muscles near the EOG electrodes. Feedback from the field suggests the usual EMG tone (voltage amplitude) changes with sleep stages and arousals is not as prominent as conventional PSG. This is similar to the amplitude difference when adhesive electrodes are used instead of gold-cup electrodes in conventional PSG. As a result, it is recommended to use all the data available when performing sleep staging and arousal scoring with Nox SAS, particularly when staging REM.

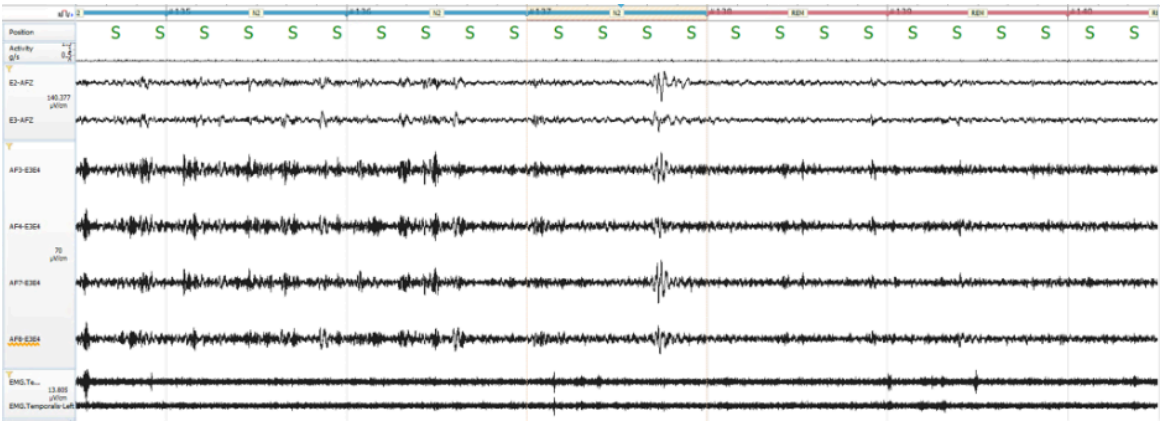
The AASM defines low chin EMG tone as "baseline EMG activity in the chin derivation no higher than in any other sleep stage and usually at the lowest level of the entire recording" (Section I, 1.1)[2]. In Nox SAS, the chin EMG tone is often not at the lowest level seen in the recording, though it has not been observed to be higher than during wakefulness or NREM sleep. It is recommended to identify definite REM epochs throughout the study to establish a baseline for the REM EMG tone.

In REM, consider the EEG for low-amplitude, mixed-frequency (LAMF) waveform, rapid eye movements in the EOG, and other characteristics of REM, such as variable respiration and heart rate, and reduced or no muscle activity (EMG, limb EMG, and activity signal). It is crucial to avoid confusing EOG bleed with NREM waveforms during REM sleep.

When determining the onset of REM, stage REM at the first obvious epoch with LAMF and rapid eye movements. Use the AASM score back rules (Section I, 1.3)[2] to score REM for contiguous epochs that feature LAMF and are missing the defining characteristics of NREM (spindles, K-complexes, and delta waves). In this example, one (1) shows the onset of rapid eye movements, and two (2) shows the score back rule for LAMF EEG without REMs.



