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REVIEW ARTICLE

# Atlas and Updated Rules for the Scoring of Cyclic Alternating Pattern (CAP) in Human Sleep. A Consensus Report by a Taskforce of the European Sleep Research Society

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## ABSTRACT

The cyclic alternating pattern is a hallmark of the dynamic organisation of non-rapid eye movement sleep, reflecting the brain's oscillatory regulation of arousal and sleep stability. Since the original publication of the rules for scoring the cyclic alternating pattern in 2001, major advances in sleep neurophysiology, signal analysis and international sleep staging standards have necessitated a comprehensive revision. This consensus report by a Taskforce of the European Sleep Research Society presents the updated 2025 Atlas and Rules for the scoring of the cyclic alternating pattern in human sleep. The new guidelines preserve the foundational framework of the cyclic alternating pattern while introducing several critical innovations: (i) expanded definitions and a broader catalogue of Phase A electroencephalographic patterns; (ii) refined onset and offset criteria based on amplitude and frequency shifts, with strict inter-lead concordance requirements; (iii) standardised metrics for the quantification and reporting of the cyclic alternating pattern; (iv) formal guidance for scoring the cyclic alternating pattern in paediatric populations and optional scoring in rapid eye movement sleep; and (v) a technical framework for computerised detection and analysis. These updates align scoring with contemporary sleep staging standards, enhancing precision, reproducibility and applicability across research and clinical contexts.

## 1 | Historical Introduction to the Cyclic Alternating Pattern (CAP)

The CAP was first described in the mid-1980s as a hallmark of the dynamic organisation of non-rapid eye movement (NREM) sleep. In their seminal paper, Terzano et al. (1985) identified CAP as a periodic EEG phenomenon characterised by alternating sequences of activation (Phase A) and deactivation (Phase B). This pattern was recognised as a physiological component of normal sleep, reflecting fluctuations in arousal that recur throughout NREM stages.

Further investigations refined the concept, demonstrating that CAP is not merely a marker of transient arousal but an intrinsic feature of NREM sleep architecture (Terzano et al. 1988). Alternating CAP phases (A and B), each lasting between 2 and 60 s, were shown to organise into longer sequences, serving as the temporal scaffolding of sleep instability and modulating transitions between wake, NREM and REM sleep. Importantly, CAP alternates with more stable EEG periods known as non-CAP, delineating a fundamental oscillatory rhythm of arousal regulation during sleep.

In the 1990s and early 2000s, CAP analysis became increasingly standardised and was applied across different age groups, revealing a U-shaped age distribution of CAP rate, with the lowest expression in young adults and higher rates in children and the elderly (Bruni et al. 2002, 2005; Parrino et al. 1998). The classification of Phase A into three subtypes (A1–A3) provided a detailed understanding of arousal intensity, with A1 associated with synchronised slow-wave activity and A3 with desynchronized fast electroencephalography (EEG) patterns akin to cortical arousal (Parrino et al. 2001; Terzano and Parrino 1993).

CAP was also found to play a pivotal role in sleep-related disorders. Its fluctuations facilitate both physiological and pathological motor, respiratory and EEG events, acting as a permissive framework for phenomena such as seizures, periodic leg movements and apnoea (Terzano and Parrino 1993). CAP thus emerged as a powerful tool not only for understanding the neurophysiology of sleep but also for evaluating sleep instability in clinical contexts.

Subsequent studies extended the concept by integrating spectral analysis, functional connectivity and network theory, revealing that CAP, particularly subtype A1, reflects optimal conditions for information processing and EEG synchronisation (Ferri, Bruni, Miano, Plazzi, et al. 2005; Ferri, Bruni, Miano, and Terzano 2005; Ferri et al. 2008; Ferri, Rundo, et al. 2005). CAP is now widely regarded as a fundamental organising principle of sleep microstructure, bridging the domains of arousal regulation, sleep continuity and cognitive processing during sleep.

## 2 | Method of Rule Arrangement

Since the publication of the original CAP scoring rules in 2001 by Terzano and a group of experts from both Europe and North America (Terzano et al. 2001), the field of sleep research has undergone substantial progress, not only in neurophysiological insight and signal analysis but also in the evolution of sleep staging standards. The introduction and widespread adoption of updated scoring rules of the American Academy of Sleep Medicine (AASM) Manual for the Scoring of Sleep and Associated Events (Berry et al. 2020; Iber et al. 2007; Troester et al. 2023) have changed the landscape of sleep architecture classification, necessitating a corresponding revision of CAP criteria to ensure alignment and compatibility. While the 2001 guidelines (Terzano et al. 2001) established a foundational framework for identifying CAP as a marker of sleep instability, they relied on standard EEG montages that have since been updated, included a more limited set of EEG patterns, and lacked precise definitions for event onset and offset, leaving them open to interpretation. Moreover, they offered minimal guidance regarding REM sleep, paediatric populations and standardised quantitative metrics. The updated rules presented in this Atlas address these limitations through refined definitions, expanded EEG event classifications, clearer scoring criteria and structured recommendations for CAP analysis in both adult and paediatric populations. These revisions ensure that CAP scoring remains a relevant and rigorously applicable tool in modern sleep research and clinical practice.

The updated rules for the scoring of CAP presented in this Atlas and Rules were structured following a systematic approach aimed at balancing historical consensus with recent advances in sleep research. Initial definitions and core concepts were retained where consistent with new evidence, while refinements were introduced to improve clarity, precision and applicability across age groups and clinical contexts. Each rule was developed through expert consensus within the Taskforce, supported by a critical review of the literature and organised to follow the logical sequence of CAP detection: from fundamental definitions, through EEG characteristics of Phase A activities, to sequence construction, boundaries, subtyping and specific considerations for paediatric and REM sleep scoring. In addition, a technical note was added, specifying the core technical principles for computerised CAP detection and scoring. The final arrangement aims to ensure ease of application while preserving scientific rigour, offering a standardised reference for both clinical and research use.

## 3 | Definition of CAP

CAP is a periodic EEG activity, characterised by sequences of transient electrocortical events that are distinct from background EEG activity and recur at up to 1-min intervals. CAP is a physiological component of NREM sleep.

## 4 | Background and Overview

CAP is a distinctive EEG phenomenon that reflects the dynamic regulation of sleep stability/instability across all ages. CAP sequences represent periodic fluctuations in brain activity during NREM sleep and are understood as a physiological marker of the brain's response to internal mechanisms and external perturbations during sleep. CAP occurs spontaneously, as part of the natural oscillatory organisation of sleep, but

is also prominently associated with identifiable sleep pathologies, including sleep-disordered breathing (Thomas et al. 2004), periodic limb movement disorder and restless legs syndrome (RLS) (Ferri et al. 2010; Parrino et al. 2004; Terzano et al. 2003) and other conditions characterised by sleep fragmentation (Parrino et al. 2012). Sleep-disruptive pathologies usually increase the proportion of NREM sleep exhibiting CAP.

Originally conceptualised as an arousal-related phenomenon, CAP has evolved into a broader model encompassing both sleep maintenance and disruption processes (Halasz et al. 2004). CAP events reflect not only cortical arousability but also the brain's attempt to preserve sleep when challenged. CAP has been described as the EEG marker of sleep instability (Parrino et al. 2012), and more recent work suggests subtypes of CAP may operate in a protective manner under stress or arousal challenge (Hirshkowitz 2002). This dynamic interplay highlights CAP as both a biomarker of sleep instability and an indicator of adaptive protective mechanisms within sleep architecture. This conceptual duality reflects the coexistence of arousal-related and stabilising components within CAP dynamics. Phase A subtypes dominated by fast, low-voltage EEG rhythms (A3, partly A2) are primarily associated with cortical arousability and sleep fragmentation, whereas subtypes rich in slow, high-amplitude activity (A1) correspond to adaptive, sleep-preserving responses (Terzano and Parrino 2000; Terzano et al. 2002, 1988). CAP reflects a dynamic continuum between arousability and stability. Phase A subtypes characterised by fast, low-voltage EEG activity (A3, partly A2) correspond to transient cortical activation and arousal-related processes, whereas slow, high-amplitude subtypes (A1) represent synchronised, protective responses that help maintain sleep continuity despite internal or external challenges. Increased CAP represents a marker of heightened sleep instability. Depending on the predominant subtype composition, this may reflect either sleep fragmentation (when A3/A2 subtypes prevail) or adaptive stabilisation (when A1 events dominate). CAP analysis thus provides insight into how the nervous system regulates the balance between disruption and protection of sleep continuity in pathological conditions (Parrino et al. 2012).

High-amplitude EEG bursts such as delta waves or K-complexes, once considered isolated signs of possible arousal, are integrated into the CAP framework as components of organised sleep microstructure. CAP represents a continuum between effective sleep preservation and progressive instability leading to frank cortical arousal. When homeostatic mechanisms succeed, sleep continuity is preserved; when they fail, increased CAP activity culminates in EEG-defined arousals and sleep disruption.

This Atlas and Rules are designed to facilitate the clinical and research application of CAP recording and scoring, providing clear consensus-based terminology and criteria. The goal is to support the standardised use of CAP analysis across studies and clinical contexts, helping to stimulate further investigation into its relevance for sleep physiology and pathology. In particular, CAP analysis opens new avenues for exploring the relationships between cortical and autonomic activation, the role of synchronisation and desynchronisation dynamics in sleep regulation, and the mechanisms underlying sleep continuity failure in disease states. Furthermore, changes in CAP periodicity and organisation may reflect sleep system integrity (Terzano et al. 1988).

Importantly, CAP scoring is not intended to replace conventional sleep staging or arousal scoring. Instead, it extends quantitative sleep analysis by adding a novel dimension that captures the microstructural complexity of sleep. Through CAP analysis, we gain a deeper, physiologically grounded understanding of the processes that support or disrupt human sleep.

## 5 | EEG Rhythms, Frequencies and Transients

Rhythms are bioelectrical cerebral oscillations, subdivided into frequency bandwidths (delta, theta, alpha, sigma and eta), which constitute the EEG background activity and vary according to overall neurophysiological state; that is, wakefulness, NREM sleep and REM sleep. According to the 2023 AASM Manual for the Scoring of Sleep and Associated Events (Troester et al. 2023), the standard EEG frequency bands used in sleep staging are defined as follows: delta: $<4$ Hz, theta: 4 to $<8$ Hz, alpha: 8–13 Hz, and beta: $>13$ Hz. The sigma band (~11–16 Hz), not listed as a separate band, is the range of sleep spindles, key for N2. Transient EEG activities are brief, phasic events characterised by abrupt changes in amplitude or frequency relative to the ongoing background rhythm (De Carli et al. 2004). They may occur within periods of otherwise stable EEG activity and constitute the elementary units of sleep microstructure.

## 6 | Periodic EEG Activities

Periodic EEG activities are constituted by transient EEG activities when they recur at regular intervals in the range of seconds. These EEG transients are clearly distinguishable from the background rhythm as abrupt frequency shifts or amplitude changes.

Periodic activities can be characterised with three parameters:

A. The repetitive element (Phase A) is represented by the recurring EEG transient.

B. The intervening background (Phase B) is identified by the interval that separates the repetitive elements.

C. The cycle, measured from the onset of Phase A to the end of the following Phase B (Figure 1).

## 7 | Definition of CAP Phase A EEG Events

EEG activities appearing in CAP Phase A can be composed of slow and high-voltage rhythms, fast low-voltage rhythms, or mixed EEG activities, and may include the activities reported in Table 1. The morphological descriptors provided below are qualitative and intended to guide visual recognition.

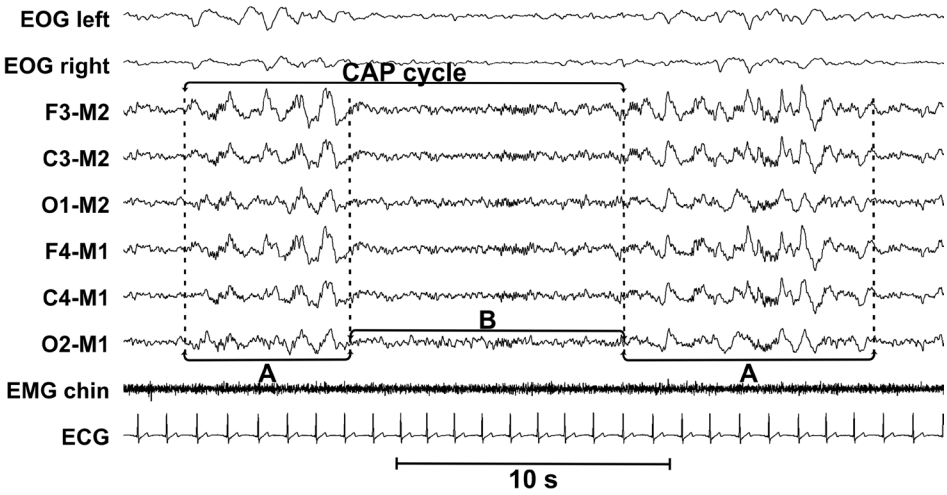


**FIGURE 1** | Example of a periodic EEG activity illustrating the structure of a CAP cycle. Two Phase A segments (labelled A) are visible as transient EEG activations clearly distinguishable from the background. These are separated by a Phase B segment (labelled B), which represents the intervening background activity. The CAP cycle extends from the onset of the first Phase A to the end of the following Phase B. Phase A events show synchronised EEG activity across most channels, fulfilling the criteria for CAP scoring.

