EEG del bambino: peculiarità rispetto all'adulto

Maturazione dell'EEG

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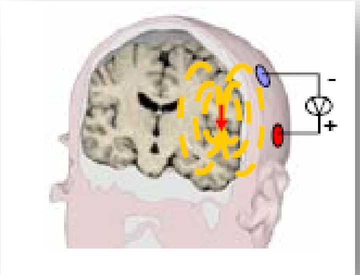
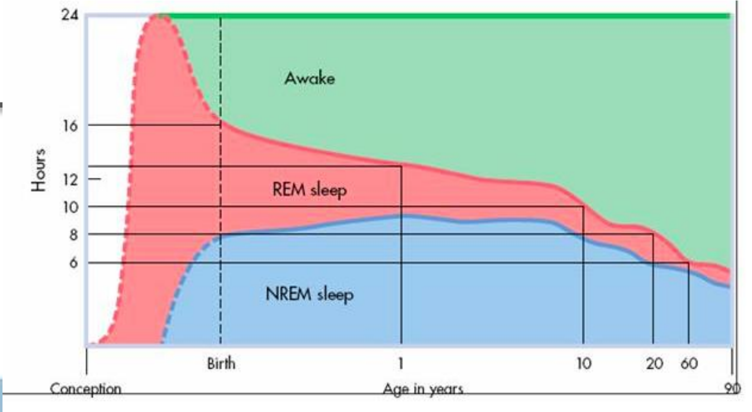


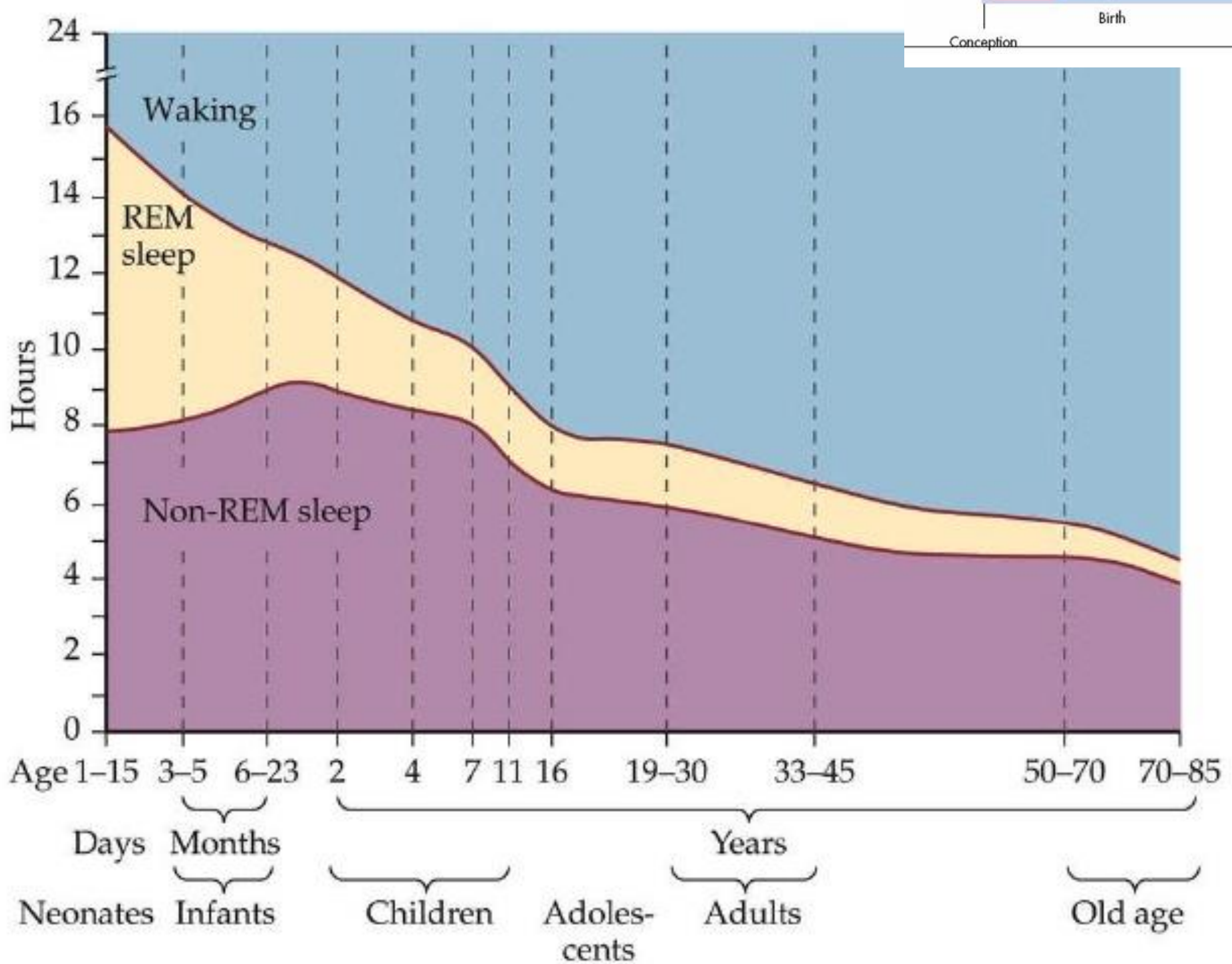
- Dichiaro l’assoluta autonomia dei contenuti scientifici del mio intervento ed indipendenza da interessi economici commerciali con possibili aziende sponsorizzatrici.

Special temporal course of EEG according to age

- One of the major characteristics of EEG in children is its **course over time** that parallels the **rapid brain maturation**
- EEG changes are particularly **rapid in early age** and they involve both **spatial and temporal** organization
- Changes can be noticed **each months in infancy**
  - **Sleep organization**
  - **Morphology of patterns (type, frequency, amplitude)**
  - **Spatial-temporal organization**

Human sleep patterns with age





Biological Psychology 5e, Figure 14.18

Sleep in Childhood and Adolescence: Age-Specific Sleep Characteristics, Common Sleep Disturbances and Associated Difficulties

Nicola L. Barclay and Alice M. Gregory

Curr Topics Behav Neurosci (2014) 16: 337–365

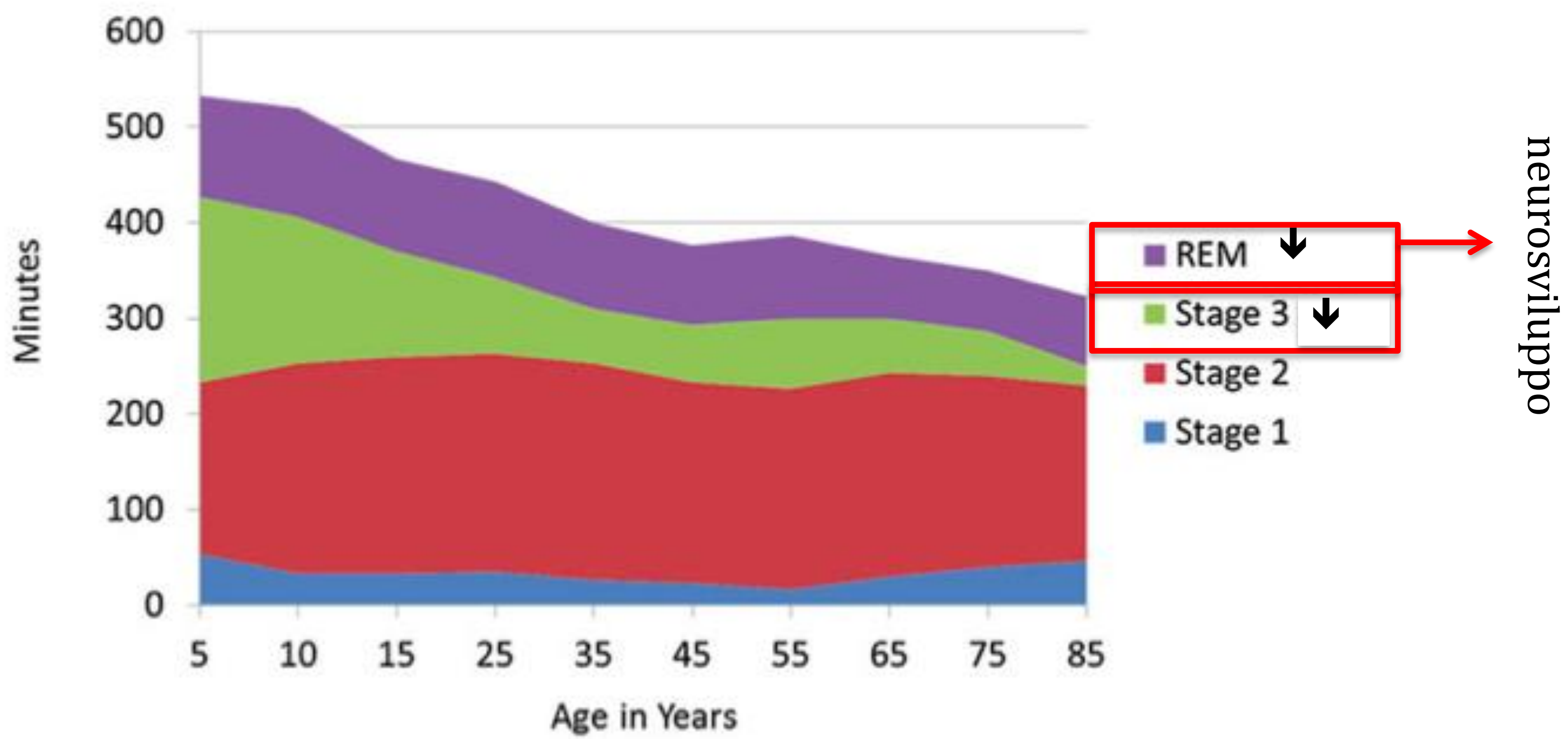
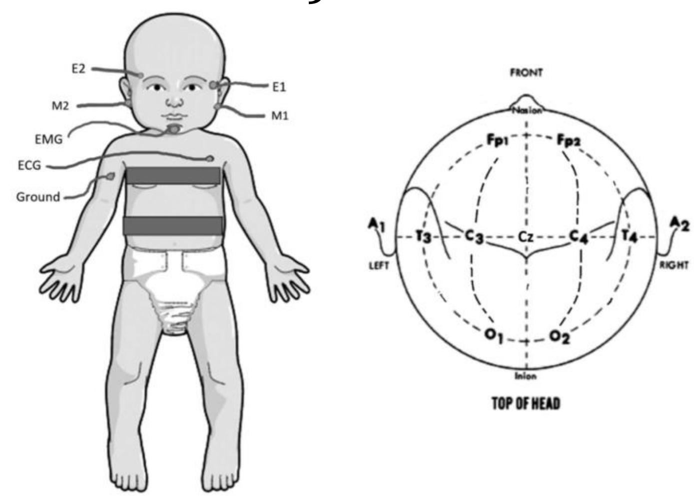


Fig. 1 Minutes of the night spent in sleep stages across the lifespan. Data from Ohayon et al. (2004)

Normal EEG in infancy (**1-12 months**)

- Following the first **3 weeks** of life:
  - **Nycthemeral organization changes**, with increasingly longer periods of daytime weakfulness and nocturnal sleep (naps decrease in number and duration)