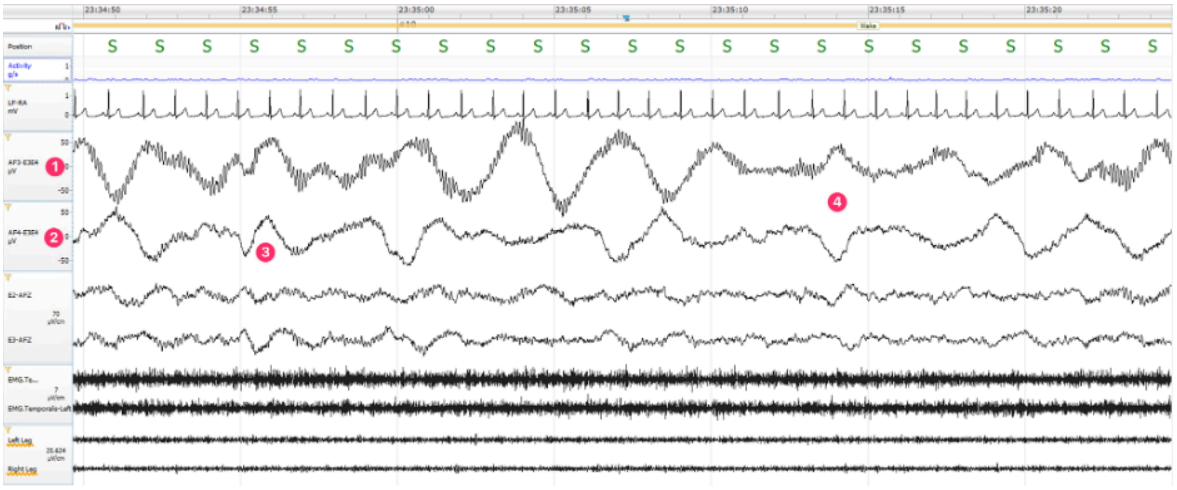

This second example again shows the change from the N2 waveform into the LAMF waveform of REM. Changing the time signature for the EEG can help when determining REM onset when EMG changes are not definitive.

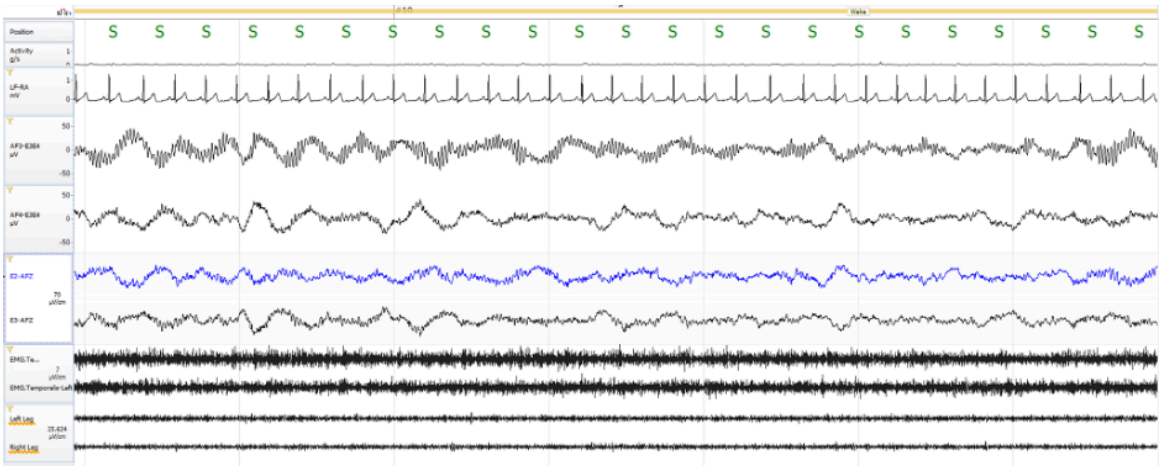

Position
Activity
E2-AFZ
E3-AFZ
AF3-E3E4
AF4-E3E4
AF7-E3E4
AF8-E3E4
EMG.Temporalis Left

# Detailed Nox SAS Examples:

## Stage Wake

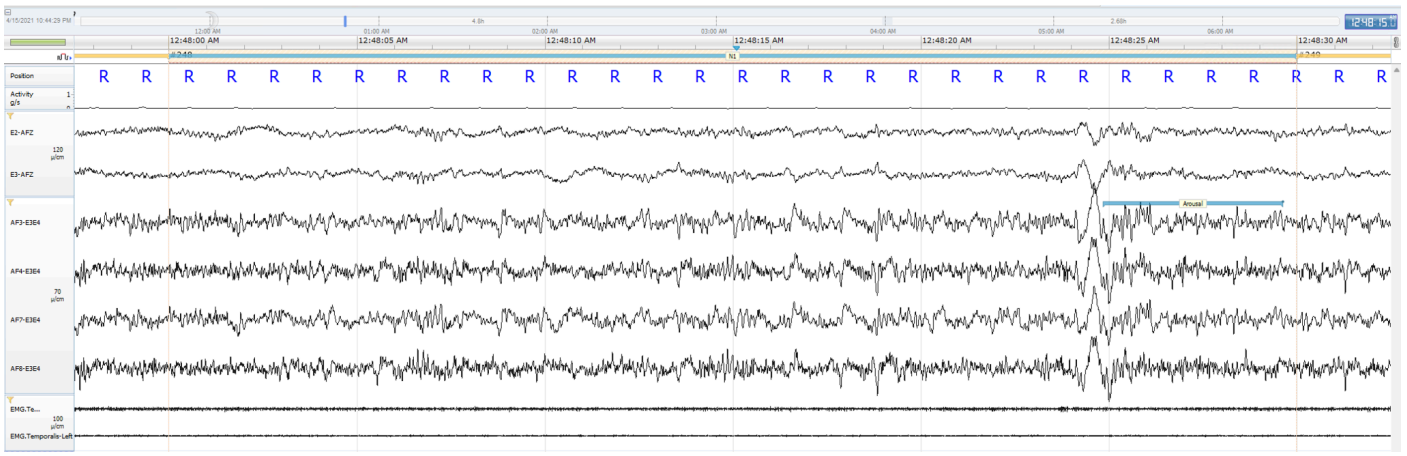
This example shows stage wake just prior to the transition to N1. Signal 1 features the frontal filter and shows strong alpha rhythm. The slow rolling eye movements of N1 can be seen bleeding into the EEG. Below is the same epoch but the low-frequency filter (LFF) has been adjusted from 0.3 to 0.5Hz to aid in the removal of some of the slow eye movements from the EEG.