**TABLE 1** | EEG activities observed during CAP Phase A.

| Slow and high-voltage rhythms | Fast low-voltage rhythms[a] | Mixed EEG activities[a] |
|---|---|---|
| – Delta bursts<br>– High-amplitude slow transients 'hypersynchronous delta activity'<br>– K-complex sequences (with or without spindles)[a]<br>– Vertex sharp transients[a,b] | – Intermittent alpha<br>– Low-voltage beta bursts | – K-alpha complexes<br>– Polyphasic bursts (delta mixed with theta/alpha)<br>– Mixed frequency transients |

[a]According to AASM criteria, arousals are defined by abrupt shifts in EEG frequency, including alpha, theta and/or frequencies > 16 Hz (excluding spindles) lasting ≥ 3 s. Therefore, intermittent alpha, K-alpha complexes and low-voltage beta bursts may qualify as arousals if they meet these criteria. Vertex sharp transients, when occurring within theta range, may also be scored as arousals. However, the AASM arousal rule lacks specificity and may lead to ambiguity in identifying fast low-voltage rhythms or mixed frequency transients as true arousals.
[b]Vertex sharp transients, while high-voltage, are not classified as slow waves in the AASM Manual.

Amplitude and duration should be interpreted relative to the concurrent background rhythm, provided that the general CAP criteria are fulfilled (amplitude increase ≥ 33% and phase duration 2–60 s). Absolute numerical ranges are not specified, as they may vary with montage, reference and recording settings.

### 7.1 | Delta Bursts

A delta burst is defined as a sequence of at least two consecutive waves within the frequency range of 0 to < 4 Hz. Delta bursts are most prominently expressed in the fronto-temporal regions. They typically emerge during the consolidated Stage N2 sleep and become increasingly prevalent during Stage N3. Compared to the background delta rhythm characteristic of Stage N3, delta bursts often display slightly lower frequencies and higher peak-to-peak amplitudes, reflecting a distinct transient amplification of slow-wave activity.

### 7.2 | High-Amplitude Slow Transients

High-amplitude slow transients, also referred to as 'hypersynchronous delta activity', are EEG patterns characterised by bursts of very-high-voltage, low-frequency activity, typically within the delta range (0 to < 4 Hz). These transients are often observed in children (usually 300–400 μV).

### 7.3 | K-Complex Sequences

A K-complex sequence is defined as the occurrence of two or more consecutive K-complexes. Each K-complex is characterised by a stereotyped bi- or triphasic waveform, consisting of an initial sharp negative deflection followed by a broader positive component. K-complexes may appear in isolation or be temporally associated with a sleep spindle. The typical duration of a single K-complex ranges between 0.5 and 2 s. K-complex sequences are predominantly observed during NREM sleep Stages N2 and N3, where they contribute to the microstructural complexity of sleep.

### 7.4 | Vertex Sharp Transients

Vertex sharp transients are sharply contoured EEG waveforms of short duration, typically lasting less than 0.5 s (measured at the base of the wave), with maximal amplitude recorded over the central vertex regions. They are characterised by a steep negative deflection, sometimes followed by a positive component, and can reach amplitudes up to approximately 250 μV. Vertex sharp transients most commonly appear during the transition from

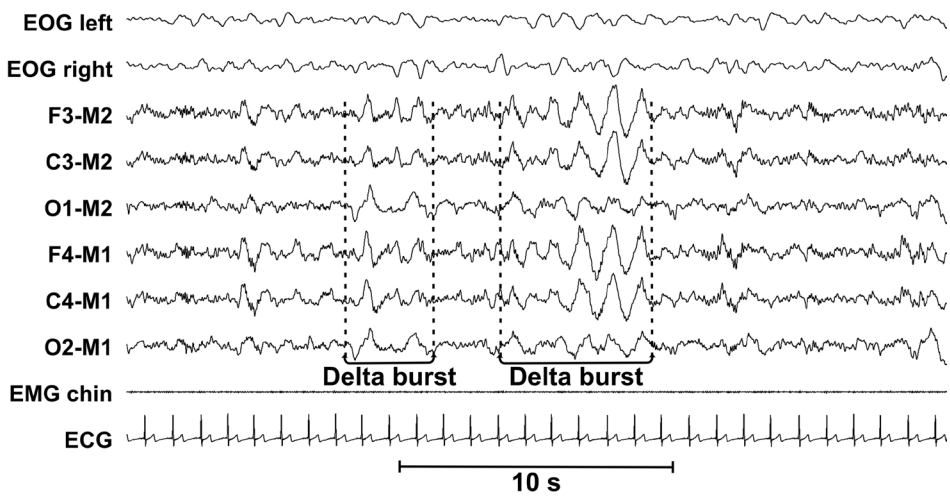


**FIGURE 2** | Example of delta bursts during NREM sleep. The marked segments highlight series of consecutive high-amplitude slow waves within the delta frequency range (< 4 Hz), visible across bilateral fronto-central and occipital EEG channels. Delta bursts typically consist of at least two consecutive slow waves and are most prominent over fronto-temporal regions. These events emerge in Stage N2 and become more frequent in Stage N3. Compared to background delta activity, delta bursts are characterised by slightly lower frequency and markedly higher amplitude.

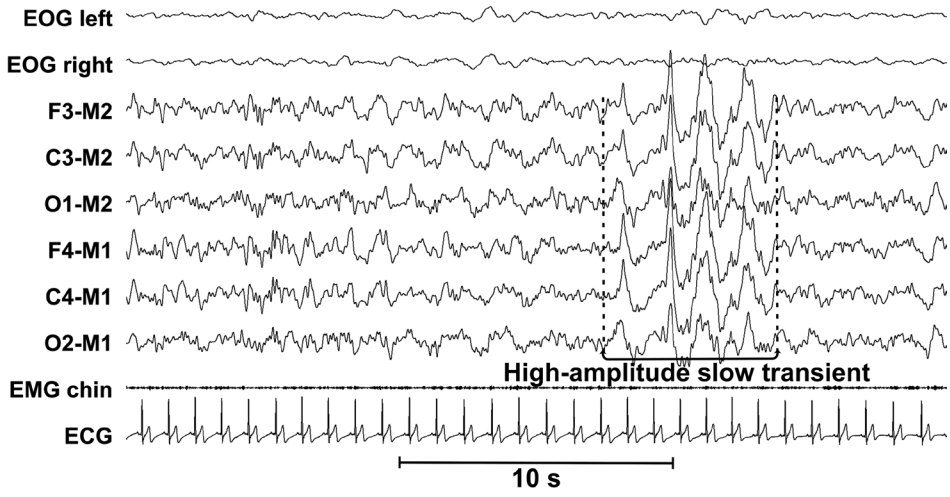


**FIGURE 3** | High-amplitude slow transient recorded during NREM sleep in an 8-year-old child. The marked segment displays a burst of hypersynchronous, high-voltage slow waves within the delta frequency range (0 to < 4 Hz), clearly exceeding 300 μV in amplitude and visible across bilateral fronto-central regions. These high-amplitude slow transients are commonly observed in paediatric sleep. While morphologically similar to delta bursts, they are distinguished by their markedly greater amplitude and more synchronous waveform morphology, usually involving all channels, and may represent a developmental variant of CAP Phase A activity.

wakefulness to sleep and are prominent in Stage N1, persisting into early Stage N2. They may occur singly or in brief trains.

### 7.5 | K-Alpha

The K-alpha sleep EEG pattern is characterised by the periodic occurrence of K-complexes immediately followed by bursts of alpha frequency activity (typically 8–11 Hz) lasting between 0.5 and 5.0 s (MacFarlane et al. 1996; Maes et al. 2014).

### 7.6 | Intermittent Alpha

The alpha rhythm (8–13 Hz), typically dominant in posterior EEG derivations, is most prominent over the occipital regions. At sleep onset, alpha activity spreads anteriorly, fragments during Stage N1 and progressively disappears as sleep deepens. Before vanishing, alpha may show a transient increase in amplitude and a slight frequency reduction. Intermittent alpha bursts may also recur during transitions back to Stage N1 and occasionally during REM sleep. Intermittent alpha can be scored as CAP Phase A when the eyes are closed. Before disappearing entirely as sleep deepens, alpha activity may show a temporary increase in amplitude and a slight slowing of frequency.

### 7.7 | EEG Arousals

According to the AASM Manual for the Scoring of Sleep and Associated Events (Troester et al. 2023), EEG arousals are brief

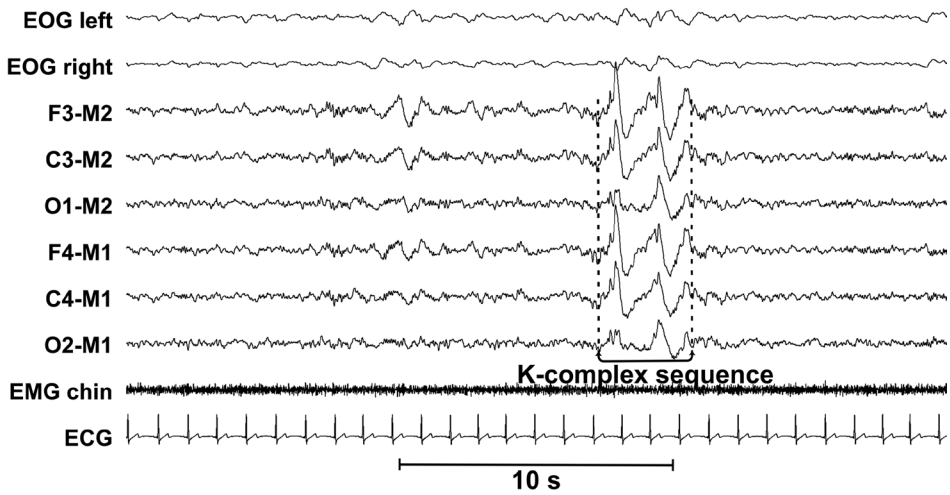


**FIGURE 4** | K-complex sequence recorded during NREM sleep. The highlighted segment shows a series of two consecutive K-complexes, each displaying a characteristic biphasic morphology, comprising an initial sharp negative deflection followed by a broader positive component. These waveforms are best visualised over fronto-central regions (F3-M2, C3-M2, F4-M1 and C4-M1). K-complex sequences typically occur during sleep Stages N2 and N3 and may appear independently or in association with sleep spindles. With durations ranging from 0.5 to 2 s per waveform, K-complex sequences reflect transient cortical synchronisations that contribute to the microstructural organisation of NREM sleep and CAP Phase A activity.

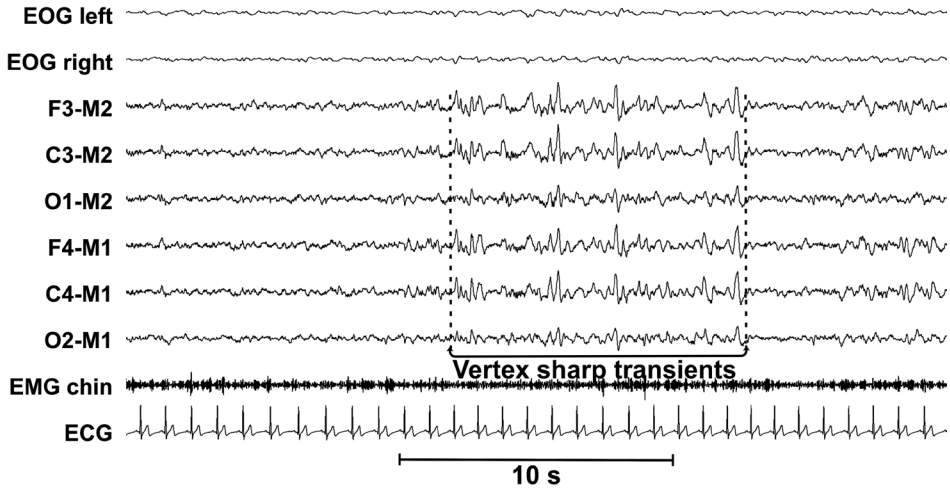


**FIGURE 5** | Vertex sharp transients recorded during early NREM sleep. The marked segment shows a train of sharply contoured waveforms with short duration (< 0.5 s), maximal over the central regions (notably C3-M2 and C4-M1), consistent with vertex sharp transients. They can occur as isolated events or in brief sequences, as shown here.

activations characterised by an abrupt elevation in frequency, such as a shift to alpha, theta, or beta activity, excluding spindles and must be distinguishable from the preceding EEG background. These arousals must be preceded by at least 10 s of uninterrupted sleep and have a minimum duration of 3 s, up to a maximum of 15 s. In REM sleep, scoring requires a simultaneous increase in chin electromyography (EMG) tone lasting at least 1 s. Under CAP scoring criteria, however, arousals may be classified as Phase A components if they last at least 2 s and do not exceed 60 s.

### 7.8 | Low-Voltage Beta Bursts

Low-voltage beta bursts are transient EEG events characterised by brief episodes of low-amplitude, high-frequency activity within the beta range (approximately > 13–30 Hz, excluding spindles). These bursts are typically observed during NREM sleep.