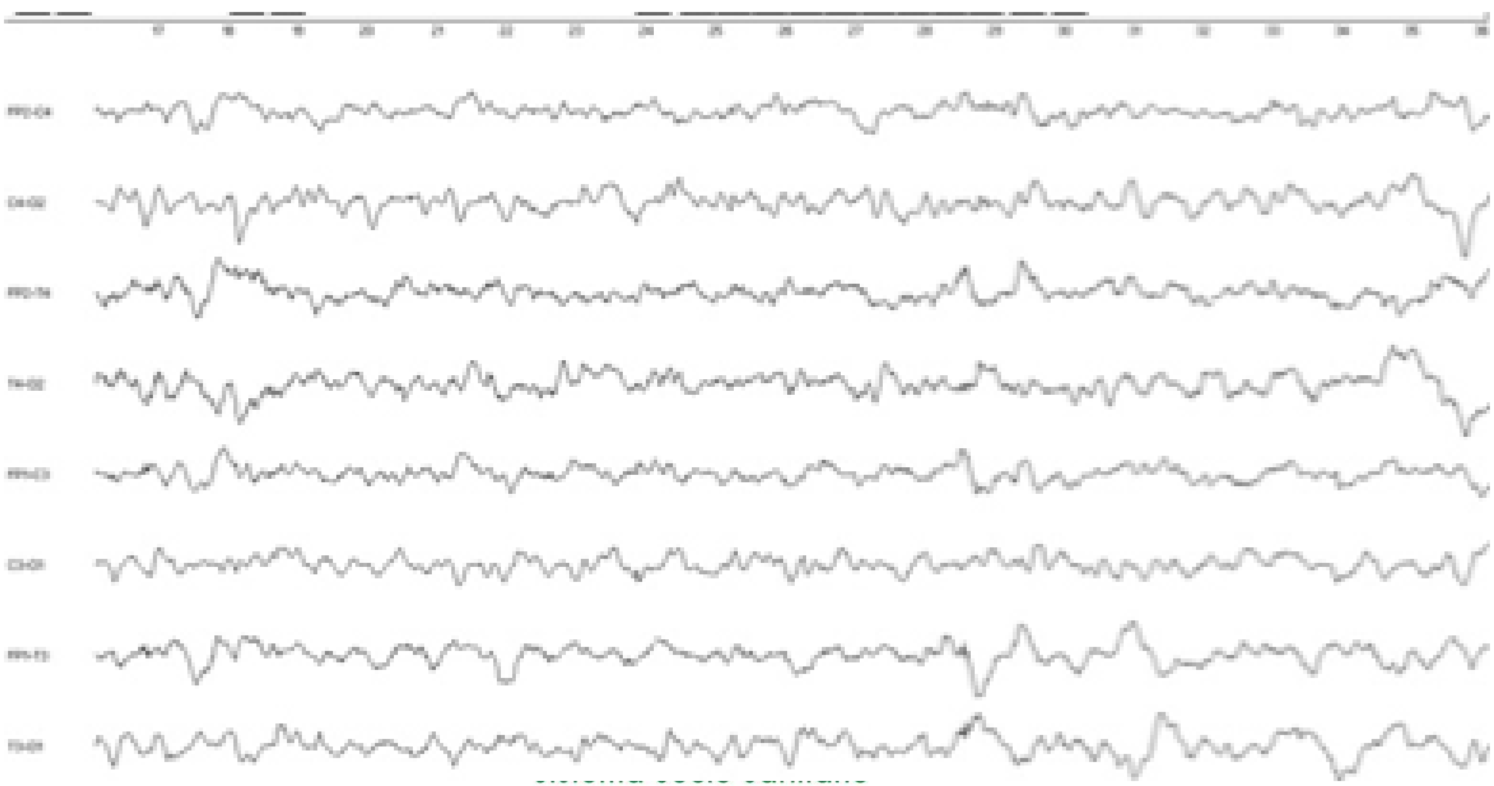


Normal EEG in infancy (1-12 months)

- **Weakfulness:**
  - The diffuse, low ampliturde **theta activity** that is seen at birth is replaced by a **MORE REGULAR THETA activity**
    - **4 Hz at 3 months**
    - **5 Hz at 5 months**
    - **6-7 Hz by the end of the first year of life**
  - Centro-occipital → **OCCIPITAL areas**
  - May reach **75 uV** amplitude
  - **VISUAL ARREST REACTION** exists from **3 months** of age postterm

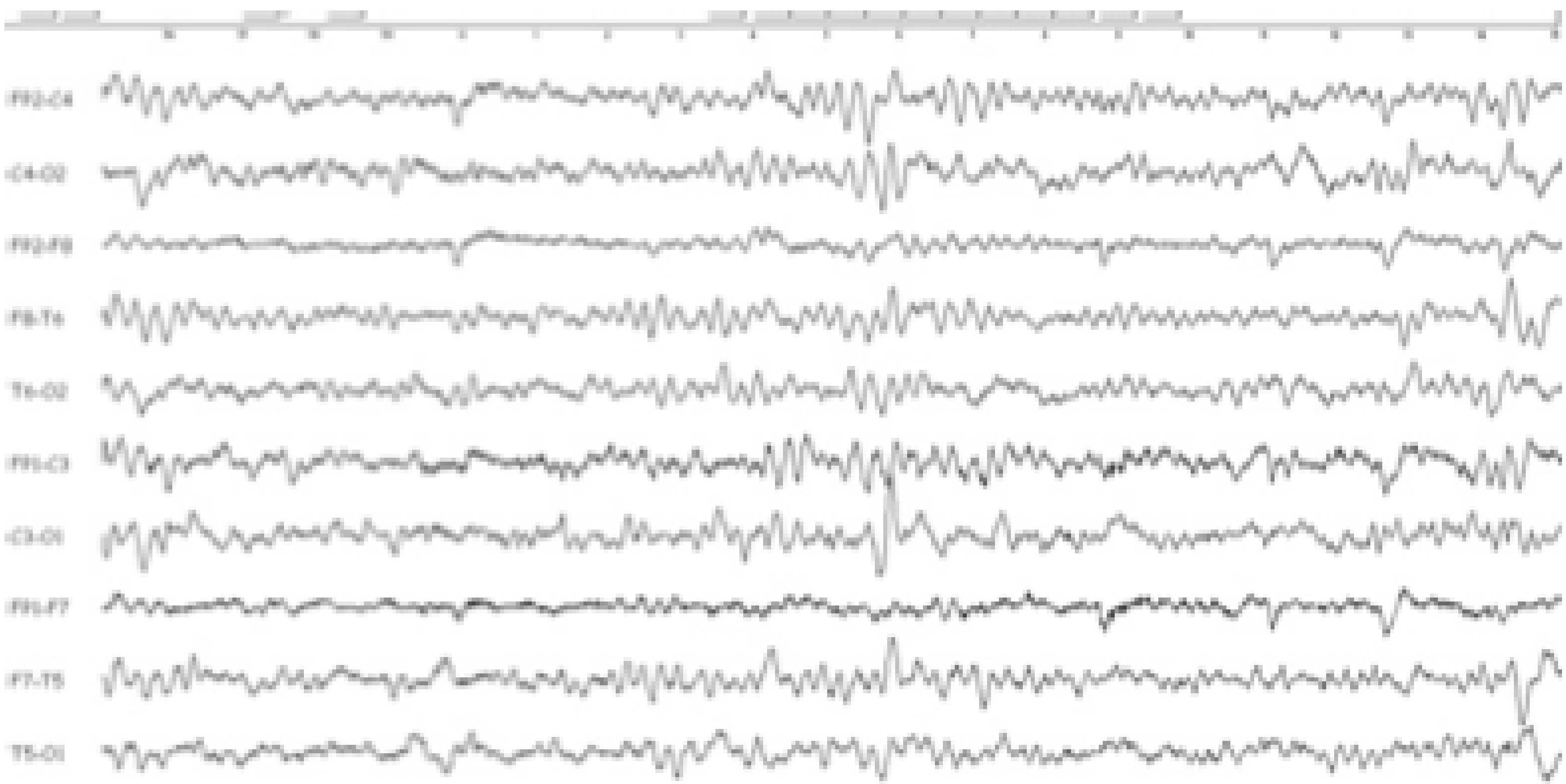
Normal EEG in infancy (1-12 months)

- **Weakfulness**



Normal EEG in infancy (**1-12 months**)

- **Weakfulness 9 months**



Normal EEG in infancy (1-12 months)

- **Somnolence:**
  - **Intermediary stage** between wakefulness and the first stage of slow sleep (SS)
  - Charachterized by **HYPNAGOGIC HYPERSYNCHRONY** of the background ➔
    - **high amplitude (100-250 uV) slo**
    - diffuse and rhytmic
    - **centroparietal** predominance
  - Constant between **8-12 months**

A normal variant. Paroxysmal bursts of **3–5 c/s,** high amplitude (75–350 uV) diffuse, but maximal **fronto-central**, sinusoidal activity occurring at the onset of sleep in normal infants and children, aged 3 months to 13 years (but typically 4–9 years).

Patterns Specific to Pediatric EEG

Raj D. Sheth

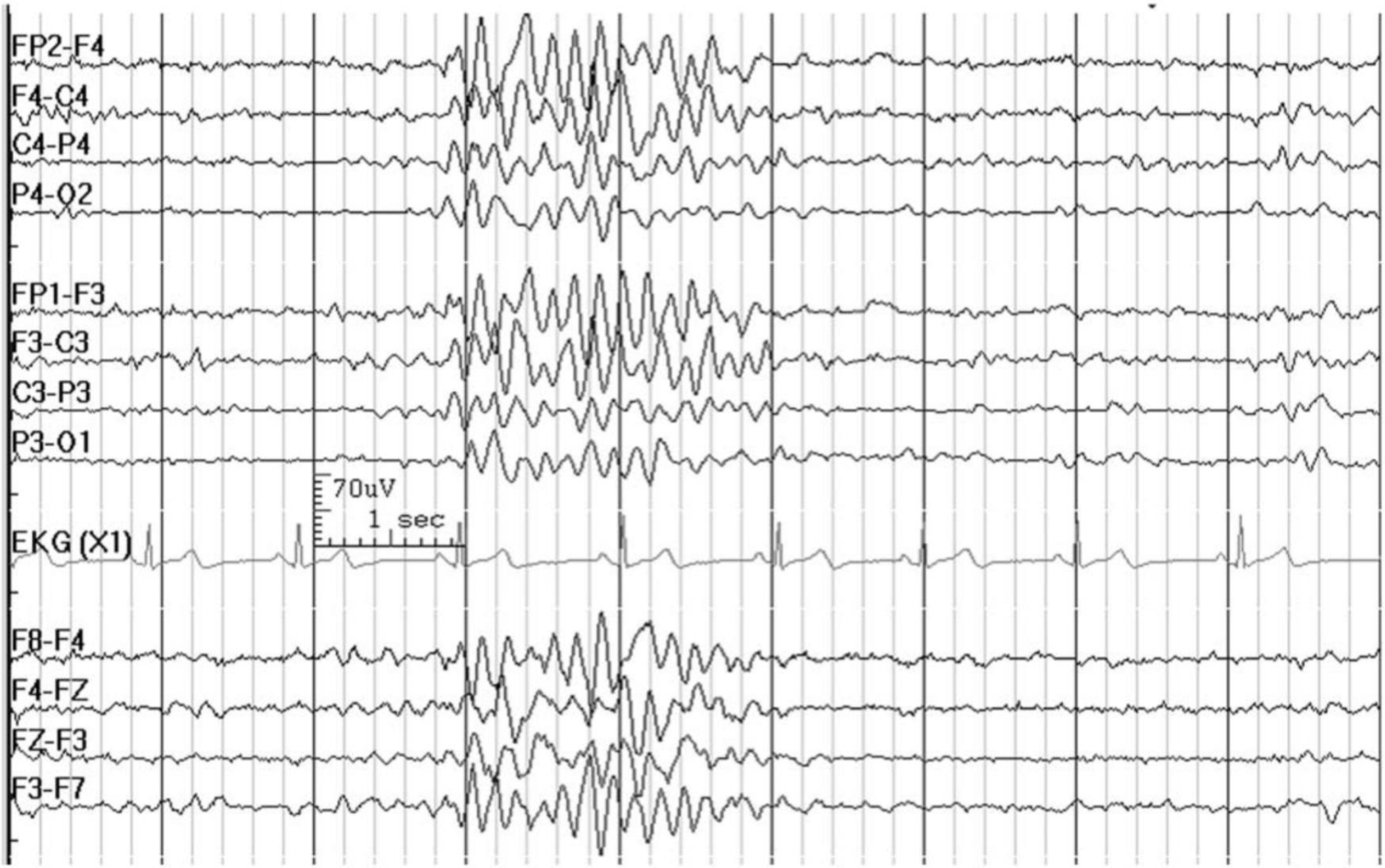
Mayo Clinic College of Medicine, Nemours Children Subspecialty Clinic, Jacksonville, Florida, U.S.A.