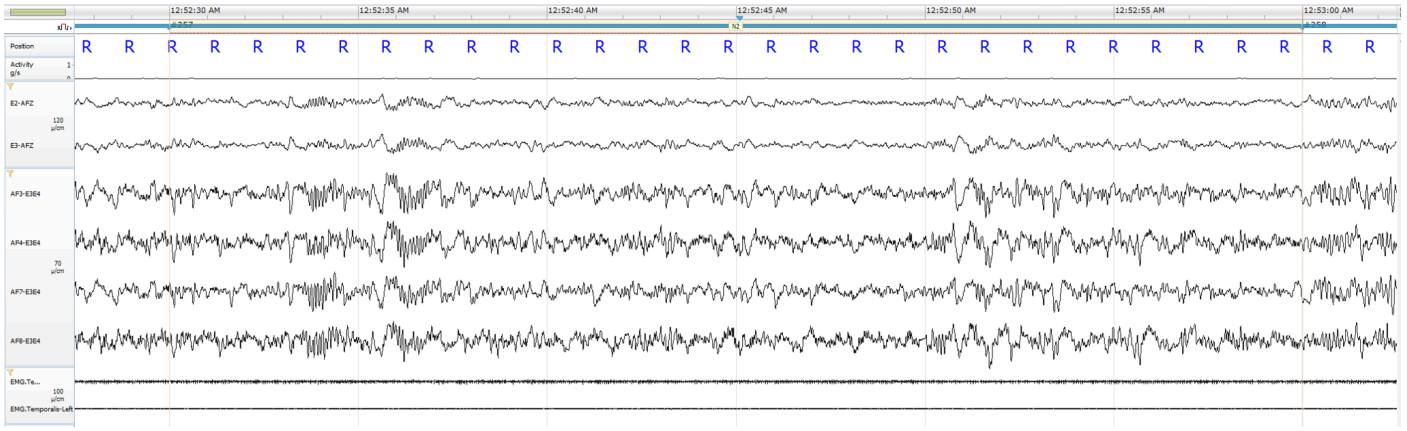
## Stage N1

This example shows the transition from wake to N1 with the slower EEG frequency and the cessation of the slow eye movements.