### 7.9 | Polyphasic Bursts

Polyphasic bursts are transient EEG patterns composed of multiple slow waves in the delta frequency range (0 to < 4 Hz), intermixed with faster components from the theta (4 to < 8 Hz) and/or alpha (8–13 Hz) frequency bands. These bursts are characterised by the presence of at least two or more consecutive high-amplitude slow waves, interspersed with brief intrusions of faster oscillations. This complex waveform configuration is best visualised over fronto-central derivations and is characteristic of sleep microstructure associated with CAP Phase A events.

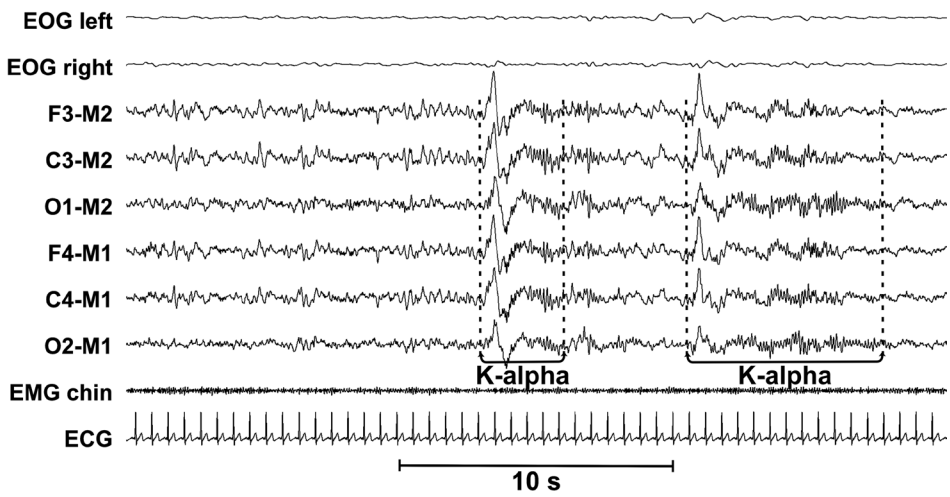


**FIGURE 6** | K-alpha pattern during NREM sleep. The marked EEG segments show two K-complexes immediately followed by a rhythmic burst of alpha-frequency activity (~8.5 Hz), consistent with the definition of a K-alpha pattern. These alpha bursts (~8.5 Hz), following the two K-complexes, last approximately 1.5 and 5.5 s, respectively, and are most prominent over central and occipital derivations (C3-M2 and C4-M1). The K-alpha pattern reflects a transient microstructural oscillation within NREM sleep, often observed in association with CAP Phase A events.

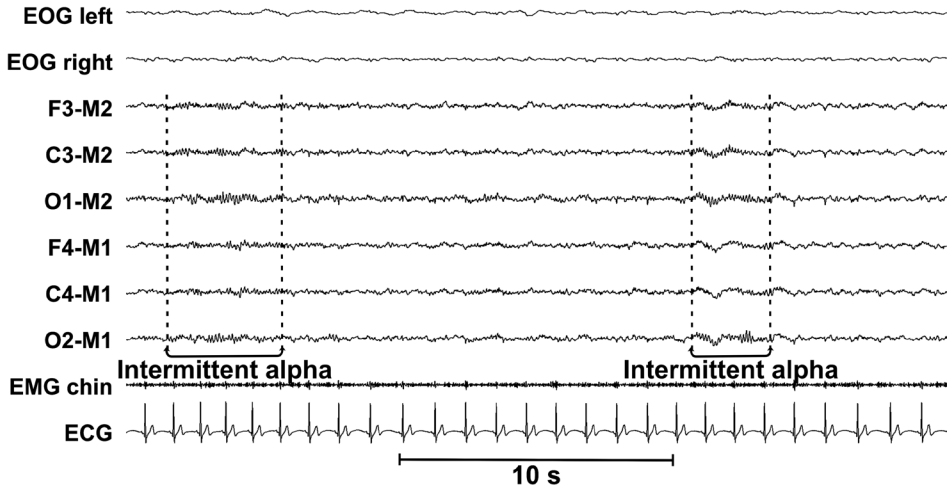


**FIGURE 7** | Intermittent alpha activity recorded during transitional sleep. The marked segments show two brief bursts of alpha rhythm (8–13 Hz), predominantly visible over posterior and central derivations (notably O1-M2, O2-M1, C3-M2 and C4-M1).

Polyphasic bursts reflect a dynamic interplay between cortical synchronisation and desynchronisation processes, often emerging during unstable sleep states or transitions between sleep stages. This pattern is frequently noted in those with alpha–delta sleep.

### 7.10 | Mixed Frequency Transients

Mixed-frequency transients are EEG events characterised by the simultaneous presence of slow background activity, typically in the theta range (>4 to <8Hz), with superimposed faster frequencies, such as alpha or beta activity, but not including sleep spindles.

The individual EEG patterns described above represent potential components of CAP Phase A. Each becomes a valid CAP Phase A event only when it fulfils the general CAP criteria regarding duration (2–60 s) and amplitude or frequency change relative to background activity. In addition, a pause shorter than 2 s between consecutive EEG transients, such as K-complexes, delta bursts, vertex sharp waves, intermittent alpha, or other Phase A components, does not represent a separate Phase B and may therefore link the events within the same CAP Phase A. Only pauses longer than 2 s should be considered as separating distinct phases or events.

## 8 | CAP During Sleep

CAP during sleep is a specific type of periodic activity in which both Phase A and Phase B can range between 2 and 60 s (Figure 1). In physiological sleep, CAP appears throughout NREM sleep stages (N1–N3). The identification of CAP should be preceded by the definition of sleep stages according to the conventional AASM scoring criteria (Figures 2–11).

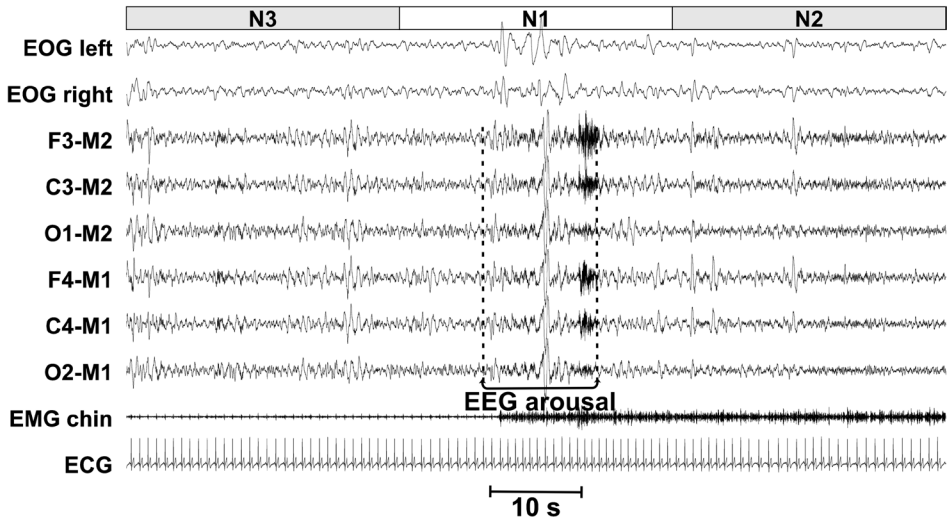


**FIGURE 8** | An EEG arousal is characterised by an abrupt shift in EEG frequency, such as to alpha, theta, or frequencies above 16 Hz (e.g., beta), that is clearly distinguishable from the preceding background activity. As illustrated here, the arousal occurs during a transition from Stage N3 to Stage N1 and is followed by Stage N2. According to the AASM Manual for the Scoring of Sleep and Associated Events (Troester et al. 2023), an EEG arousal must last between 3 and 15 s and be preceded by at least 10 s of stable sleep. The frequency shift must not include sleep spindles. In REM sleep, a concurrent increase in chin EMG tone (≥1 s) is also required. Although AASM arousals are defined as events lasting at least 3 s (Troester et al. 2023), under CAP scoring criteria, events lasting as little as 2 s that fulfil all other arousal criteria may be scored as Phase A components.

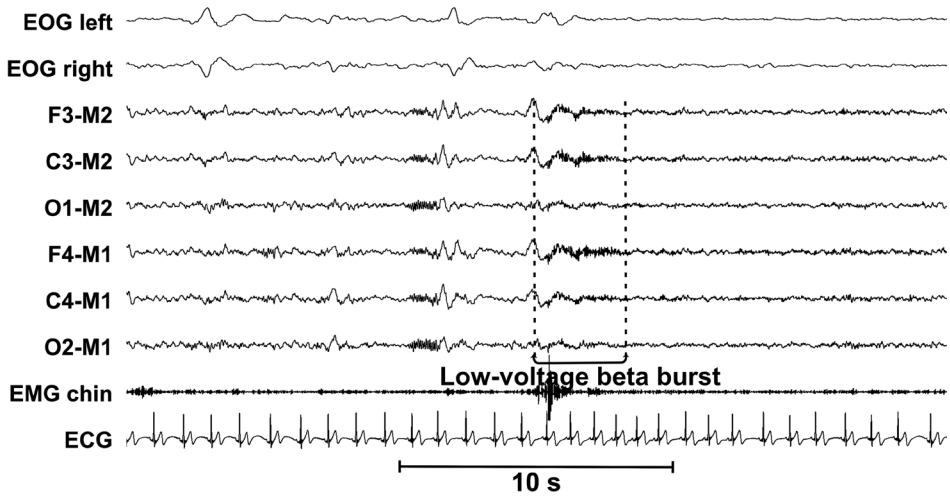


**FIGURE 9** | Low-voltage beta burst during NREM sleep. The highlighted segment shows a brief, well-defined burst of low-amplitude, high-frequency EEG activity within the beta range (approximately 16–25 Hz), most visible in fronto-central derivations (e.g., F3-M2, C3-M2, F4-M1 and C4-M1). These events are transient, lasting only a few seconds and are distinguishable from the slower background rhythm. Low-voltage beta bursts typically occur during NREM sleep and are commonly associated with CAP Phase A subtype A3. Despite their low amplitude, they must be clearly visible above the background in at least 60% of EEG leads to be scored within the CAP analysis.

### 8.1 | Onset and Termination of a CAP Sequence

A CAP sequence is composed of a succession of CAP cycles (Figure 12). All CAP sequences begin with a Phase A and end with a Phase B.

### 8.2 | Minimal Criteria for the Detection of a CAP Sequence

A CAP cycle is defined as one Phase A followed by the subsequent Phase B. A CAP sequence is an uninterrupted succession of at least two consecutive CAP cycles (A–B–A–B–A–...). The sequence terminates when a Phase A is followed by a stable EEG period lasting more than 60 s, indicating the transition to non-CAP activity. Consequently, at least three consecutive Phases A must be identified, with the last Phase A followed by a non-CAP period (with the last Phase A included in the non-CAP period) or wakefulness. CAP sequences have no upper limits in duration and in the number of CAP cycles included.

### 8.3 | Non-CAP

The absence of CAP for > 60 s is scored as non-CAP (Figure 13). An isolated Phase A (i.e., preceded or followed by stable EEG activity for > 60 s) is classified as non-CAP.

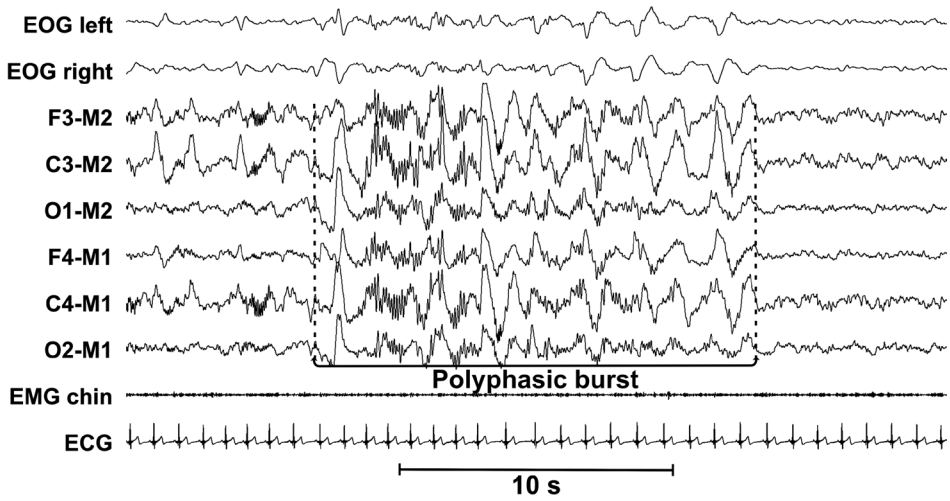


**FIGURE 10** | Polyphasic burst during NREM sleep. The highlighted EEG segment displays a transient pattern composed of multiple high-amplitude slow waves in the delta range (< 4 Hz), interspersed with brief intrusions of faster theta (4 to < 8 Hz) and alpha (8–13 Hz) components.