- **Hypnagogic Patterns**
  - Normal **variants of drowsiness** are initially realized at **3 months of age**, reach a maximal crescendo by **age 2 years**, and typically **disappear by age 12 years.**
  - Similarly, **vertex waves** can be very high amplitude and sharp and can **be mistaken for epileptiform discharges**
    - ➔ be mistaken for **generalized spike–wave discharges** particularly if the latter waveforms are seen with **overriding faster frequencies**.
    - Typically, **a posterior dominant rhythm is seen before the burst, which then transforms to drowsy patterns after the paroxysm.**
  - **Infants can have eyes open and still develop drowsy patterns**; this typically occurs **around feeding.** A similar phenomenon **occurs with arousal from sleep**. This pattern is referred to as **hypnopompic hypersynchrony** and is also a benign variant that is frequently seen in the EEG laboratory **where patients are aroused from sleep**.

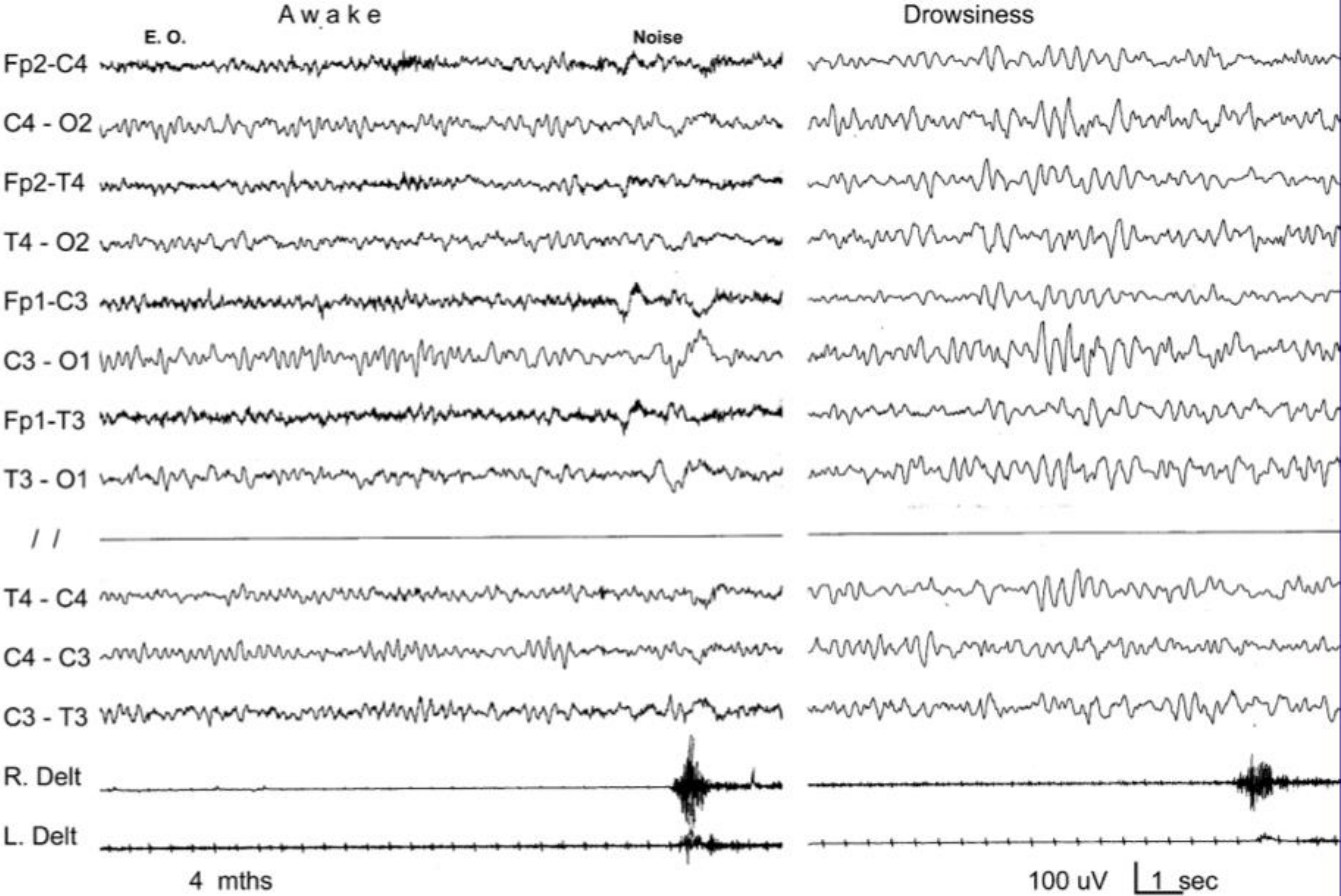
Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

Ali A. Asadi-Pooya*† and Michael R. Sperling*

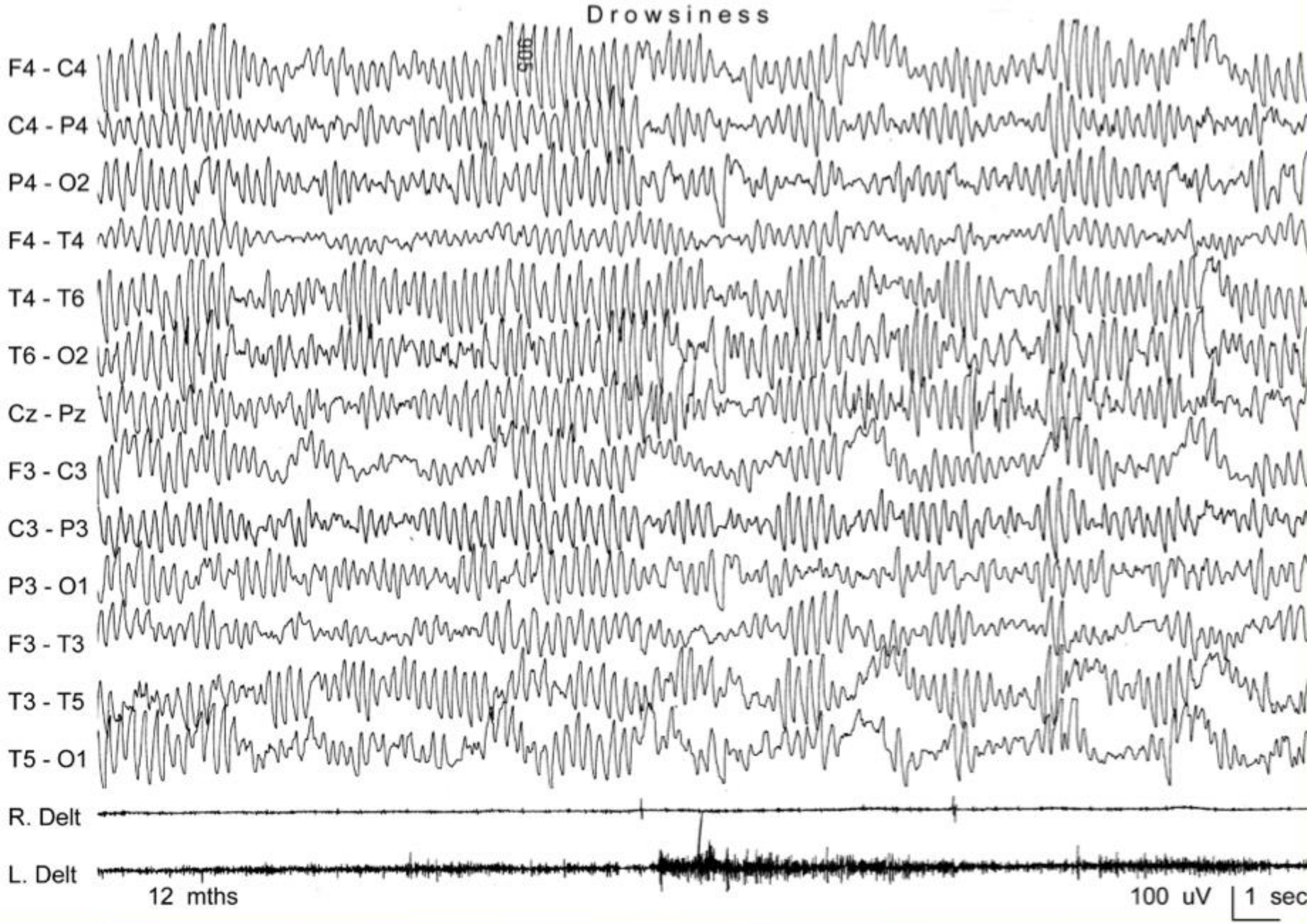
- **Hypnagogic and Hypnopompic Hypersynchrony**