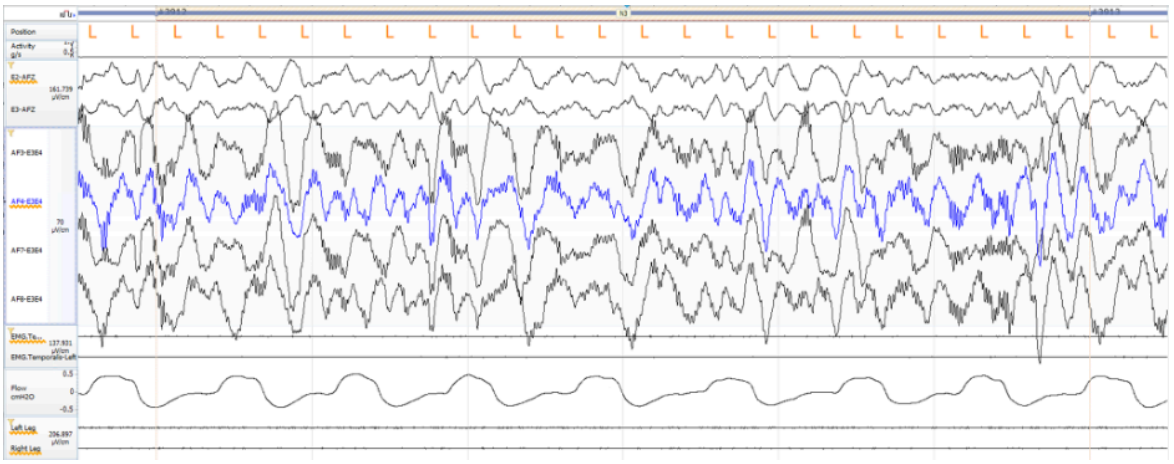

## Stage N2

This example shows the N2 with the SAS frontal EEG and the Frontal Filter applied.



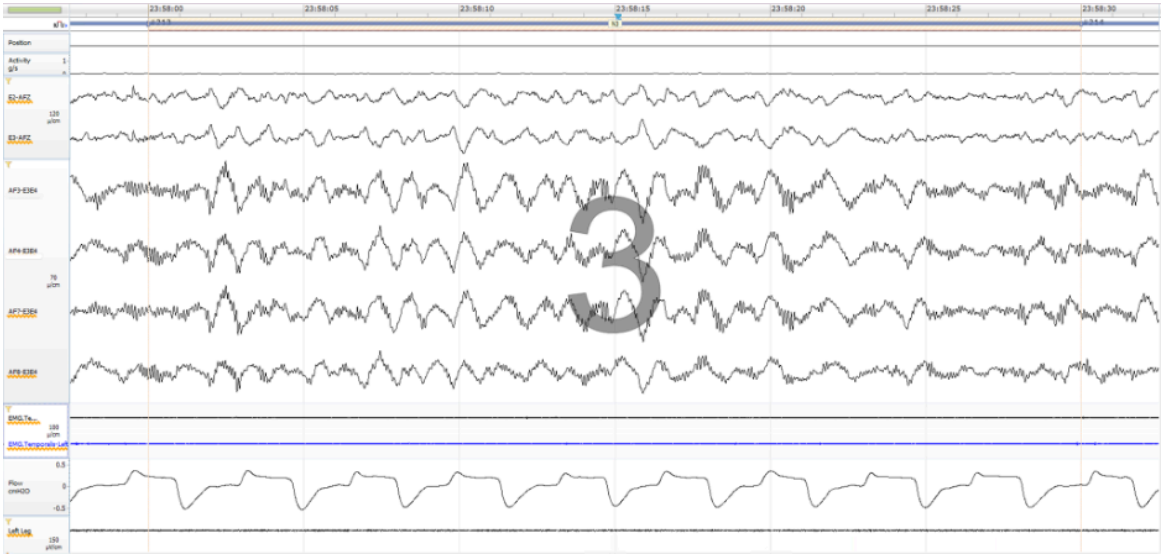

## Stage N3

The example epoch below shows distinctive delta wave morphology for all EEG signals (frontal signal ON).