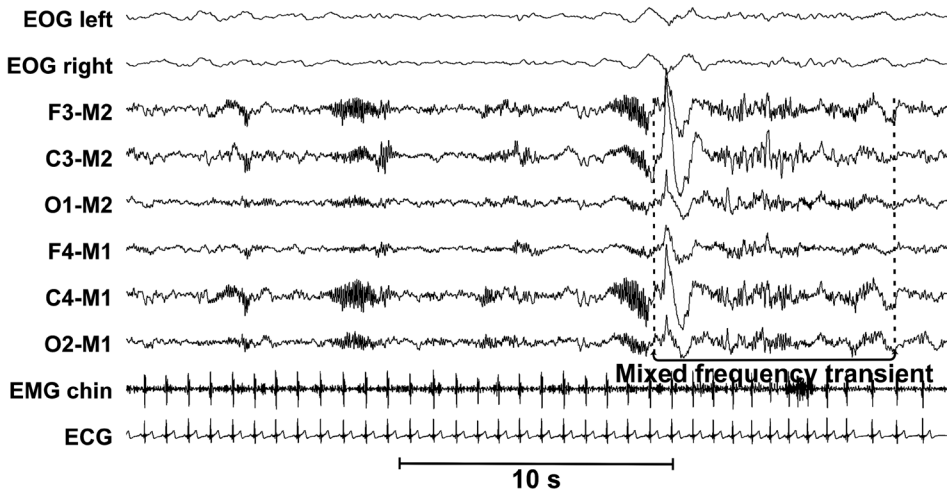


**FIGURE 11** | Mixed-frequency transient during NREM sleep. The marked segment displays a composite EEG event beginning with a well-formed K-complex, followed by a sequence of mixed-frequency activity. This includes simultaneous slow background waves in the theta range (4 to < 8 Hz) with superimposed faster frequencies, such as alpha and low-voltage beta activity. Notably, a sleep spindle appears near the onset of the transient but is not used to define its boundaries.

### 8.4 | Stage Shifts

Within NREM sleep, a CAP sequence is not interrupted by a sleep stage shift if CAP scoring requirements are satisfied. Consequently, CAP sequences can extend across adjacent sleep stages (Figure 14).

### 8.5 | REM Sleep

CAP sequences commonly precede the transition from NREM to REM sleep and end just before REM sleep onset (Figure 15). Pre-REM CAP typically exhibits relatively sharp complexes. Under normal circumstances, CAP does not occur in REM sleep. See below (Section 14) for additional special considerations about scoring CAP during REM sleep.

### 8.6 | Movements

Movement and EMG artefacts, such as those associated with large muscle group movements, as defined in the 2021 International Restless Legs Syndrome Study Group position statement (Ferri et al. 2021), can trigger or interrupt a CAP sequence and can be included within the CAP sequence, as a Phase A or part of it, if other scoring criteria are met (Figure 16). If included, the Phase A should still be classified as A1, A2 or A3 depending on the relative content of slow and fast EEG activities, as detailed below in Section 11.

## 9 | Recording Techniques and Montages

Polysomnographic sleep recordings should be conducted in accordance with the AASM Manual for the Scoring of Sleep and

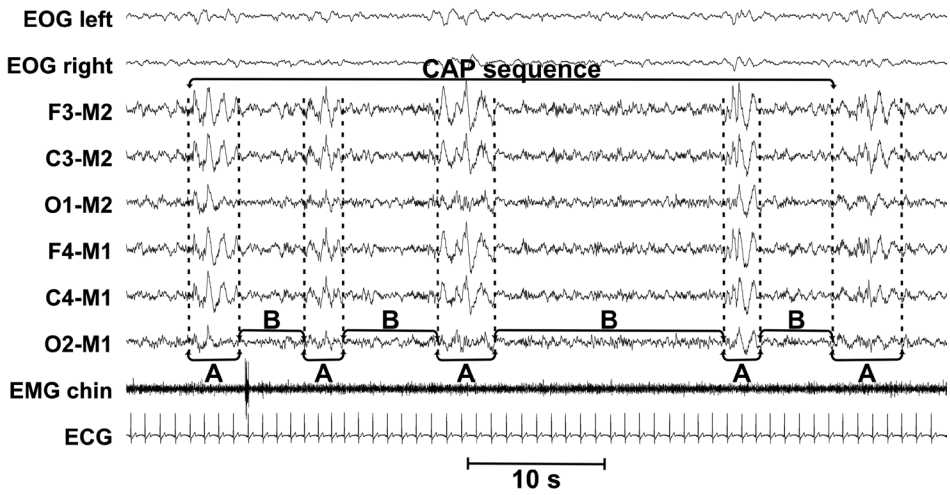


**FIGURE 12** | CAP sequence during NREM sleep. The EEG trace illustrates a CAP sequence consisting of multiple CAP cycles, each composed of a Phase A (transient activation) followed by a Phase B (background activity). The CAP sequence begins with the first Phase A and ends with the final Phase B, before a Phase A followed by a non-CAP period (the last Phase A is included in the non-CAP period). The CAP time refers to the cumulative time occupied by all CAP cycles within the sequence. To define a CAP sequence, at least two consecutive CAP cycles must be present, that is, a minimum of three Phase A events, with the final Phase A followed by sustained background activity or wakefulness. There is no upper limit to the number of CAP cycles or the duration of a CAP sequence. This figure demonstrates four CAP cycles fulfilling these criteria, with clear labelling of Phases A and B across multiple EEG derivations.

Associated Events and must include, at a minimum, EOG, EEG and submental EMG signals. While the use of six EEG channels is preferable to ensure reliable CAP detection and topographic resolution, a minimum of three EEG channels is acceptable.

The recommended six-channel EEG montage includes: F4-M1, F3-M2, C4-M1, C3-M2, O2-M1 and O1-M2. When only three channels are used, they should be confined to either the right hemisphere (F4-M1, C4-M1 and O2-M1) or the left hemisphere (F3-M2, C3-M2 and O1-M2) to preserve hemispheric consistency in CAP detection.

For a CAP event to be scored, the defining EEG activity must be clearly visible in ≥60% of the available EEG channels. This proportional visibility criterion applies to any montage meeting the minimum EEG channel requirements defined by the AASM Manual (Troester et al. 2023) (i.e., at least three derivations: frontal, central and occipital). When a larger number of EEG channels is used, the same 60% rule applies relative to the total number of channels included in the analysis.

## 10 | CAP Phase A Onset and Offset

### 10.1 | Primary Onset Amplitude Criterion

The onset of a CAP Phase A is defined by a ≥33% increase in peak-to-peak amplitude, sustained for at least 2s, relative to the mean absolute background voltage (Figure 17). The background voltage is measured over the 2s preceding the onset. If this amplitude criterion is met, no frequency change is required.

### 10.2 | Alternative Onset Frequency Criterion

If the onset amplitude criterion is not met, the onset of a CAP Phase A may still be identified based on a frequency change from background, evaluated over the 2s before onset. A frequency change is defined as a shift to a higher frequency band (e.g., delta → theta, or theta → alpha), lasting at least 2s.

### 10.3 | Primary Offset Amplitude Criterion

The offset of a CAP Phase A is defined as the point at which the average peak-to-peak amplitude during the 2s preceding it remains at least 33% higher than the average amplitude during the 2s following it.

### 10.4 | Alternative Offset Frequency Criterion

If the offset amplitude criterion is not met, the offset of a CAP Phase A based on frequency is defined as the point at which the average frequency during the 2s preceding it shifts to a lower frequency band compared to the average frequency during the 2s following it, with the shift sustained for at least 2s.

### 10.5 | Concordance Across Leads

In all cases, whether amplitude- or frequency-based, onset and offset criteria must be observed in at least 60% of EEG leads to be considered valid.

*Note:*

- Sleep spindles occurring near the onset or offset of a Phase A should not be used to determine boundaries and must be excluded from consideration (see Figure 11).
- Onset and offset amplitude and/or frequency criteria can be used in any combination to identify each CAP Phase A.

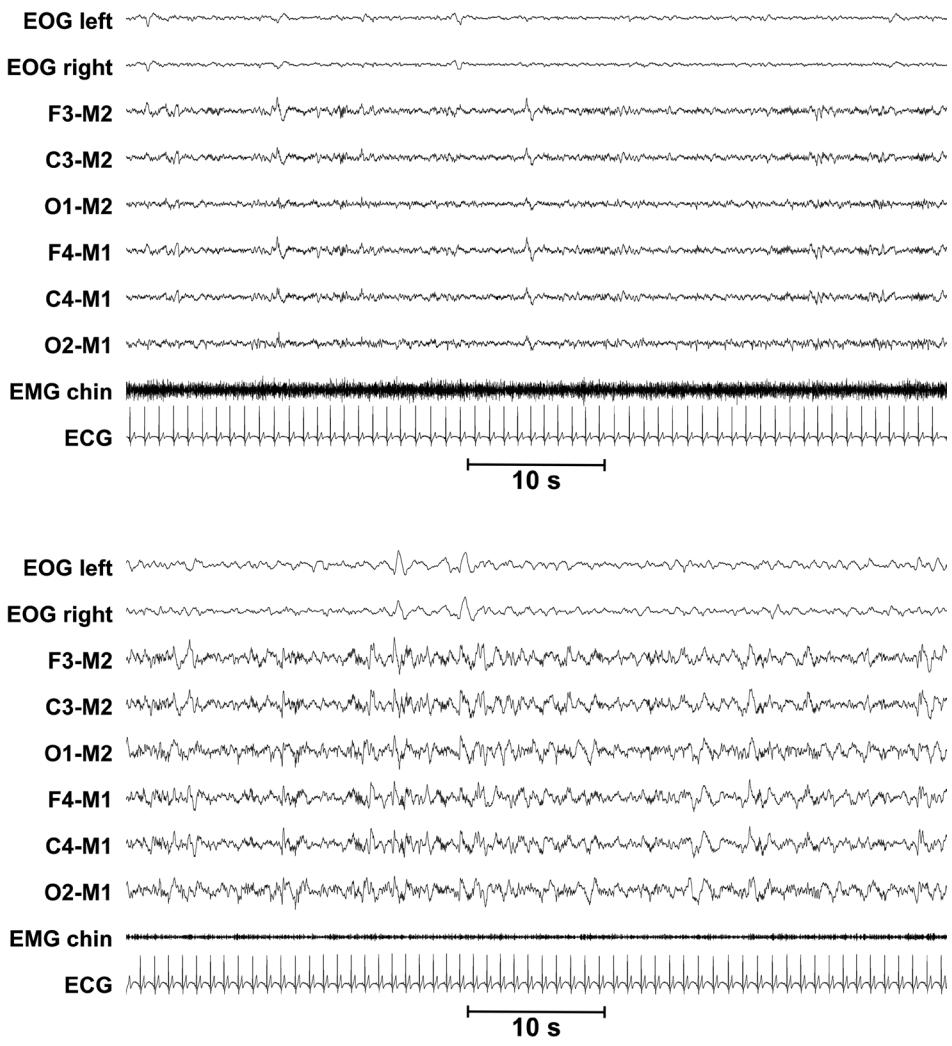


**FIGURE 13** | Representative examples of EEG activity during Stage N2 (top panel) and Stage N3 (bottom panel). The segments illustrate typical features of each respective stage in NREM sleep. The N2 segment shows hallmark features such as sleep spindles and occasional K-complexes superimposed on a low-amplitude mixed-frequency background. The N3 segment displays prominent high-amplitude delta waves, characteristic of deep slow-wave sleep. Both traces are extracted from stable non-CAP periods, with no evidence of CAP Phase A events.

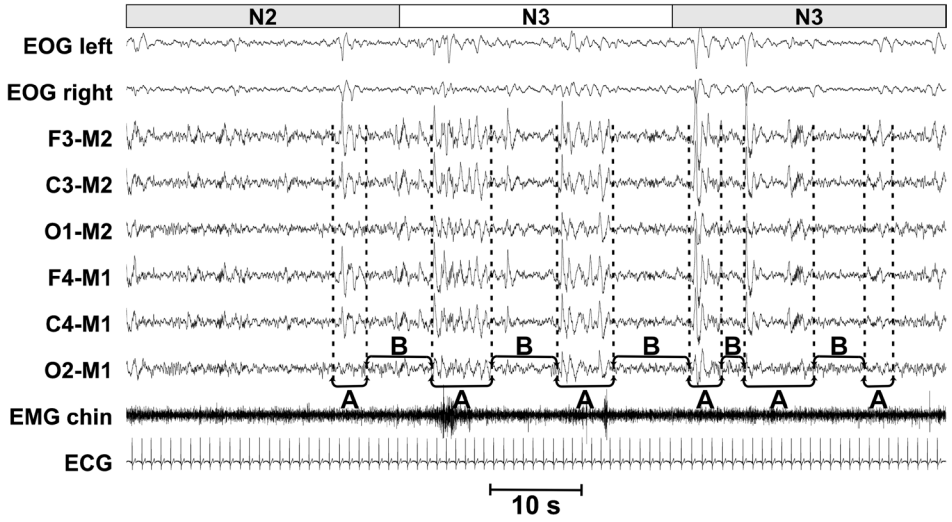


**FIGURE 14** | CAP sequence extending across NREM stage boundaries. The EEG traces demonstrate a continuous CAP sequence composed of multiple CAP cycles (Phases A and B) spanning the transition from Stage N2 to Stage N3. According to CAP scoring criteria, a CAP sequence is not interrupted by a shift between adjacent NREM stages, provided all CAP rules are met. In this example, the sequence begins in Stage N2 and continues seamlessly into Stage N3 without a break in Phase A–B alternation.