J Clin Neurophysiol 2019;36: 250–256

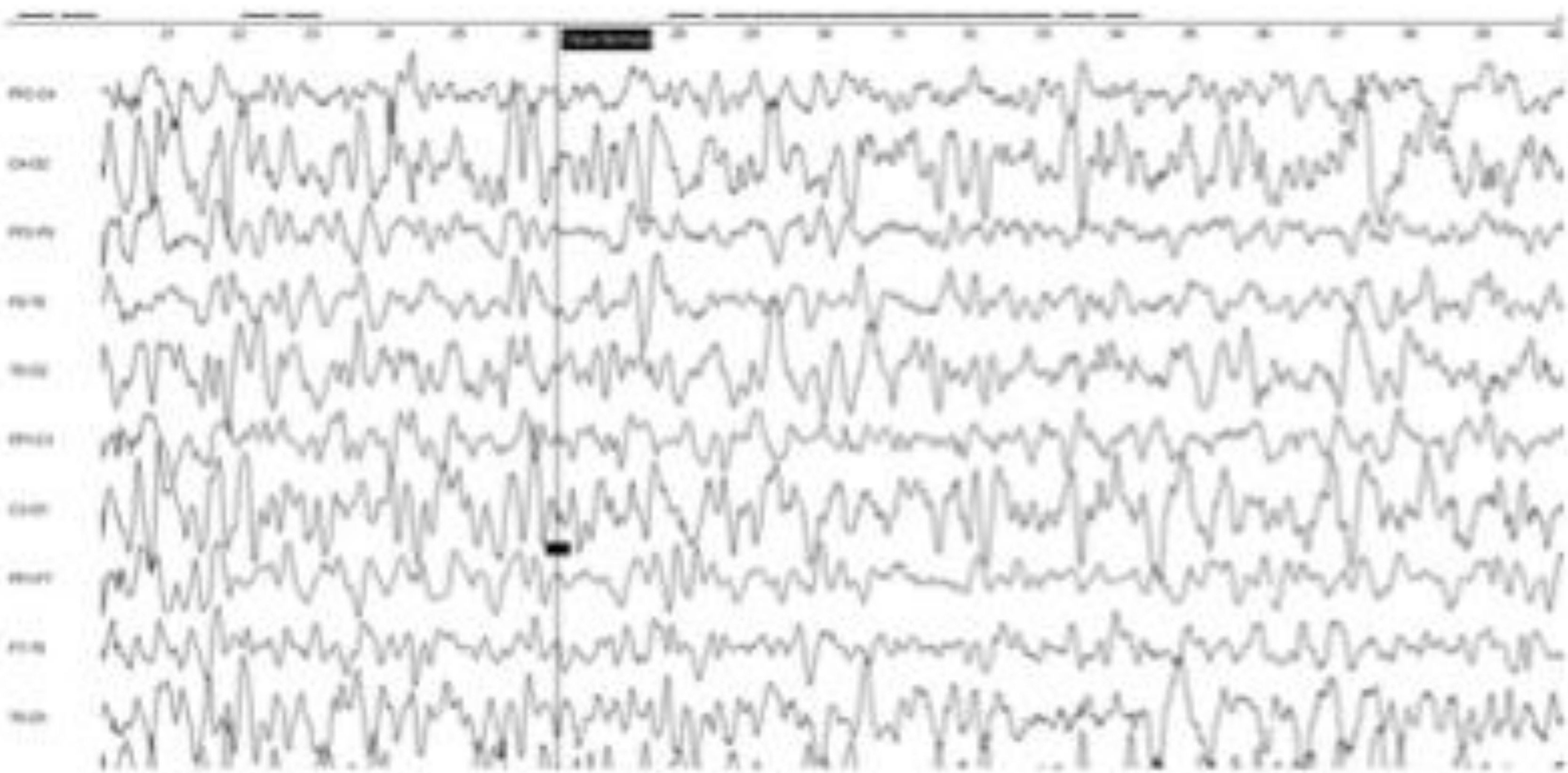


Awake
E. O.
Noise
Drowsiness
Fp2-C4
C4 - O2
Fp2-T4
T4 - O2
Fp1-C3
C3 - O1
Fp1-T3
T3 - O1
/ /
T4 - C4
C4 - C3
C3 - T3
R. Delt
L. Delt
4 mths
100 uV
1 sec


Drowsiness
906
F4 - C4
C4 - P4
P4 - O2
F4 - T4
T4 - T6
T6 - O2
Cz - Pz
F3 - C3
C3 - P3
P3 - O1
F3 - T3
T3 - T5
T5 - O1
R. Delt
L. Delt
12 mths
100 uV
1 sec

Normal EEG in infancy (**1-12 months**)

- **Somnolence 9 months**



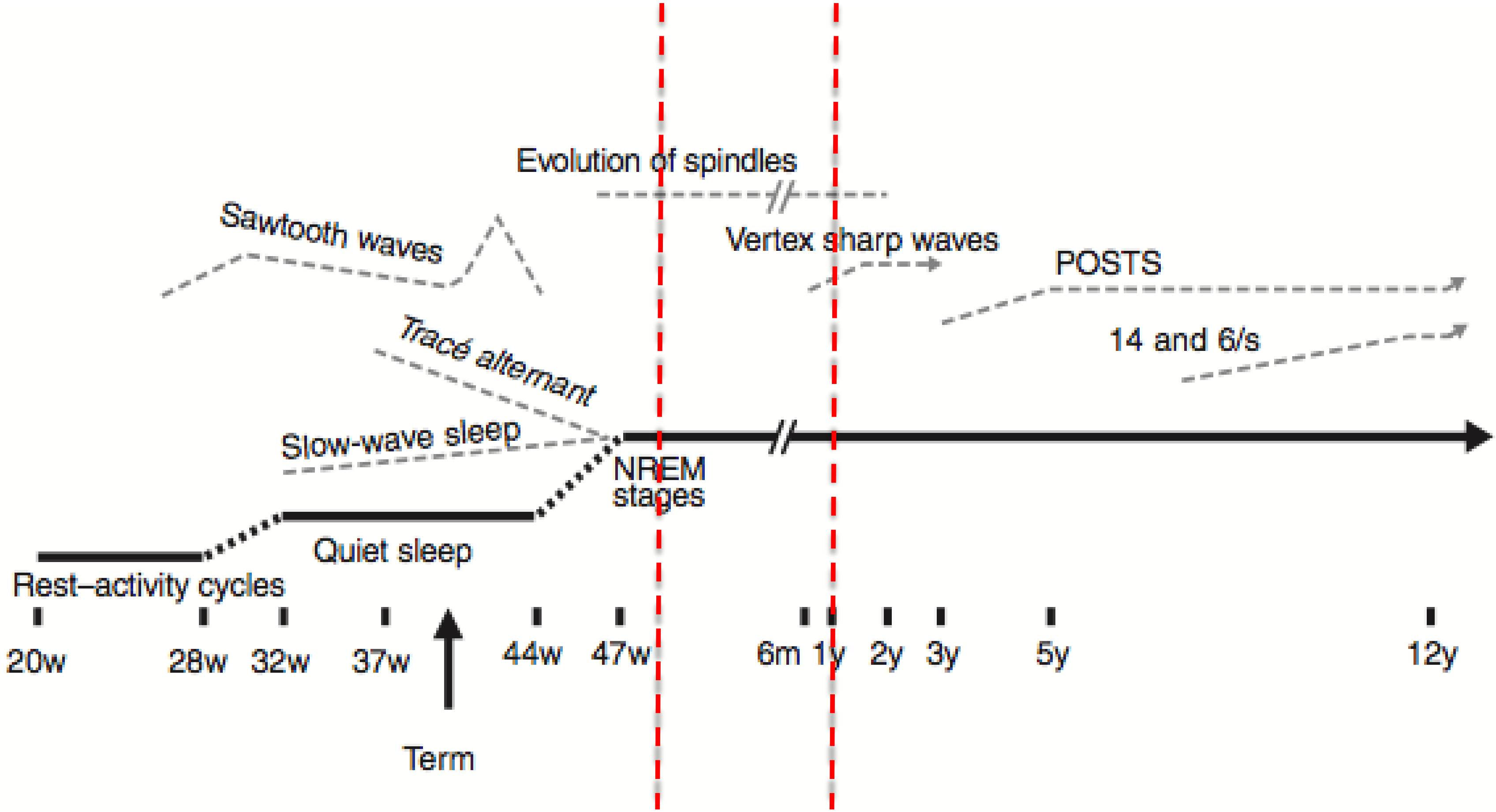


Figure 1: *Schematic diagram of temporal evolution of main neurophysiological features of sleep in infancy and early childhood. Black lines indicate periods of appearance of main behavioural stages. Ascending dotted lines indicate periods of transition between stages. Grey dashed lines indicate occurrence and maturational trends of distinctive electroencephalographic features (ascending lines=increase in occurrence, descending lines=decrease in occurrence, horizontal lines=stability, and arrows=continuation). POSTS, positive occipital sharp transients of sleep; 14 and 6/s, 14 and 6 per second positive spikes; NREM, non-rapid eye movement.*

Normal EEG in infancy (**1-12 months**)

- **Sleep:**
  - Disappearance of the trace alternant of QS
  - Replaced by **polymorphous 1 Hz delta waves** which may reach **70 to 100 uV**
  - **6 weeks**: appearance **of sleep spindle**
    - Burst of 12-15 Hz fast rhytms (mean 14 Hz)
    - Occurring 2 to 5 times per minute
    - **Centro-parietal** area
    - Often **asynchronous** in the first year of life

arise from **interactions between the thalamic reticular nucleus and thalamocortical neurons**, which together make up the 'thalamocortical loop' (Steriade, 2006).

Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

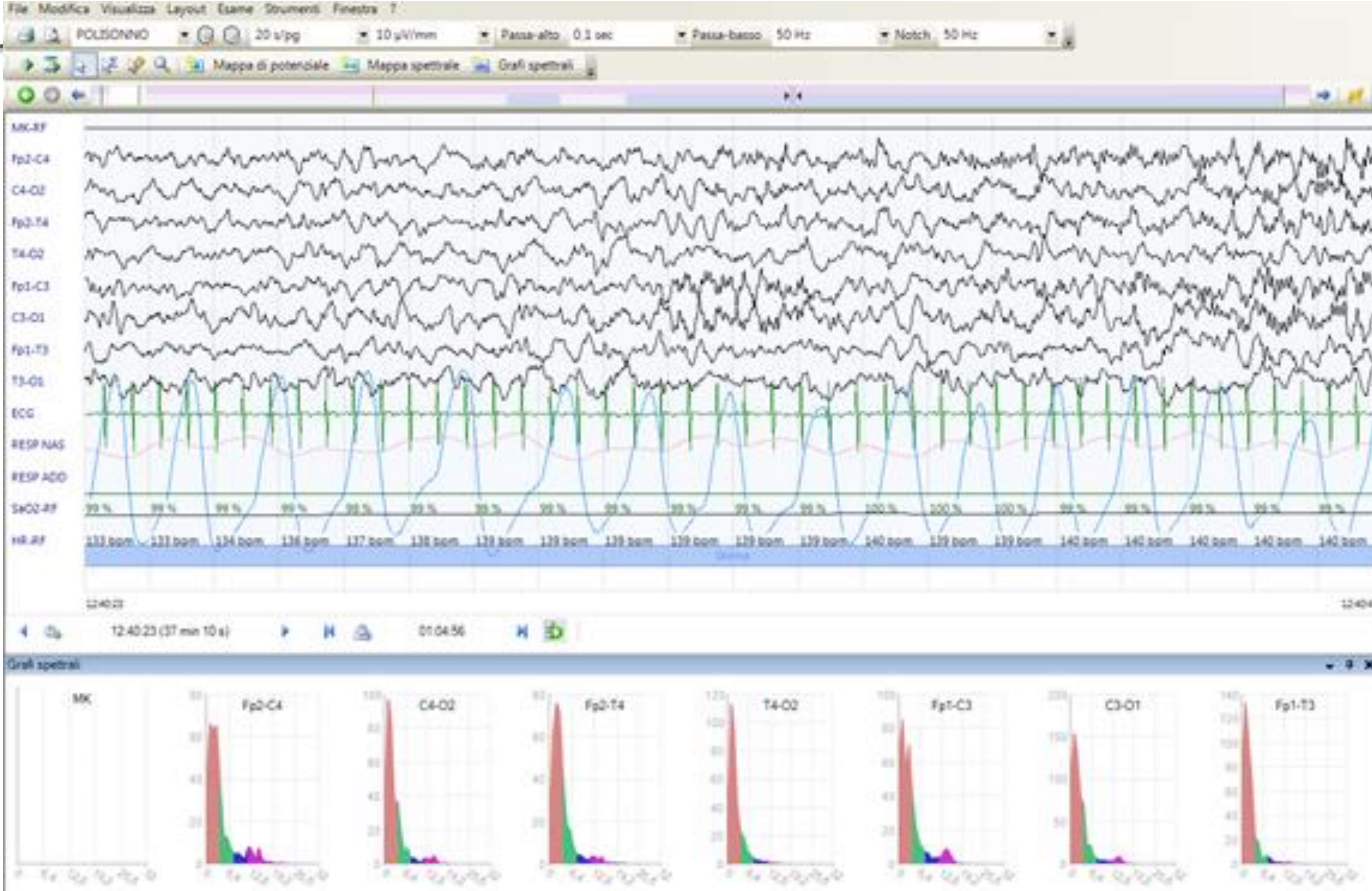
Ali A. Asadi-Pooya*† and Michael R. Sperling*