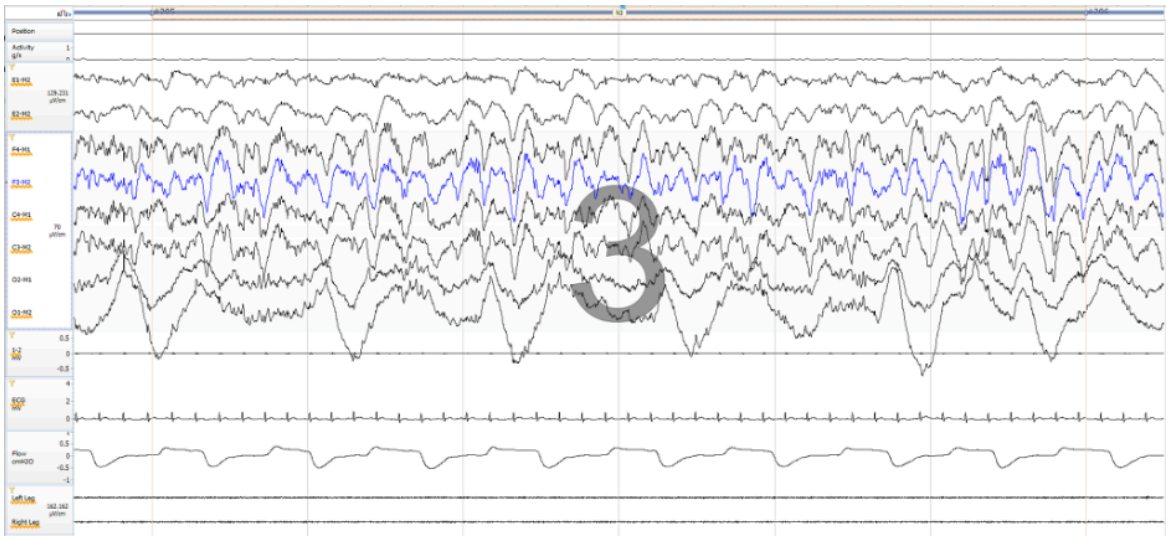


Below is a comparison of delta wave activity between SAS and conventional PSG. Both have clearly defined delta wave activity consistent with N3 staging. The amplitude of the Nox SAS waveforms can be seen to be slightly reduced, consistent with the findings of the Nox Medical team and feedback from the field. In both examples, the sleep stage is easily identifiable with the AASM staging rules.