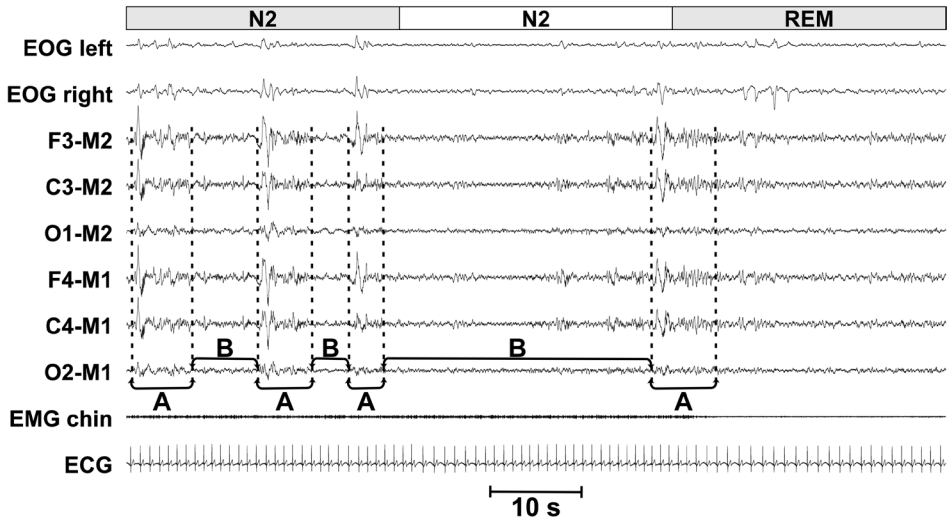


**FIGURE 15** | CAP sequence preceding REM sleep onset. The EEG traces show a CAP sequence during Stage N2 sleep, consisting of multiple CAP cycles with alternating Phase A and Phase B segments. The sequence terminates immediately before the transition to REM sleep, which is marked by the emergence of low-amplitude, mixed-frequency EEG activity and rapid eye movements, visible in the electrooculography (EOG) channels, along with reduced submental EMG tone. Additional exceptions and special criteria for scoring CAP in REM sleep are addressed in Section 14 of this Atlas and Rules.

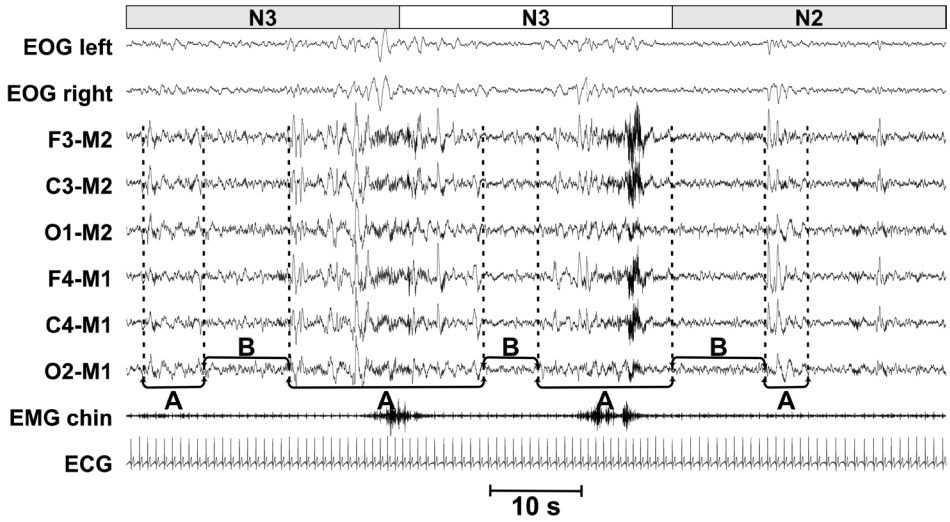


**FIGURE 16** | Inclusion of movement- and EMG-related artefacts within a CAP sequence. The EEG trace illustrates a CAP sequence composed of multiple CAP cycles during Stages N3 and N2. Two Phase A segments include brief EMG bursts associated with large muscle group movements, also evident in the submental EMG channel. Movement and EMG artefacts can trigger or interrupt CAP sequences and may be included as part of Phase A, provided all standard scoring criteria are met. In this example, the EMG bursts are temporally aligned with abrupt EEG frequency changes, supporting their inclusion within the CAP scoring framework.

## 11 | CAP Phase A Subtypes

Phase A activities can be classified into three subtypes. Subtype classification is based on the reciprocal proportion of high-voltage slow waves and low-amplitude fast rhythms (see Table 1) throughout the entire Phase A duration. The three Phase A subtypes are described below.

1. *Subtype A1*: EEG slow waves are the predominant activity. If present, EEG fast rhythms occupy (including movements) < 20% of the entire Phase A duration (Figure 18).
2. *Subtype A2*: The EEG activity is a mixture of slow and fast rhythms, with 20%–50% of Phase A occupied by EEG fast rhythms or movements (Figure 18).
3. *Subtype A3*: The EEG activity is predominantly rapid low-voltage rhythms (including movements) in > 50% of Phase A (Figure 18). An event only constituted by a movement within a CAP sequence is also classified as subtype A3 if the duration criteria are met.

*Note:*

- Different Phase A subtypes can occur within the same CAP sequence (Figure 19).
- If different leads express different subtypes, assign the highest CAP subtype number to the event (e.g., if A1 and A2 assign A2, if A1 and A3 assign A3, if A2 and A3 assign A3).

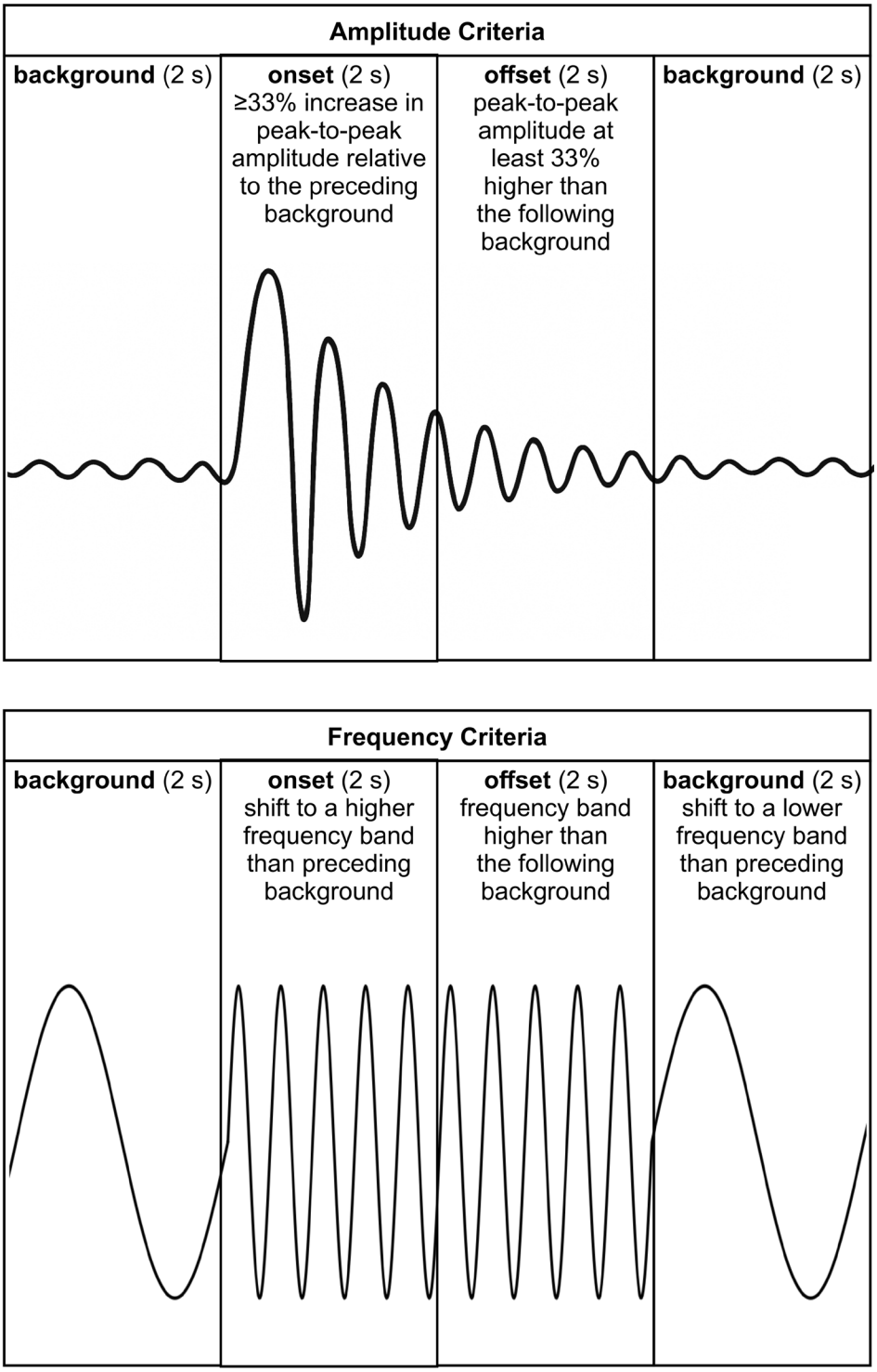


**FIGURE 17** | This figure illustrates the primary amplitude and alternative frequency criteria used to define the onset and offset of a CAP Phase A. Top panel—Amplitude criteria: The Phase A onset is marked by a ≥ 33% increase in peak-to-peak amplitude compared to the average background voltage measured over the preceding 2 s. This increase must be sustained for at least 2 s. The offset is defined as the point where the average amplitude in the preceding 2 s remains at least 33% higher than the average amplitude in the following 2 s. Bottom panel—Frequency criteria (alternative): If the amplitude criterion is not met, a Phase A may begin when there is a clear shift to a higher frequency band (e.g., delta → theta), lasting at least 2 s compared to the prior background. The offset is identified as the point where the frequency shifts back to a lower band for at least 2 s compared to the prior 2-s segment.

## 12 | Metrics to Report in CAP Analysis

After sleep staging, the scoring of CAP is performed following a logical progression from identification of Phase A EEG Events, application of amplitude and frequency criteria, assessment of lead concordance and confirmation of CAP sequences. Quantitative indices such as CAP Time and CAP Rate are subsequently derived. This structured approach

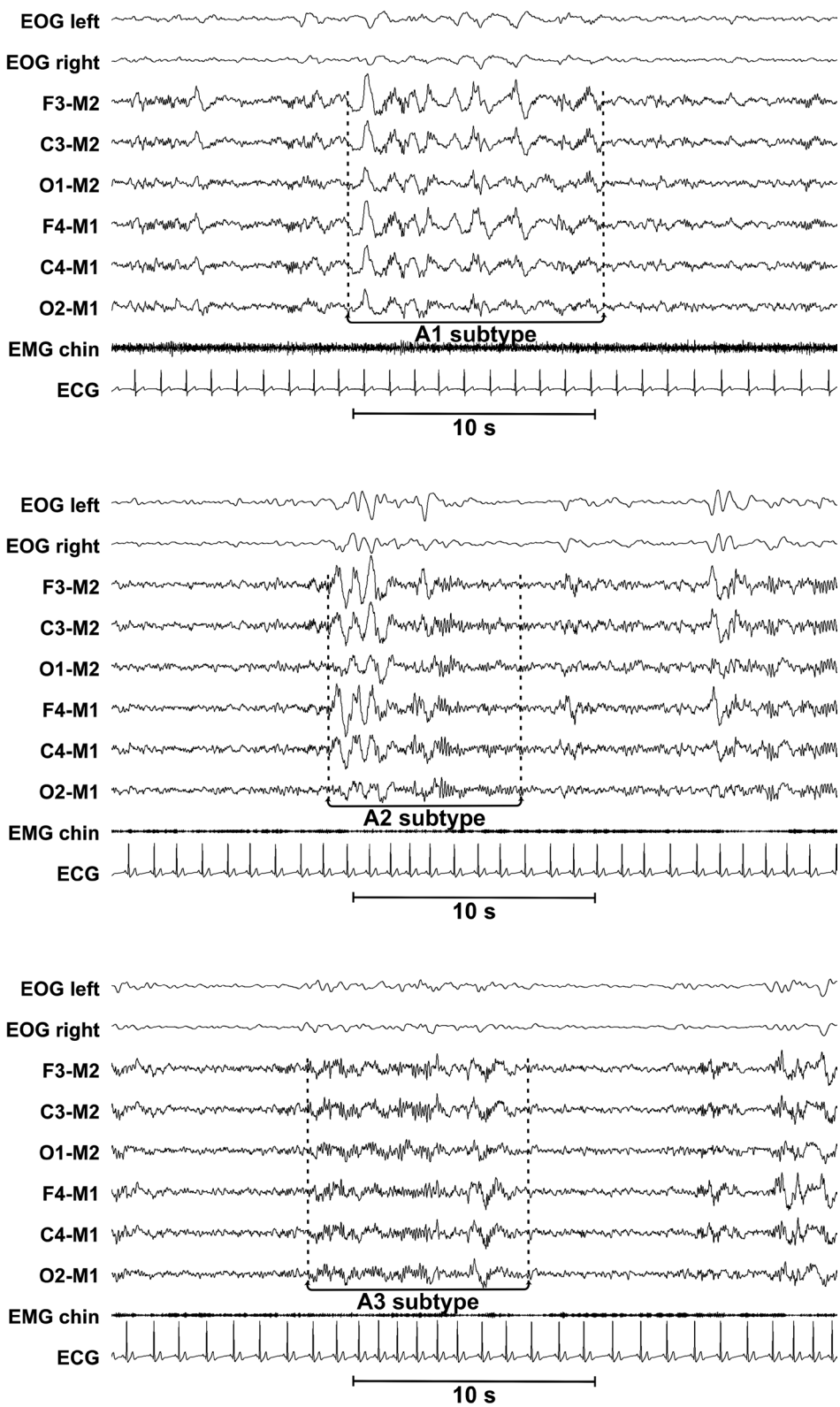


**FIGURE 18** | This figure illustrates the three subtypes of CAP Phase A, defined by the relative proportion of high-voltage slow waves and low-amplitude fast EEG rhythms across the entire duration of Phase A. Subtype A1 (top panel): Phase A is predominantly composed of high-voltage slow waves. Low-voltage fast rhythms account for less than 20% of the total Phase A duration. Subtype A2 (middle panel): Phase A contains a mixture of slow and fast rhythms, with fast EEG components occupying between 20% and 50% of the Phase A duration. Subtype A3 (bottom panel): Phase A is predominantly composed of low-voltage fast EEG rhythms, which account for more than 50% of its duration.