- **Asynchronous Sleep Spindles**
  - These appear at **6 to 8 weeks** postterm with **prolonged "comb-like" morphology**.
  - Sleep spindles are **asynchronous in the first year of life, are rare in the second year of life, and appear in mature form (bilaterally synchronous) by age 2 years**.
  - Therefore, one should bear in mind the ontogeny of sleep spindles when reading a pediatric EEG.
  - **Asynchronous sleep spindles in an infant below 2 years of age should not be interpreted as abnormal**

Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

Ali A. Asadi-Pooya*† and Michael R. Sperling*

- **Asynchronous Sleep Spindles**


File Modifica Visualizza Layout Esame Strumenti Finestra ?
POLISONNO
20 s/pg
10 µV/mm
Passa-alto 0,1 sec
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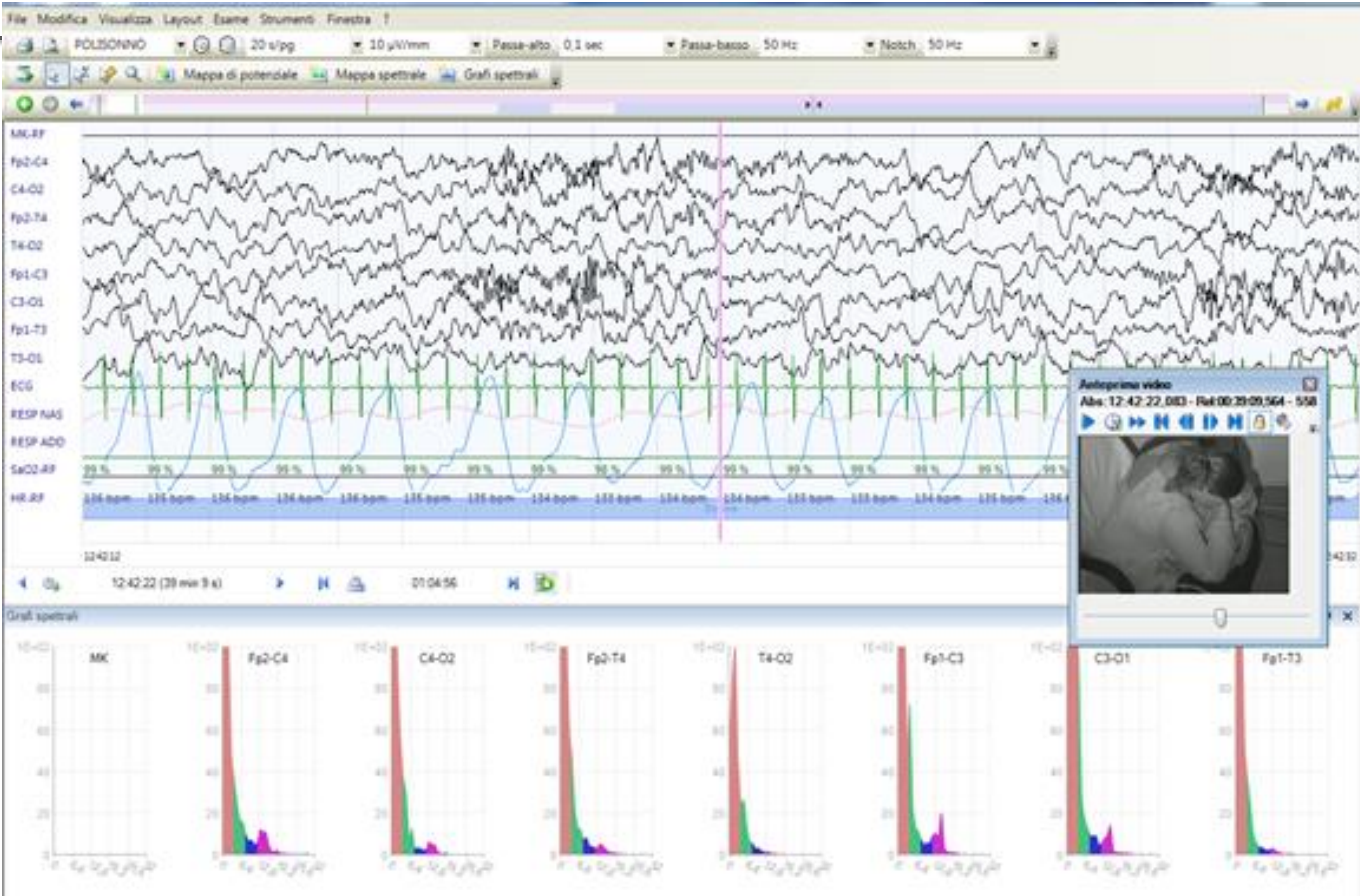
Mappa di potenziale
Mappa spettrale
Grafi spettrali
MK-RF
Fp2-C4
C4-O2
Fp2-T4
T4-O2
Fp1-C3
C3-O1
Fp1-T3
T3-O1
ECG
RESP NAS
RESP ADD
SaO2-RF
HR-RF
12:40:23 (37 min 10 s)
01:04:56
Grafi spettrali
MK
Fp2-C4
C4-O2
Fp2-T4
T4-O2
Fp1-C3
C3-O1
Fp1-T3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MK-RF
Fp2-C4
C4-O2
Fp2-T4
T4-O2
Fp1-C3
C3-O1
Fp1-T3
T3-O1
ECG
RESP NAS
RESP ADD
SaO2-RF
HR-RF
Anteprima video
Grafi spettrali
MK
Fp2-C4
C4-O2
Fp2-T4
T4-O2
Fp1-C3
C3-O1
Fp1-T3

Patterns Specific to Pediatric EEG

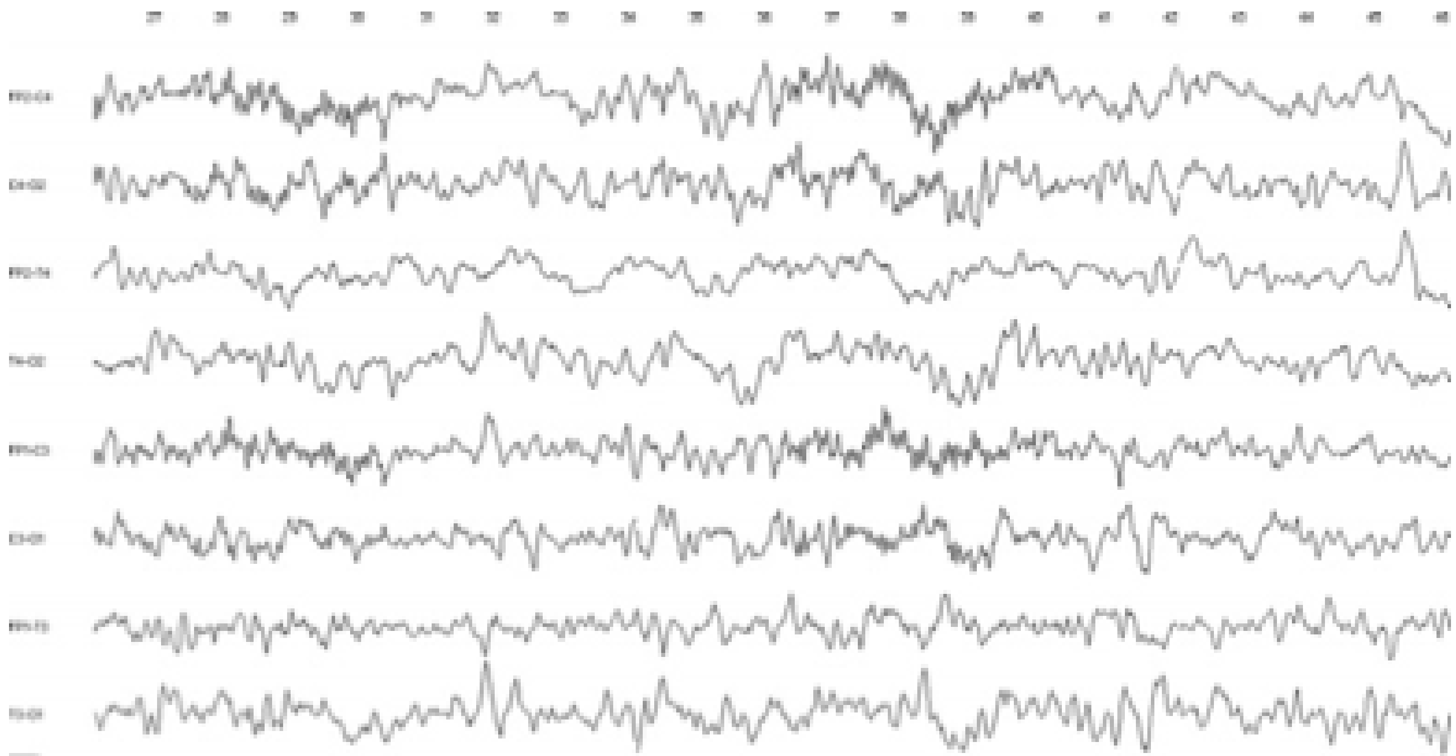
Raj D. Sheth

Mayo Clinic College of Medicine, Nemours Children Subspecialty Clinic, Jacksonville, Florida, U.S.A.