**Nox SAS:**

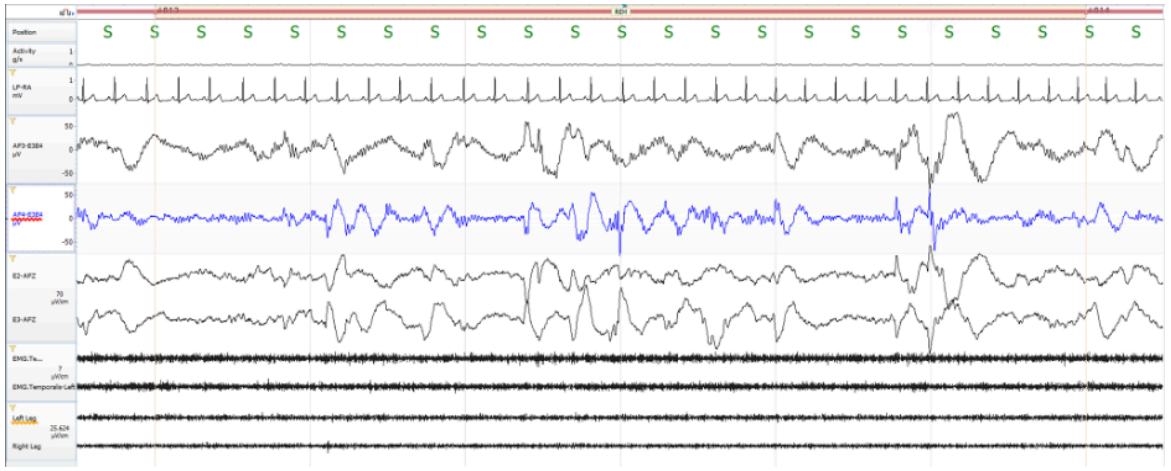


**Conventional PSG:**



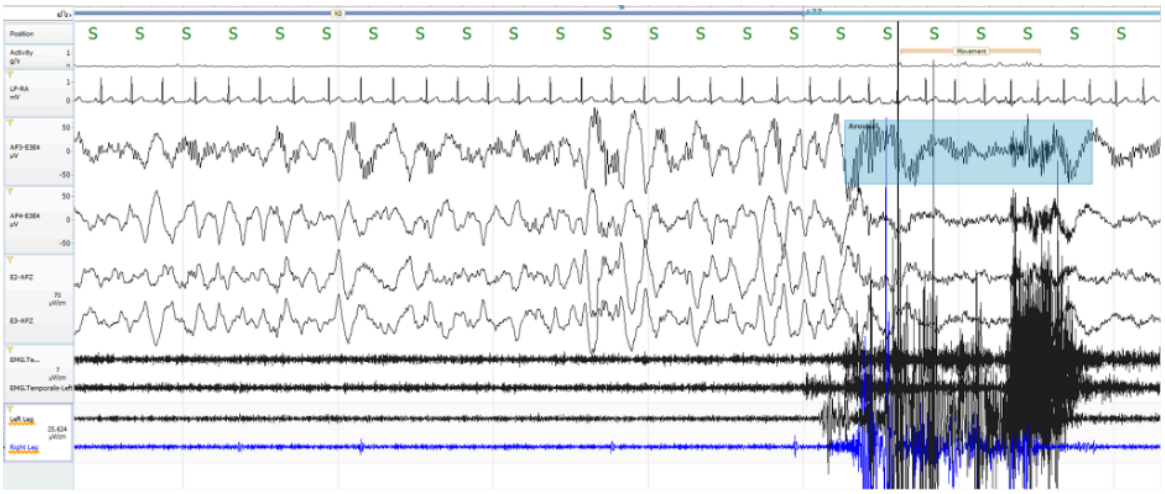

## Stage R

The example epoch below shows clear REM waveforms and rapid eye movements with a flat EMG. Note the EOG bleed with REMs featuring in the EEG. It is important not to see this EOG bleed as a deviation from the low amplitude mixed-frequency (LAMF) waveform consistent with REM.

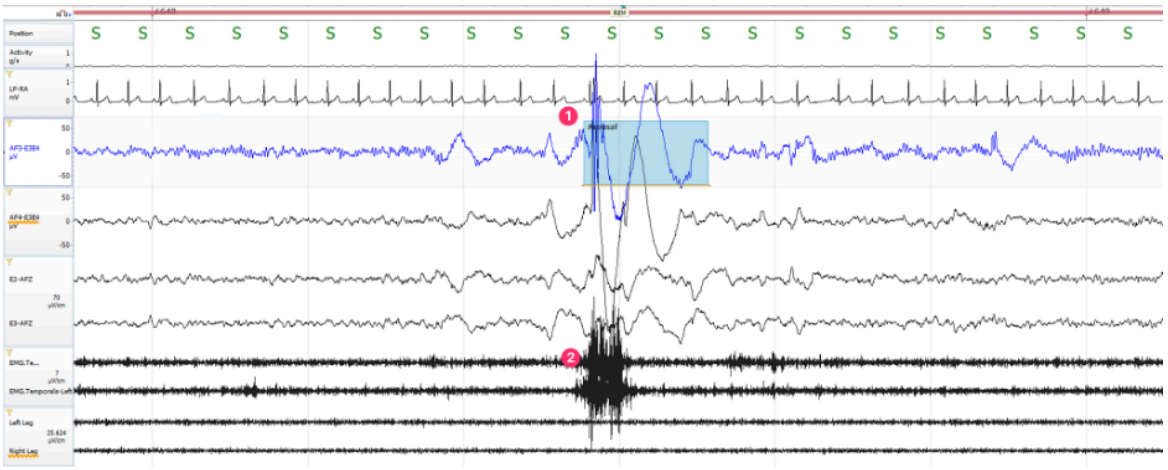


## Nox SAS Arousals

**Stage N3 arousal**



The below example features an abrupt change in EEG frequency and amplitude and increased EMG (EOG) consistent with REM arousal.



## References:


1. S. Kainulainen *et al.*, "Comparison of EEG Signal Characteristics Between Polysomnography and Self Applied Somnography Setup in a Pediatric Cohort," in *IEEE Access*, vol. 9, pp. 110916-110926, 2021, doi: 10.1109/ACCESS.2021.3099987.
2. Troester MM, Quan SE, Berry RB, ct al; for the American Academy of Sleep Medicine. The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications. Version 3. Darien, IL: American Academy of Sleep Medicine; 2023..
3. Punjabi NM, Brown T, Aurora RN, et al. Methods for home-based self-applied polysomnography: the Multicenter AIDS Cohort Study. *Sleep Adv*. 2022;3(1):zpac011. Published 2022 Apr 29. doi:10.1093/sleepadvances/zpac011
4. N M Punjabi, P W Kaplan, J Margolick, R N Aurora, 0319 A Simplified Bipolar Frontal Montage for Recording and Staging Sleep, Sleep, Volume 41, Issue suppl_1, April 2018, Page A122, https://doi.org/10.1093/sleep/zsy061.318
5. Rusanen, M., Korkalainen, H., Gretarsdottir, H., Siilak, T., Olafsdottir, K. A., Töyräs, J., Myllymaa, S., Arnardottir, E. S., Leppänen, T., & Kainulainen, S. (2024). Self-applied somnography: technical feasibility of electroencephalography and electro-oculography signal characteristics in sleep staging of suspected sleep-disordered adults. Journal of Sleep Research, 33(2), e13977. https://doi.org/10.1111/jsr.13977