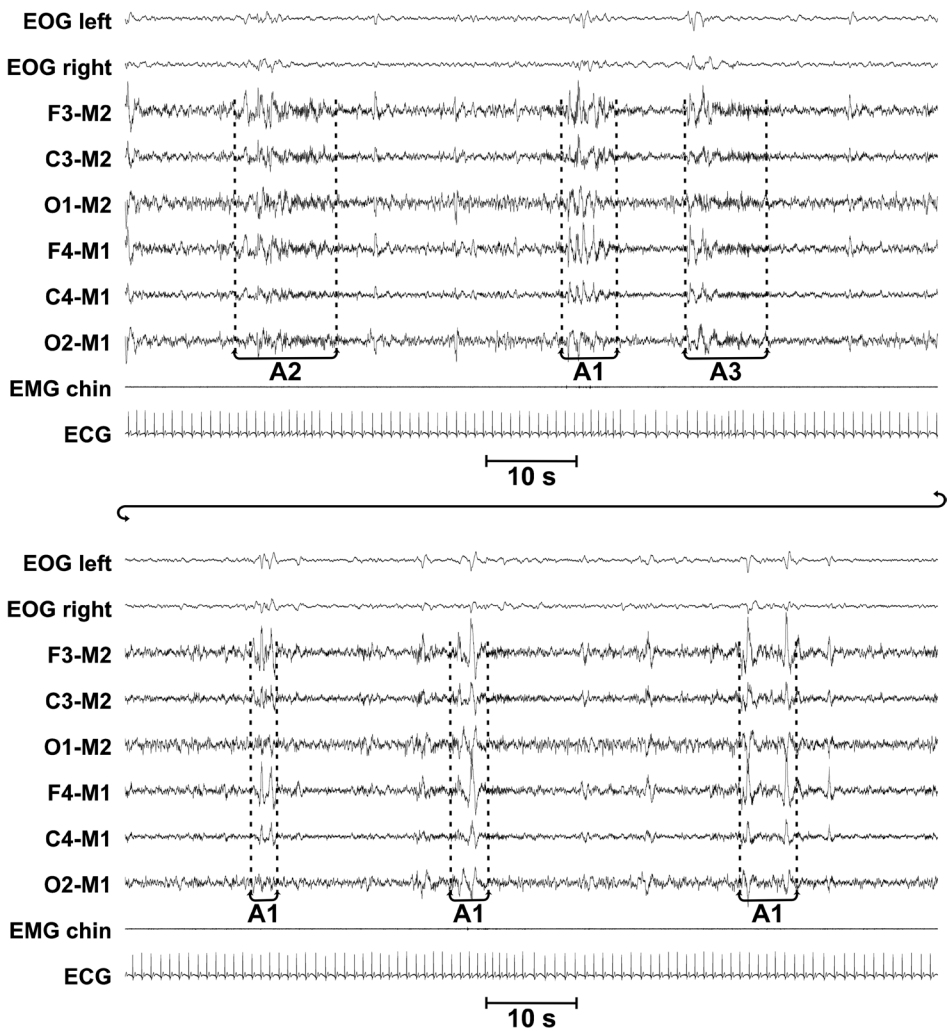


**FIGURE 19** | This figure illustrates a continuous CAP sequence spanning two consecutive panels. The sequence includes a variety of CAP Phase A subtypes, highlighting the coexistence of different morphologies within the same uninterrupted CAP sequence. In the upper panel, the sequence begins with a Phase A2, followed by an A1 and then an A3 subtype. The lower panel continues the same sequence with additional Phase A1 subtypes. This example underscores that CAP sequences may include heterogeneous Phase A morphologies, which must each be individually classified according to established subtype criteria.

ensures standardised application of CAP scoring across research and clinical contexts.

### 12.1 | Recommended Metrics

- Total CAP rate (%): (Total CAP Time/NREM Sleep Time) × 100
- Distribution of Subtypes: % of A1, A2 and A3
- A1 Index (events/h); A2 Index (events/h); and A3 Index (events/h)

These quantitative indices can be illustrated through simple numerical examples; for instance, if 300 min of NREM sleep include 90 min of CAP sequences, the CAP Time equals 90 min (CAP Rate = 30% of NREM sleep). In the same recording, if a total of 150 Phase A events are identified (80 of subtype A1, 45 of subtype A2 and 25 of subtype A3), the corresponding proportions would be A1 = 53.3%, A2 = 30% and A3 = 16.7% of all Phase A events. Consequently, if the total NREM sleep time is 300 min (5 h), the corresponding subtype indices would be: A1 Index = 80 ÷ 5 = 16.0 events/h, A2 Index = 45 ÷ 5 = 9.0 events/h and A3 Index = 25 ÷ 5 = 5.0 events/h.

### 12.2 | Optional Metrics

CAP time (min); CAP rate N1 (%); CAP rate N2 (%); CAP rate N3 (%); CAP Index (*n* of CAP cycles/h); Mean A1 duration (s); Mean A2 duration (s); Mean A3 duration (s); B mean duration (s); Mean Cycle duration (s); Mean number of cycles in sequence (*n*); CAP sequences (*n*); and Sequence mean duration (s).

*Note:* CAP Time refers to the total duration during NREM sleep when CAP is present. It is calculated as the sum of the durations of all CAP sequences, that is, the cumulative time from the onset of the first Phase A to the offset of the last Phase B within each CAP cycle, across the entire recording or a specified sleep period (Figure 20).

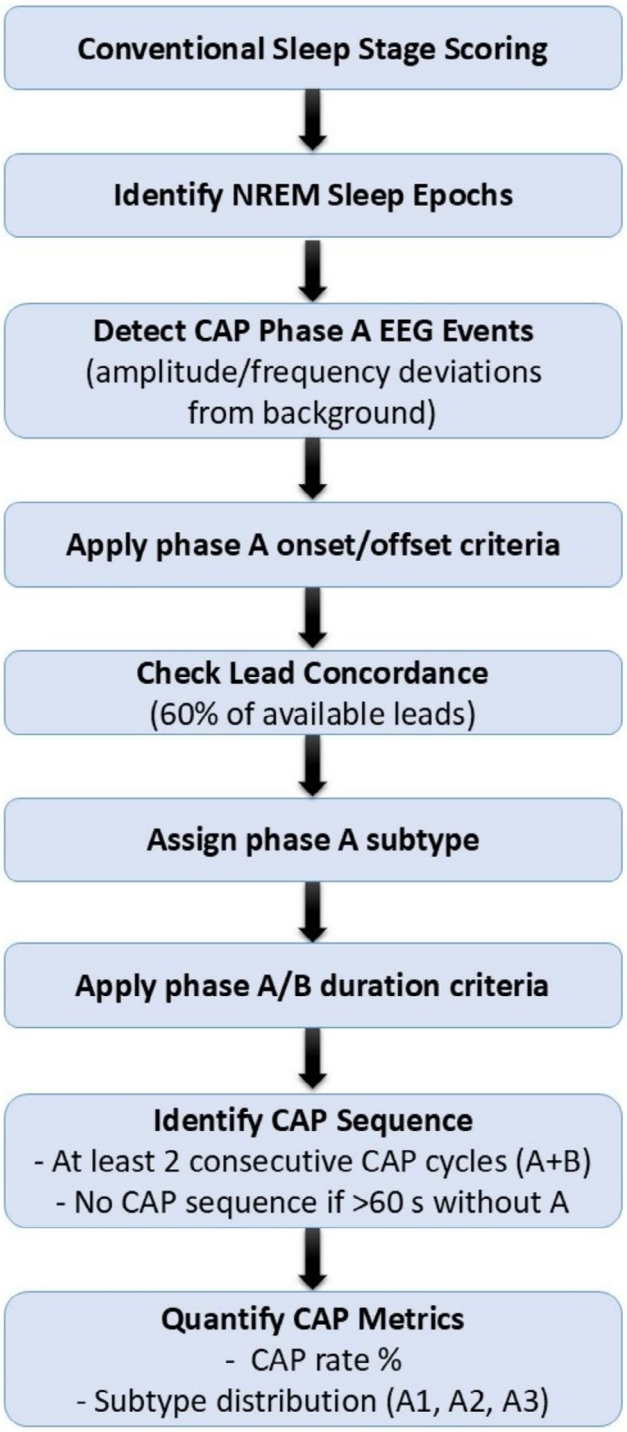


**FIGURE 20** | Flowchart summarising the scoring of CAP. It outlines the necessary steps for detecting Phase A onset and offset, confirming CAP sequences, subtyping, and final quantitative reporting.

## 13 | Special Considerations for Scoring CAP in Children

The recommendations in Sections 13.1–13.7 are harmonised with the AASM paediatric scoring rules. Where available, age-related amplitude and frequency variations are indicated; however, validated quantitative thresholds for many EEG patterns are still limited. Future updates of the Atlas will include formal age-specific reference values and summary tables as further normative data become available.

### 13.1 | Developmental EEG Characteristics

Age range and EEG features:

- Newborns (< 2 months): Discontinuous EEG, low-voltage activity and *tracé alternant* gradually disappear.
- Infants (2–12 months): Sleep spindles begin between 6 and 9 weeks, slow-wave activity gradually emerges, and K-complexes appear at approximately 5 months.
- Toddlers (1–3 years): Dominant delta activity, well-formed spindles, rhythmic theta activity 4–6 Hz, hypnagogic hypersynchrony and increased CAP prevalence.
- Children (4–12 years): Dominant delta activity, well-formed spindles and mature CAP structure.
- Adolescents (13–18 years): Adult-like EEG with delta activity and higher CAP rate.

### 13.2 | CAP Timing Thresholds

- Maintain standard Phases A and B durations: ≥ 2 s.
- Expect shorter CAP cycles in younger children.
- Use adaptive amplitude thresholds based on age-specific EEG baselines.

### 13.3 | Frequency Band Adaptation

- Delta (0 to < 4 Hz): Dominant in children, A1 is more frequent in children.
- Theta (4–8 Hz): Prominent in early childhood, it can be the dominant rhythm while awake and in arousals.
- Alpha (8–13 Hz): Lower amplitude or delayed emergence in young children.
- Beta (> 13 Hz): Less prominent until adolescence.
- Sigma (12–16 Hz): Spindles appear after 2–3 months.

### 13.4 | Subtype Distribution

- A1 subtypes are most common in children.
- A3 events increase after adolescence.
- CAP sequences may be less structured in infants.

### 13.5 | Amplitude Thresholds

- Normalise amplitude within channel to control for developmental variation.