- **Sleep Spindles**
  - **Sleep spindles** can be detected outside the neonatal period and can be **asymmetric and persistent** for **10 to 15 seconds** in duration
    - Their origin is believed to be in the **peri-Rolandic areas**, which can also be the source of frequent epileptiform discharges, further leading to its misidentification as epileptiform

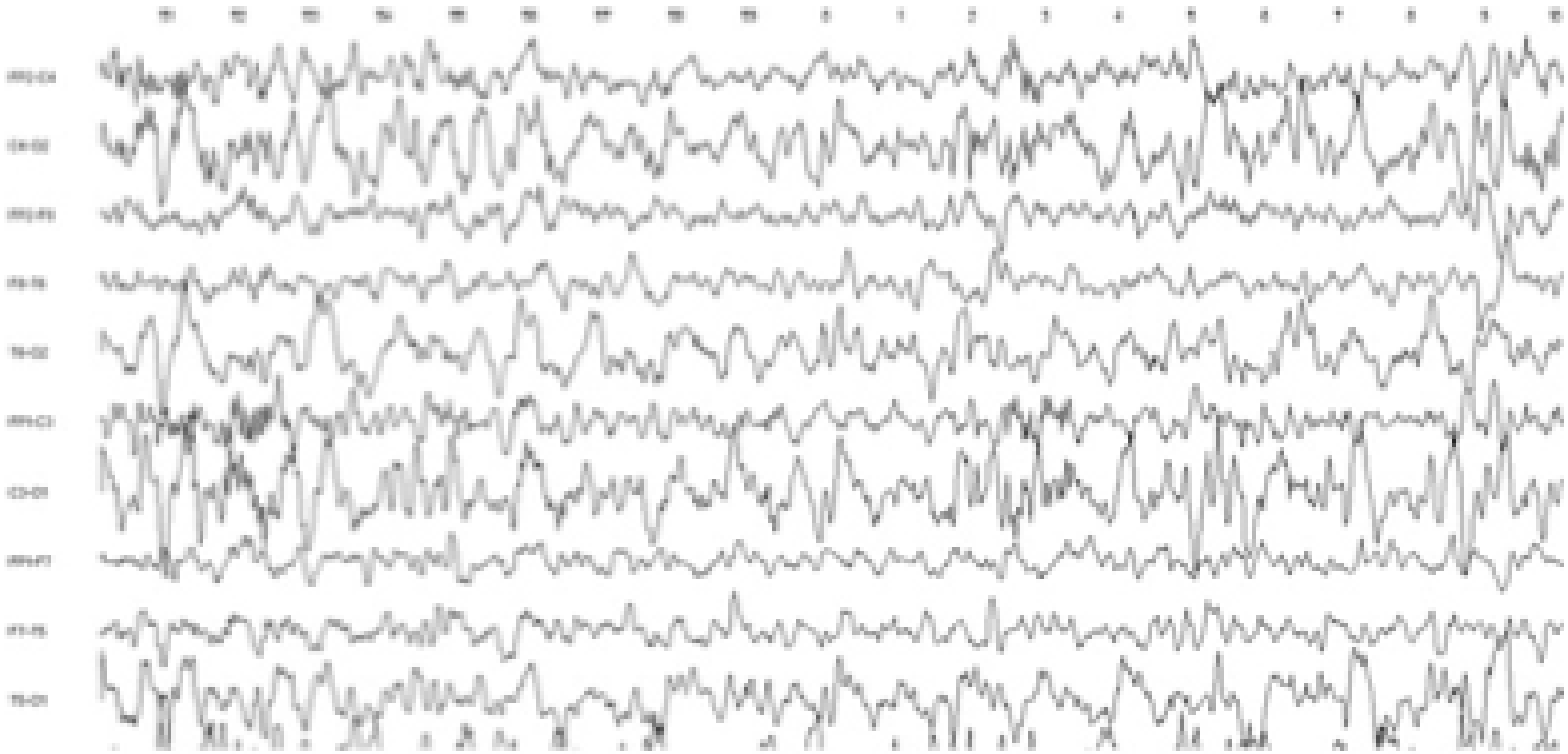
Normal EEG in infancy (**1-12 months**)

- **Sleep 3 months**



Normal EEG in infancy (1-12 months)

- **Sleep 9 months: stage 1-2**

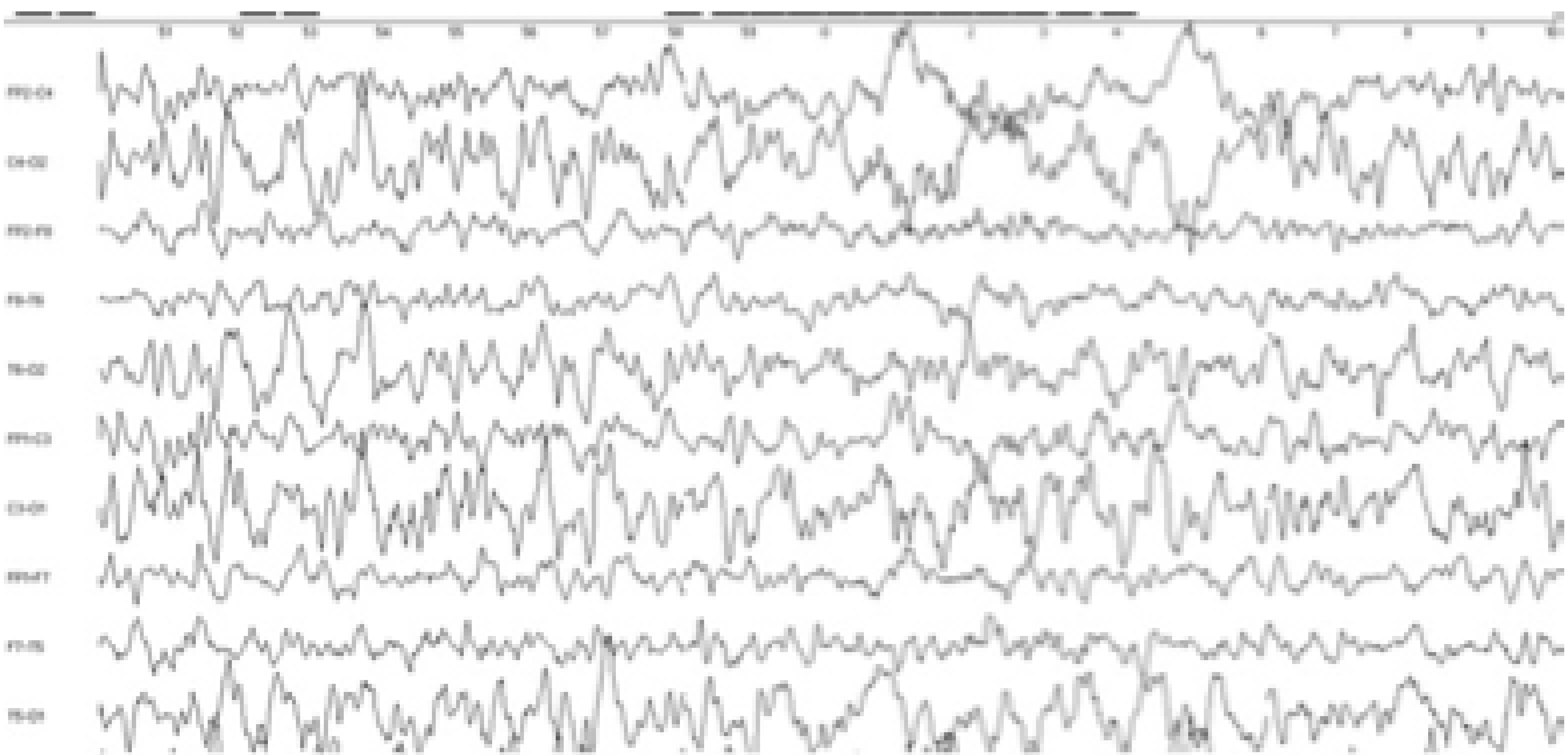


Normal EEG in infancy (**1-12 months**)

- **Sleep:**
  - **Stage 3 of SS**:
    - High amplitude (100-200 uV) delta slow waves (0.75-3 Hz)
    - Predominating **occipital area**

Normal EEG in infancy (**1-12 months**)

- **Sleep: Stage 3 of SS:**



Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

Ali A. Asadi-Pooya*† and Michael R. Sperling*

- **K-Complex**
  - One should be careful not to interpret a K-complex as a spike–wave or sharp and slow wave complex;
  - this caution particularly applies **to children, whose vertex waves are quite sharply contoured**.
  - the background rhythms often change in the few seconds after the transient from that seen immediately before K-complex, as **it represents an arousal**

Normal EEG in infancy (**1-12 months**)

- **Sleep:**
  - **5-6 months**
    - **Vertex spikes and K complexes** (stage 2 SS)

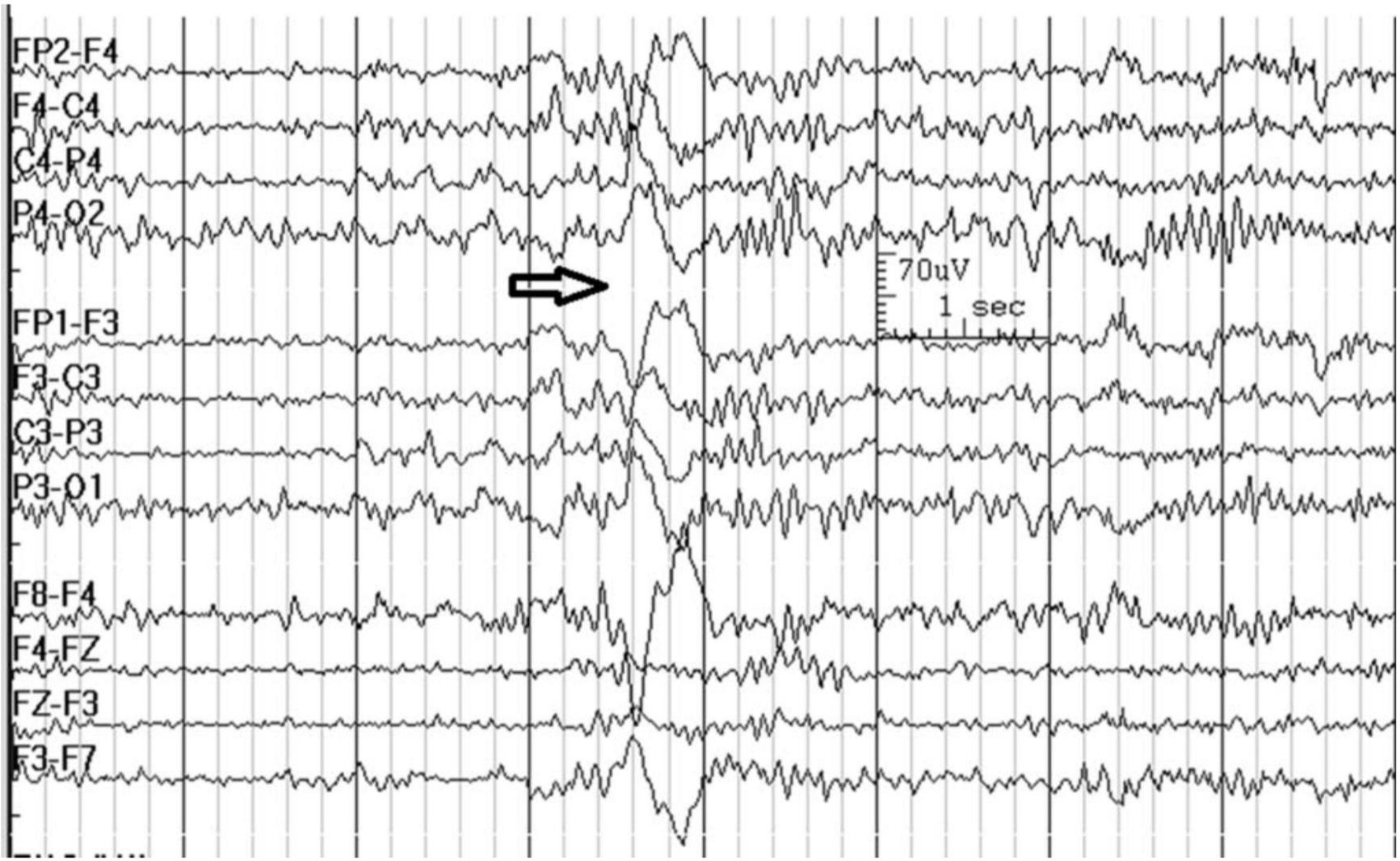
The **K-complex (KC)** is a sharp, well-delineated, **high-voltage, biphasic wave** that lasts for more than 0.5 seconds

  - The amount of time spent in the AS stage of sleep decreases from 50% ai birth to **30% by 1 year of age**

Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

Ali A. Asadi-Pooya*† and Michael R. Sperling*

- **K-complex**

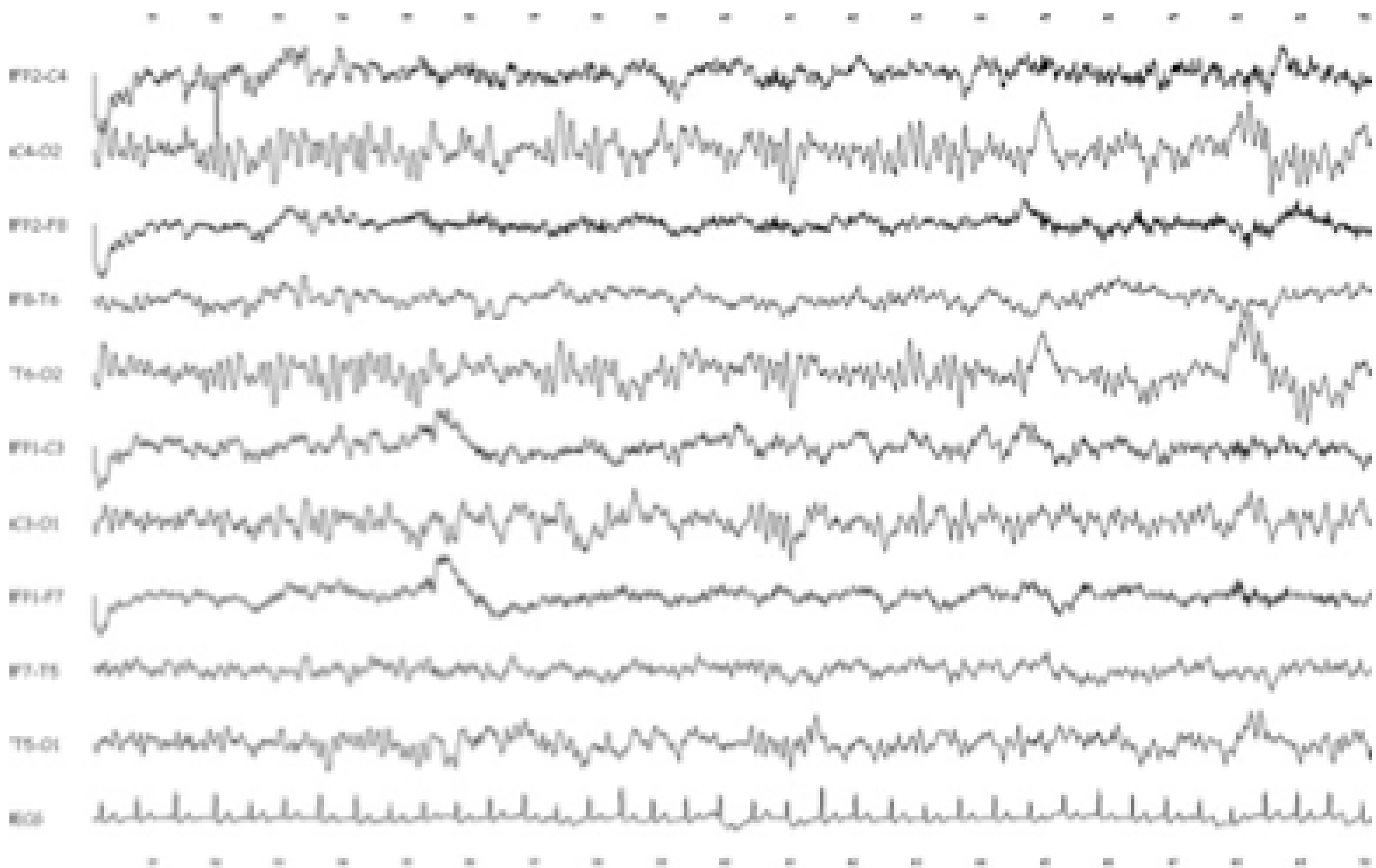


Normal EEG in infancy (1-12 months)

- **Awakening**
  - From the age of **5 months** onwards, the tracing at **awakening is comparable to that of somnolence** with **diffuse hypersynchrony of the background activity**

Normal EEG between **12 and 36 months**

- **Awake 24 months**

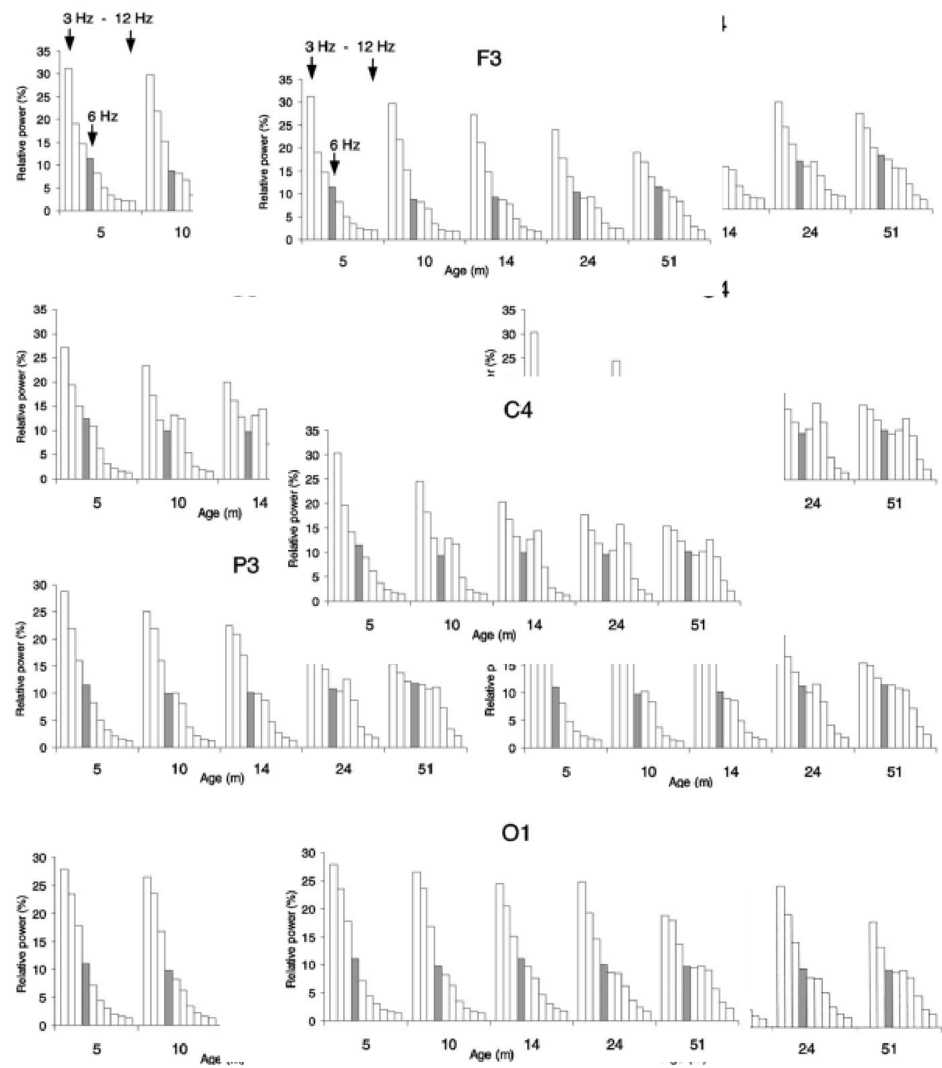


Normal EEG between 12 and 36 months

- **Awake**
  - The **occipital rhythm** increases from rapid theta to **low alpha frequency**
    - **6-7 Hz in the 2° year of life**
    - **7-9 Hz in the 3° year**
  - Major interindividual **variability**
  - **Theta rhythms** are frequent at that age and **diffusely** distributed

Marshall PJ, Bar-Haim Y, Fox NA.
Development of the EEG from 5 months to 4 years of age.
Clin Neurophysiol. 2002 Aug.

- Spectral analysis of **RELATIVE POWER** data:
  - a general developmental **decrease in low-frequency** power (below approximately **6 Hz**) and a concurrent **increase in higher frequency** power that was concentrated in a band from **around 6 to 10 Hz**.
  - the development of a **clear peak at central sites** that emerges at **10 months** of age and rises to maximum relative power at **14 or 24 months** of age before declining to a **lower level at 4 years** of age. The peak frequency of this central rhythm also shows a clear pattern in the power spectrum, **rising from 7 Hz at 10 months of age to 9 Hz at 4 years of age**.
  - Aside from the **central rhythm**, there are peaks in the **6–9 Hz** range in the averaged power spectra **for other electrode sites**, although these peaks appear to follow **a different development course**, and none reaches the levels of relative power shown by the central peaks.



Power spectra for relative power in the **3–12 Hz bins** at each age point (5, 10, 14, 24, and 51 months of age). The 6 Hz bin is indicated in gray

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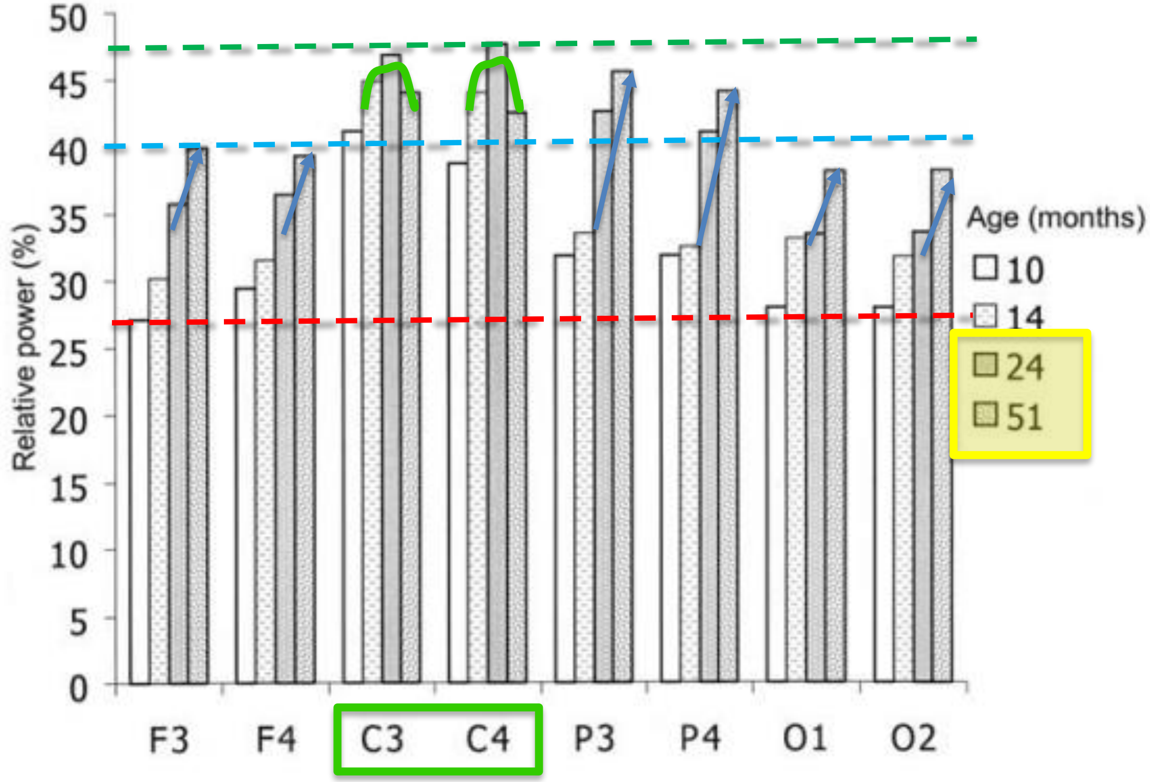

Fig. 3. Mean relative power at each electrode site for the 6–9 Hz frequency band at 10, 14, 24, and 51 months of age.