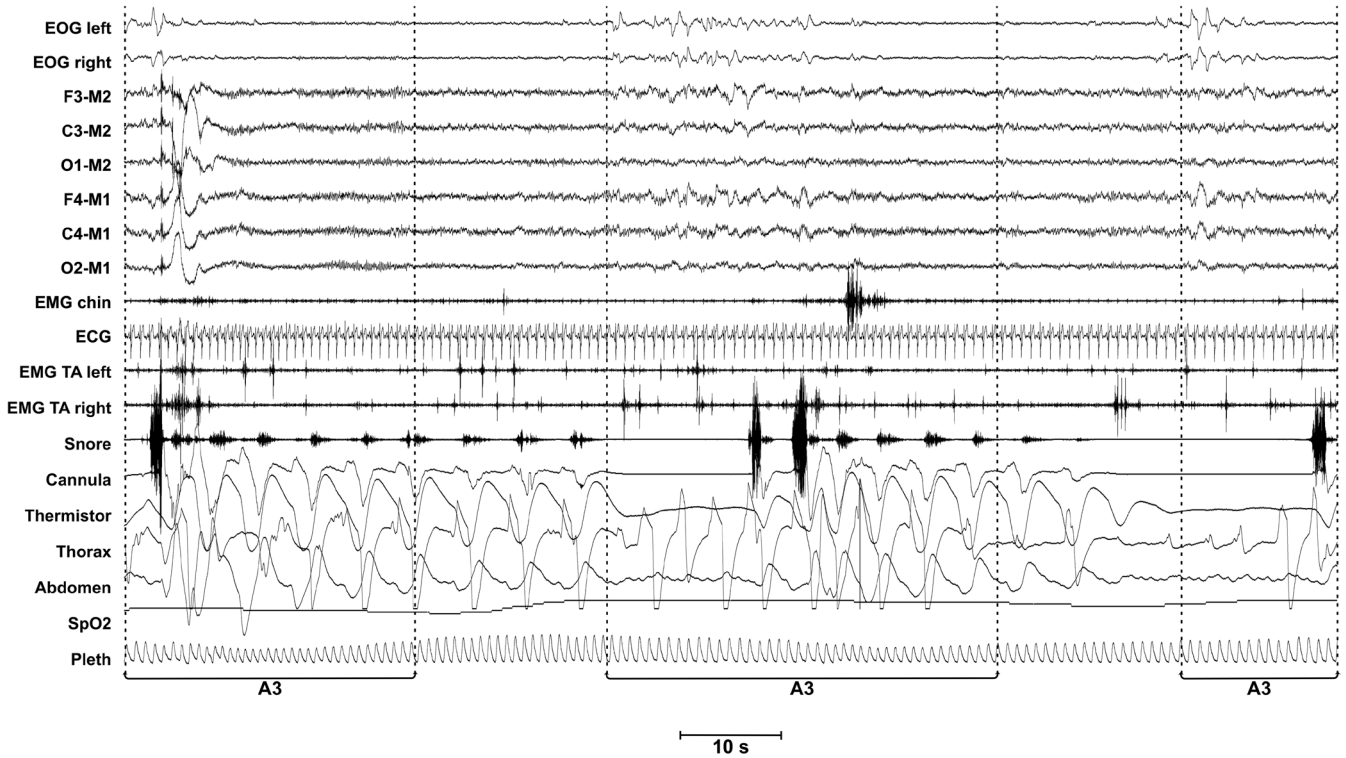


**FIGURE 21** | CAP-like activity in REM sleep in a patient with obstructive sleep apnoea. Note that CAP is constituted only by A3 subtypes. Pleth = plethysmography; $SpO_2$ = peripheral oxygen saturation; TA = tibialis anterior.

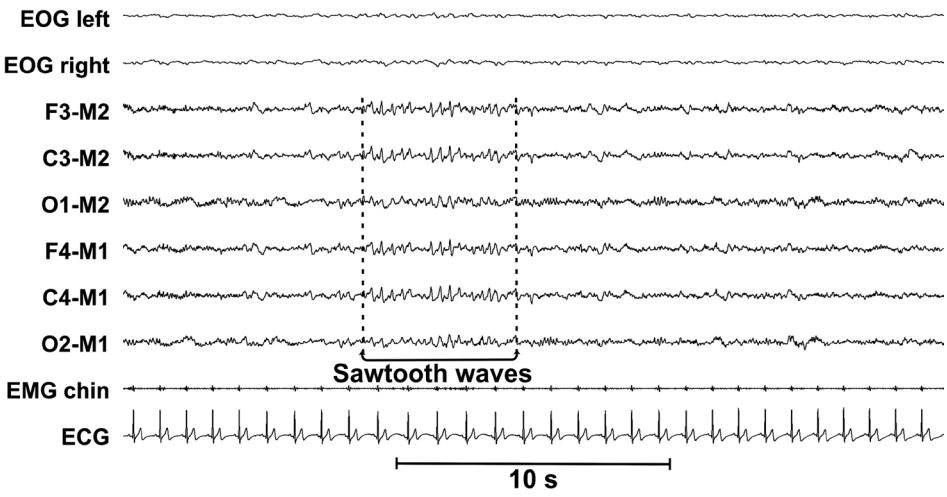


**FIGURE 22** | Sawtooth waves recorded during REM sleep. The highlighted EEG segment displays a cluster of notched, triangular-shaped waveforms predominantly seen in the central and frontal derivations (e.g., C3-M2 and F3-M2). Sawtooth waves typically occur at a frequency of 2–6 Hz and are most often observed immediately preceding or accompanying rapid eye movements, as seen in the concurrent EOG traces. These rhythmic, sharply contoured waveforms are a hallmark of REM sleep and serve as a distinguishing electrophysiological feature of phasic REM episodes and are not considered to pertain to CAP.

- Expect higher amplitude variability in infants and toddlers.

### 13.6 | Sleep Architecture Considerations

- NREM cycles are shorter in infants.
- Sleep stage transitions are less defined in infants.
- Align CAP scoring with AASM paediatric staging rules.

### 13.7 | Summary of Paediatric CAP Scoring Adjustments

Domain and Paediatric Adaptation

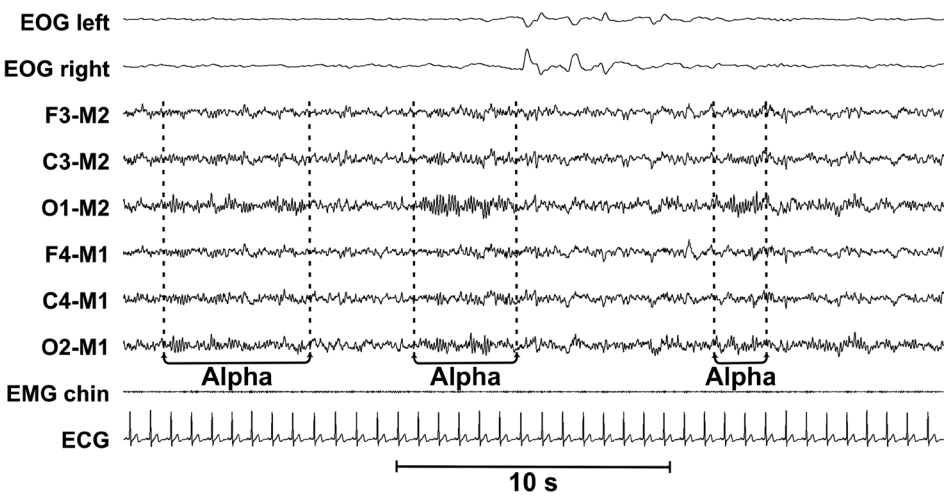


**FIGURE 23** | Polysomnographic example showing intermittent alpha activity during REM sleep, with bursts clearly visible over occipital derivations (O1-M2 and O2-M1) and concurrent rapid eye movements in the EOG channels. Chin EMG tone is reduced, consistent with REM sleep atonia. Intermittent alpha during REM sleep can be classified as part of CAP only if it meets the amplitude criterion in at least 60% of EEG leads.

- EEG frequency bands: Adjust interpretation by age (Bruni et al. 2002, 2005).
- Phase A/B durations: Keep at 2–60 s.
- CAP cycle length: Shorter and more frequent in young children (Miano et al. 2009).
- Subtype prevalence: A1 dominates; A3 is rare in young children (Bruni et al. 2002, 2005).
- Amplitude thresholds: Use relative increases from baseline.
- Sigma (spindles): Present after 2 months.

*Note:* CAP analysis becomes feasible with the emergence of mature stage N2 features—namely, the presence of sleep spindles and slow delta waves intermixed with theta activity—typically observable by approximately 3 months of postnatal life (Miano et al. 2009).

## 14 | Guidelines for Scoring CAP During REM Sleep (Optional)

### 14.1 | General Principles

CAP is traditionally scored only during NREM sleep. However, in certain research and pathological contexts, CAP-like activity may be observed in REM sleep (Figure 21). Thus, the expression 'CAP-like instability' refers to recurrent phasic EEG and autonomic fluctuations during REM sleep that share temporal and morphological analogies with CAP dynamics in NREM sleep, reflecting rhythmic microstructural instability characteristic of this sleep stage. Scoring CAP in REM should be done cautiously, with stricter criteria to avoid conflating normal phasic REM phenomena, such as sawtooth waves (Figure 22) and intermittent alpha (Figure 23), with CAP.

### 14.2 | REM-CAP Detection Criteria for Adults

Score AASM arousals as A3 subtypes during REM sleep.

CAP sequences during REM sleep are defined with the same rules as for NREM sleep; although only A3 are expected.

### 14.3 | Cases Where REM-CAP Might Be Considered

- Sleep-disordered breathing: CAP-like instability occurs during REM (Karuga et al. 2023).
- REM sleep behaviour disorder (RBD): Muscle tone and activation might generate detectable CAP-like events.
- Autonomic instability: heart rate and EEG coupling during REM arousals (Huo et al. 2023).

### 14.4 | Final Metrics to Report in REM CAP Analysis

- Total REM CAP rate (%): (Total REM CAP Time/REM Sleep Time)×100 Total REM CAP rate should be reported separately from the NREM CAP metrics.

Although REM sleep represents a larger portion of total sleep time in early life, systematic data on CAP expression during REM in paediatric populations are still limited. Further studies are needed to characterise developmental aspects of REM-related CAP activity before formal scoring rules can be proposed.

**Author Contributions**

**Liborio Parrino:** conceptualisation, writing – review and editing. **Heidur Gretarsdottir:** conceptualisation, writing – original draft, writing – review and editing. **Robert Thomas:** writing – review and editing. **Ivana Rosenzweig:** writing – review and editing. **Oliviero Bruni:** writing – review and editing. **Gulcin Benbir Senel:** writing – review and editing. **Fábio Mendonça:** writing – review and editing. **Antonio G. Ravelo García:** writing – review and editing. **Erna Sif Arnardóttir:** resources. **Raffaele Ferri:** conceptualisation, supervision, writing – original draft, writing – review and editing.

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## Conflicts of Interest

Robert Thomas declares: (1) Patent and licence for ECG/PPG cardiopulmonary sleep spectrograms for sleep apnoea and sleep quality; (2) licence patents for respiratory self-similarity and Enhanced Expiratory Rebreathing Space (for high loop gain apnoea detection and treatment, respectively); and (3) general sleep medicine consulting for Guidepoint and GLG Councils. Erna Sif Arnardóttir reports personal fees from Nox Medical, Jazz Pharmaceuticals, Linde Healthcare, Wink Sleep, Apnimed, Vistor and ResMed. She is a member of the medical advisory boards for Philips Sleep Medicine & Innovation Medical Board and Lilly. The other authors declare no conflicts of interest.

## Data Availability Statement

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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## Appendix A

### Comparison Between the 2001 CAP Scoring Rules and the 2025 Updated Rules

Main differences between the 2001 CAP scoring rules and the new 2025 updated rules (Table A1):

A. Definition and scope
   - Both documents define CAP as periodic EEG activity during NREM sleep with ≤1-min cycles.
   - The 2025 Atlas uses more updated terminology (electrocortical events) and offers structured guidance for optional CAP scoring during REM, especially in pathological or paediatric contexts, a notable expansion beyond the original 2001 scope.

B. EEG Phase A elements
   - The 2001 rules list a foundational but limited set of EEG elements in Phase A.
   - The 2025 Atlas significantly expands this list to include additional recognised EEG patterns such as low-voltage beta bursts, high-amplitude slow transients and mixed-frequency transients, offering a more comprehensive reflection of sleep microstructure and instability.

C. Onset/offset criteria
   - In 2001, onset/offset was primarily amplitude-based with general guidance on frequency and lead concordance.
   - The 2025 rules formalise this with clear dual criteria: ≥33% amplitude increase or a frequency band shift sustained for ≥2 s, and a strict ≥60% lead concordance rule for validity, improving objectivity and reproducibility.

D. Scoring infrastructure
   - Both require ≥2 s for Phases A and B.
   - The 2025 guidelines modernise electrode recommendations: six-channel preferred, but if three are used, they must be unilateral; this was not explicitly defined in 2001.

**TABLE A1** | Summary of the differences between the 2001 CAP scoring rules and the new 2025 updated rules.

| Feature | 2001 CAP rules (Terzano et al.) | 2025 CAP rules (updated Atlas) |
|---|---|---|
| Definition of CAP | CAP defined as periodic EEG activity during NREM sleep, recurring at ≤1-min intervals. | CAP defined as periodic electrocortical events during NREM sleep, occurring at ≤1-min intervals. |
| Scope of CAP scoring | NREM sleep only, with optional notes on REM pathologies. | Primarily NREM; structured recommendations also included for optional REM CAP scoring. |
| EEG Phase A elements | Delta bursts, K-complexes, vertex sharp transients, polyphasic bursts, intermittent alpha, K-alpha and EEG arousals. | Expanded list: Delta bursts, high-amplitude slow transients, K-complex sequences, intermittent alpha, K-alpha, polyphasic bursts, low-voltage beta bursts, mixed-frequency transients, vertex harp transients and EEG arousals. |
| Onset/offset criteria | ≥33% amplitude increase; frequency shifts evaluated with ambiguity; relies on concordance across leads. | Clear dual criteria for onset/offset: ≥33% amplitude increase or frequency band shift sustained ≥2 s; must occur in ≥60% of leads. |
| Minimum duration of phases | Both Phases A and B must last ≥2 s; <2 s between Phase A results in merging. | Phases A and B durations remain ≥2 s. |
| Required channels | Bipolar derivations preferred; mono derivations mentioned for minimal setups. | Six-channel monopolar EEG preferred; if three are used, they must be unilateral (left or right hemisphere). |
| Phase A subtypes | Subtypes A1 (synchrony), A2 (mixed), A3 (desynchrony); based on proportion of EEG rhythms. | Same subtypes (A1–A3); consistent descriptions (high/low voltage and slow/fast frequencies instead of synchrony/desynchrony); clarified classification when multiple leads differ. |
| Rules for REM CAP | CAP not typically scored in REM; exceptions mentioned for REM-related pathologies. | Formal rules for REM CAP scoring in adults and children; stricter criteria than in NREM to avoid misinterpretation. |
| Paediatric adaptations | Not included. | Comprehensive section covering age-specific EEG traits, frequency adaptations, and developmental considerations. |
| Quantitative metrics | Not detailed. | Mandatory metrics (CAP time, rate, subtype distribution) and optional indices (A1–A3 indices, durations, sequences, etc.) included. |

E. Phase A subtypes
   - Both define subtypes A1, A2 and A3 based on the spectral content of the EEG signal (slow vs. fast frequencies).
   - The 2025 version adds decision rules for assigning subtypes when mixed patterns occur across leads, offering greater clarity.

F. REM sleep CAP
   - The 2001 rules mention CAP-like events in REM pathologies but discourage formal scoring.
   - The 2025 update introduces formal criteria for REM CAP scoring in select cases (e.g., REM behaviour disorder and paediatric sleep) and recommends separate reporting of REM CAP metrics in selected cases.

G. Paediatric considerations
   - The 2001 manual lacks paediatric adaptations.
   - The 2025 Atlas includes a detailed paediatric section: age-specific EEG features, developmental CAP structure and modified frequency/amplitude thresholds, a major advance.

H. Quantitative reporting
   - The 2001 rules do not provide formal guidance on reporting.
   - The 2025 rules introduce mandatory metrics (CAP rate and subtype distribution) and optional metrics (A1/A2/A3 indices, durations and sequence counts), enhancing comparability across studies.

## Appendix B

### Summary of Scoring Rules for the Cyclic Alternating Pattern (CAP)

A. General
   1. Recordings of signals should be conducted in accordance with the AASM Manual for the Scoring of Sleep and Associated Events and must include, at a minimum, EOG, EEG and submental EMG signals. While the use of six EEG channels is preferable to ensure reliable CAP detection and topographic resolution, a minimum of three EEG channels is acceptable (F4-M1, C4-M1, O2-M1 or F3-M2, C3-M2 and O1-M2).
   2. The rules for scoring CAP do not require any adaptation or changes to the AASM sleep stage scoring rules, and sleep staging is required prior to scoring CAP.

B. The following rules define CAP
   1. A CAP cycle consists of one activation phase (A phase), which represents a transient, phasic event and an intervening background phase (B phase), which separates two successive A phases.
   2. A phases and B phases last 2–60 s and are scored in NREM sleep.
   3. The absence of CAP for > 60 s is scored as non-CAP. An isolated Phase A is classified as non-CAP, and REM periods are scored as non-CAP with some exceptions (see notes).
   4. CAP is formed by sequences of at least two consecutive complete CAP cycles, delimited by at least three A phases and two B phases (A-B-A-B-A), with the last A phase assigned to the following non-CAP period.
   5. A phase can include: Delta bursts, high-amplitude slow transients, K-complex sequences, intermittent alpha, K-alpha, polyphasic bursts, low-voltage beta bursts, mixed-frequency transients, vertex sharp transients and EEG arousals.
   6. CAP Phase A onset and offset:
      *Primary onset amplitude criterion*: The onset of a CAP Phase A is defined by a ≥ 33% increase in peak-to-peak amplitude, sustained for at least 2 s, relative to the background voltage. The background voltage is measured over the 2 s preceding the onset. If this amplitude criterion is met, no frequency change is required.
      *Alternative onset frequency criterion*: If the onset amplitude criterion is not met, the onset of a CAP Phase A may still be identified based on a frequency change, evaluated over the 2 s before onset. A frequency change is defined as a shift to a higher frequency band (e.g., delta → theta, or theta → alpha), lasting at least 2 s.
      *Primary offset amplitude criterion*: The offset of a CAP Phase A is defined as the point at which the average peak-to-peak amplitude during the 2 s preceding it remains at least 33% higher than the average amplitude during the 2 s following it.
      *Alternative offset frequency criterion*: If the offset amplitude criterion is not met, the offset of a CAP Phase A based on frequency is defined as the point at which the average frequency during the 2 s preceding it shifts to a lower frequency band compared to the average frequency during the 2 s following it, with the shift sustained for at least 2 s.
   7. CAP Phase A subtypes
      *Subtype A1*: EEG slow waves are the predominant activity. If present, EEG fast rhythms occupy (including movements) < 20% of the entire Phase A duration.
      *Subtype A2*: The EEG activity is a mixture of slow and fast rhythms, with 20%–50% of Phase A occupied by EEG fast rhythms or movements.
      *Subtype A3*: The EEG activity is predominantly rapid low-voltage rhythms (including movements) in > 50% of Phase A. An event only constituted by a movement within a CAP sequence is also classified as Subtype A3 if the duration criteria are met.

C. The following should be measured and reported:

   *Recommended metrics*:

   Total CAP rate (%): (Total CAP Time/NREM Sleep Time) × 100; Distribution of Subtypes: % of A1, A2, A3.

   *Optional metrics*:

   CAP time (min); CAP rate N1 (%); CAP rate N2 (%); CAP rate N3 (%); A1 Index (*n*/h); A2 Index (*n*/h); A3 Index (*n*/h); Mean A1 duration (s); Mean A2 duration (s); Mean A3 duration (s); B mean duration (s); Mean Cycle duration (s); Mean number of cycles in sequence (*n*); CAP sequences (n); and Sequence mean duration (s).

*Note:*

1. For research purposes, the set of signals used for the detection of CAP should be kept constant within the whole experimental protocol.
2. Concordance across leads: In all cases, whether amplitude- or frequency-based, onset and offset criteria must be observed in at least 60% of EEG leads to be considered valid.
3. CAP can be scored in REM sleep in select cases using distinct criteria and reported separately (see Section 13 in Atlas).
4. If different leads express different subtypes, assign the highest CAP subtype number to the event.
5. Add notes on length, wake, paediatric criteria, frequency definitions or other?

### Technical Note: Core Technical Principles for Computerised CAP Detection and Scoring

TN1. Signal acquisition and preprocessing
   a. EEG, EOG and EMG channel requirements
      i. AASM Manual (Troester et al. 2023) derivations; bilateral input if applicable
   b. Sampling rate and resolution
      i. Recommended: ≥ 200 Hz to preserve transient features
   c. Filtering
      i. Bandpass: typically, 0.1–40 Hz
      ii. Optional: notch filtering at 50/60 Hz
   d. Artefact handling
      i. ICA or regression for eye/muscle artefacts
      ii. Decompose the signal in time-frequency by thresholding the coefficients corresponding to artefacts

TN2. Segmentation and epoch definition
   a. Segmentation strategy
      i. Continuous signal processing versus stage-specific windowing
   b. Baseline correction
      i. Local baseline adjustment (e.g., moving median)
   c. Event window constraints
      i. Minimum and maximum durations of Phase A ($\geq 2$ s, $\leq 60$ s)
      ii. Phase B minimum duration ($> 2$ s) per standard rules

TN3. Feature extraction
   Feature extraction is optional and may vary across algorithms. Automated CAP detection may rely on either direct amplitude/frequency analysis or derived features that reflect CAP-relevant dynamics. The essential requirement is that the chosen features objectively capture transient amplitude or frequency changes corresponding to Phase A events.

TN4. Event detection algorithms
   a. Rule-based approaches
   b. Machine learning models
   c. Hybrid models
   Regardless of approach, algorithms should document decision thresholds, data segmentation strategy and validation against manual scoring.

TN5. Post-processing strategies
   a. Isolated event removal
      i. If applicable, replace 1-s events with the surrounding annotated epochs when they are the same annotation
      ii. If, by correcting to a Phase A, this becomes longer than 60 s, apply a strategy to divide into two phases A
   b. If multiple one-versus-all estimations are used for subtype classification, consider strategies to select the correct subtype when the same epoch is classified as two different subtypes

TN6. CAP cycle assembly
   a. Temporal constraints
      i. Phase B duration $\leq 60$ s to maintain cyclic definition
      ii. Merging of events based on inter-event intervals
   b. Subtype assignment
      i. Based on spectral composition (slow vs. fast activity)
      ii. Quantitative criteria: per cent power above alpha/beta thresholds

TN7. Validation framework
   a. Ground truth definition
      i. Manual scoring by $\geq 2$ experts using standardised criteria
      ii. Inter-rater variability quantification (e.g., Cohen's/Fleiss' kappa)
      iii. Iterative consensus rounds among experts (e.g., Delphi-like methodology) to reduce disagreements and strengthen ground truth reliability
   b. Performance metrics
      i. Event-level: Sensitivity, specificity, precision and F1 score
      ii. Cycle-level: CAP rate, phase duration distributions
      iii. Agreement window: Define temporal tolerance (e.g., $\pm 0.5$ s)
      iv. Report model uncertainty along model predictions
   c. Cross-validation design
      i. Subject-wise splitting to avoid data leakage
      ii. Robustness to different montages and populations
      iii. Leave-one-subject-out cross-validation
      iv. Stratified *k*-fold validation maintaining class distributions
   d. Visualisation methods for performance assessment
      i. Bland–Altman plots for agreement analysis between manual and automated scoring
      ii. Confusion matrices with heat map representations
      iii. Receiver operating characteristic curves and precision–recall curves
      iv. Distribution plots comparing automated versus manual scorings
      v. Time-series alignment plots showing detection concordance
      vi. Subject-wise performance scatter plots to assess inter-subject variability (e.g., sensitivity vs. specificity)

TN8. Output formatting and compatibility
   a. Annotation standards
      i. EDF+ annotations, XML/JSON output for PSG viewers
   b. Real-time versus offline output
      i. Buffering, latency constraints
      ii. Integration with real-time data streams for monitoring

TN9. Robustness and generalizability
   a. Adaptation to inter-subject variability
      i. Normalisation methods (*z*-scoring and percentile scaling)
   b. Adaptation to sleep stage transitions
      i. Stage-specific detection thresholds
   c. Handling pathological EEG
      i. Tuning for high artefact loads or atypical EEG (e.g., in epilepsy and dementia)

TN10. Software and computational considerations
   a. Modular design
      i. Separate pipelines for preprocessing, feature extraction and classification
   b. Performance
      i. Computational load, GPU/CPU usage and inference time
   c. Open-source tools and libraries
      i. MNE-Python, EEGLAB and TensorFlow/PyTorch

TN11. Automation suggestions based on alternative windowing strategies
   Alternative windowing strategies can improve temporal context in automated CAP detection but should be applied in a standardised and transparent manner. The following principles define good practice rather than prescribing specific algorithms:
   a. Overlapping window framework
      Extended analytical windows (e.g., overlapping 1–2 s epochs) may enhance the detection of transitional dynamics between Phase A and Phase B. Any overlap or sliding-window design must preserve temporal continuity and resolution, and its parameters (window length, step size and overlap ratio) should be explicitly reported.
   b. Directional windowing approaches
      When directional or bidirectional analyses are used, their rationale must be stated clearly:
   - Leftward (retrospective) analyses should specify how pre-onset information contributes to Phase A identification
   - Rightward (prospective) analyses should define how post-event data are used for offset detection.
   - Bidirectional strategies should describe how information from both temporal directions is combined and how causality or temporal leakage is avoided.

      In all cases, developers should ensure that contextual windows are implemented consistently across subjects and stages, and that their contribution to detection performance is quantitatively evaluated and reported.

TN12. Suggested automation support for manual detection based on pre-onset window quantification
   a. Context
      Use a 2-s pre-onset window as defined in Sections 10.1 and 10.2 to identify CAP Phase A events.
   b. Automated procedure
      1. Implement automatic quantification of mean amplitude in this pre-onset window.

2. Provide real-time objective reference values to support manual review.

c. Specific metrics
   1. Calculate and display average peak-to-peak amplitude in the 2 s before suspected onset to verify ≥ 33% amplitude increase.
   2. Compute and show dominant frequency within the same window.
   3. Estimate dominant frequency using a simple FFT analysis in a longer or overlapping window.

TN13. Automated support for offset detection via post-event window quantification

a. Context

Use a 2-s post-event window as defined in Sections 10.3 and 10.4 to identify CAP Phase A offsets

b. Automated procedure
   1. Implement an automated module to quantify average amplitude and frequency after the candidate offset.
   2. Provide objective baseline references to support manual annotation.

c. Specific metrics
   1. Calculate and display average peak-to-peak amplitude in the 2 s following the offset. Verify ≥ 33% amplitude reduction.
   2. Compute and show dominant frequency in this post-event window. Optionally use longer or optimised windows to add contextual information. Verify frequency shift to confirm true offset.

TN14. Recommended reporting and validation standards

Performance should be reported primarily for NREM sleep, with optional separate REM analyses. The temporal tolerance or overlap criterion defining true positives (e.g., ±0.5 s) must be stated. When paediatric populations are included or targeted, paediatric data must be used in training or validation. Recommended metrics include sensitivity, specificity, precision, F1 score and Cohen's $\kappa$; other complementary measures may be reported as optional.

TN15. Summary of best practices

a. Use high-quality EEG with validated preprocessing
b. Prefer subject-independent validation
c. Report multiple accuracy metrics and CAP-specific indices
d. Ensure compatibility with existing PSG software ecosystems
e. Transparently share code, parameters and scoring datasets where possible
f. Support with automation for some manual event detections