- There were no significant main effects or interactions involving the sex of the child.

Marshall PJ, Bar-Haim Y, Fox NA.

Development of the EEG from 5 months to 4 years of age.

Clin Neurophysiol. 2002 Aug.

Table 3

Mean relative power (with standard errors), and significant differences for the main effects in a repeated-measures ANOVAs of region by hemisphere by age, for the 6–9 Hz frequency band from 10 to 51 months of age[a]

Region	Frontal	33.6 (1.3)	
	Central	43.7 (1.7)	C > F***, C > O***
	Parietal	37.9 (1.4)	P > F***, P > O***
	Occipital	33.0 (1.2)	
AGE (months)	10	32.0 (1.6)	
	14	35.1 (1.3)	14 > 10 months*
	24	39.6 (1.6)	24 > 14 months**
	51	41.4 (1.7)	50 > 24 months +

[a] $+P < 0.10$, $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

Marshall PJ, Bar-Haim Y, Fox NA.
Development of the EEG from 5 months to 4 years of age.
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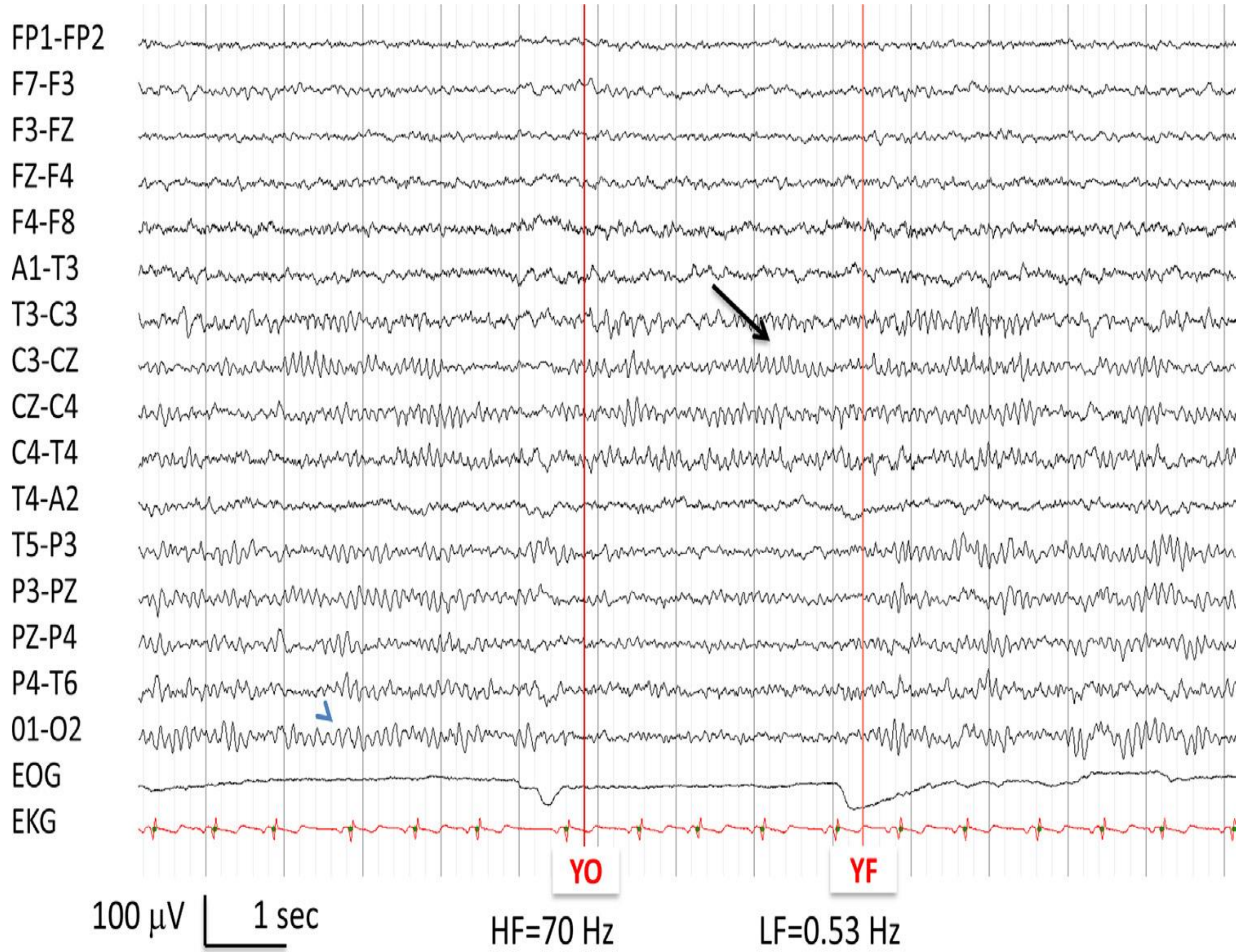
- **Development of the central 6–9 Hz rhythm in infancy**
- **the infant central rhythm was not blocked by eye-opening** (a functional **dissociation** of the central rhythm from the **occipital alpha rhythm**).
- under a condition of quiet attending, **a central rhythm clearly emerged in the second year of life, with a spectral peak at 8 Hz** that remained at around 38–40 months of age.
- a functional **relation between the 6–9 Hz central oscillation in infancy and early childhood with the adult mu rhythm**, which is also found primarily at central sites and is also promoted by a quiet, attentive state.
- **The adult mu rhythm is attenuated by voluntary movement and somatosensory stimulation**, but is minimally affected by changes in visual stimulation.
- In this sense, **mu has been considered by some to be a 'somatosensory alpha rhythm'** (Kuhlman, 1978) that is sensitive to somatic afferent input
- maximum relative power for this central rhythm occurs **during toddlerhood**, which is a time of **intense development of locomotor ability**.

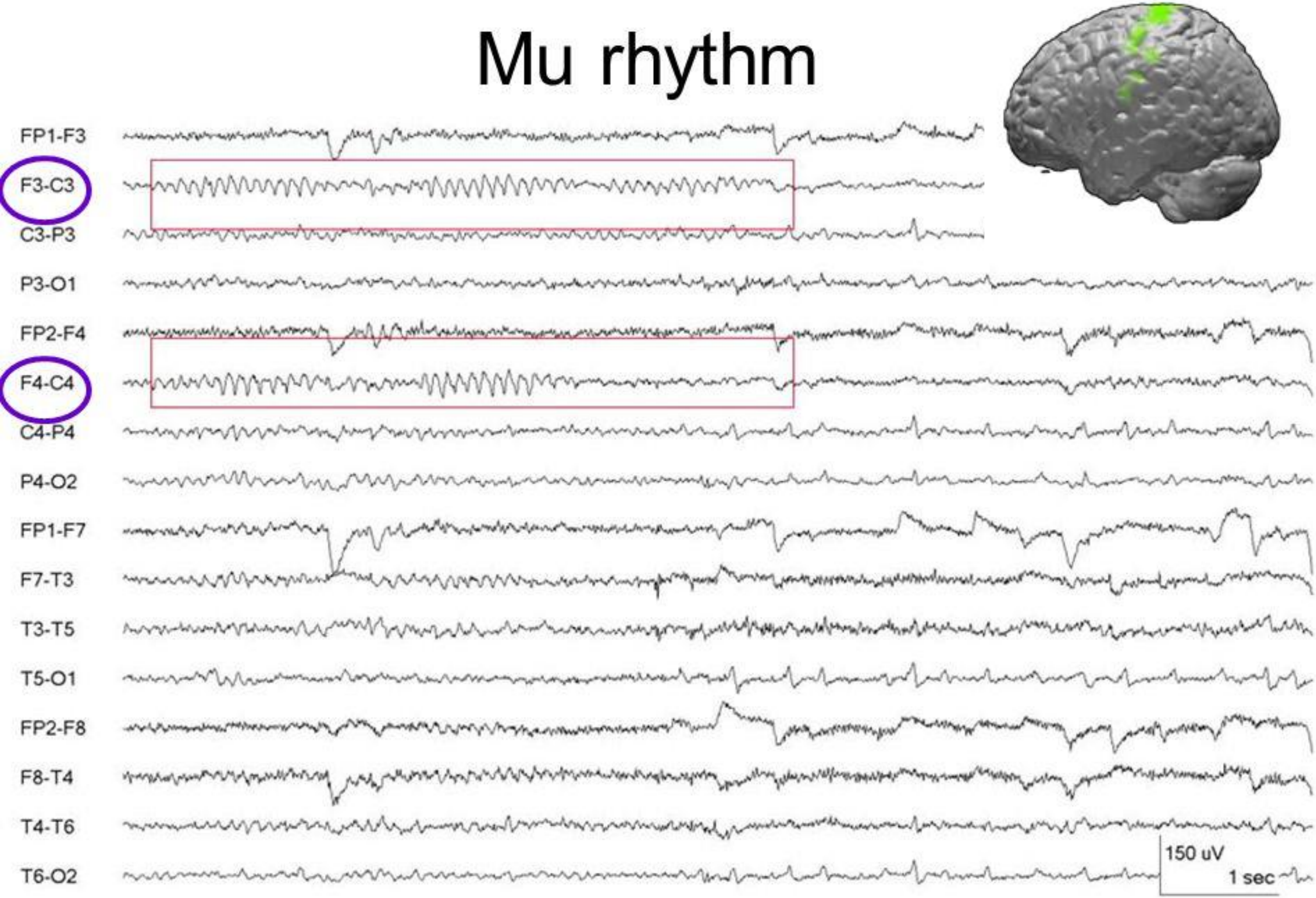
Mu rhythm: State of the art with special focus on cerebral palsy

Dèmas et al Annals of Physical and Rehabilitation Medicine (2019)

- the mu rhythm, first described by Henri Gastaut in 1952, **reflects the neural activity of the primary sensorimotor (SM1) cortex.**
- characterized **by a comb-like shape,** which implies that it is composed of **2 main frequency** components with a nearly harmonic relationship, **the alpha (~10 Hz) and the beta (~20 Hz) frequency bands.**
- called "mu alpha" and "mu beta"



Mu rhythm


FP1-F3
F3-C3
C3-P3
P3-O1
FP2-F4
F4-C4
C4-P4
P4-O2
FP1-F7
F7-T3
T3-T5
T5-O1
FP2-F8
F8-T4
T4-T6
T6-O2
150 uV
1 sec

Mu rhythm: State of the art with special focus on cerebral palsy

Dèmas et al Annals of Physical and Rehabilitation Medicine (2019)

- **Modulation of mu rhythm components occurs during motor execution tasks (e.g., a reach and grasp task), which are the most robust modulators of the mu rhythm.**
- The 2 frequency components of the mu rhythm are modulated by other types of stimuli or tasks: **somatosensory stimulations, imagined movement, observed movement, shifting spatial attention and anticipation of attended stimuli.**

- **mu alpha and mu beta may occur separately or simultaneously** suggests that these 2 components might arise from different neural generators:
  - **mu beta is generated at the precentral motor cortex,**
  - **mu alpha is located at the postcentral somatosensory cortex**

- **The frequency of mu alpha increases rapidly during the first year**, from **2.75** Hz at 11 weeks to **8.25** Hz at 47 weeks. After the first year of life, the frequency increases very slowly through adolescence.

- **Transient high gamma responses during motor tasks** are recorded over the contralateral M1 cortex from **age 6 years**

Mu rhythm: State of the art with special focus on cerebral palsy

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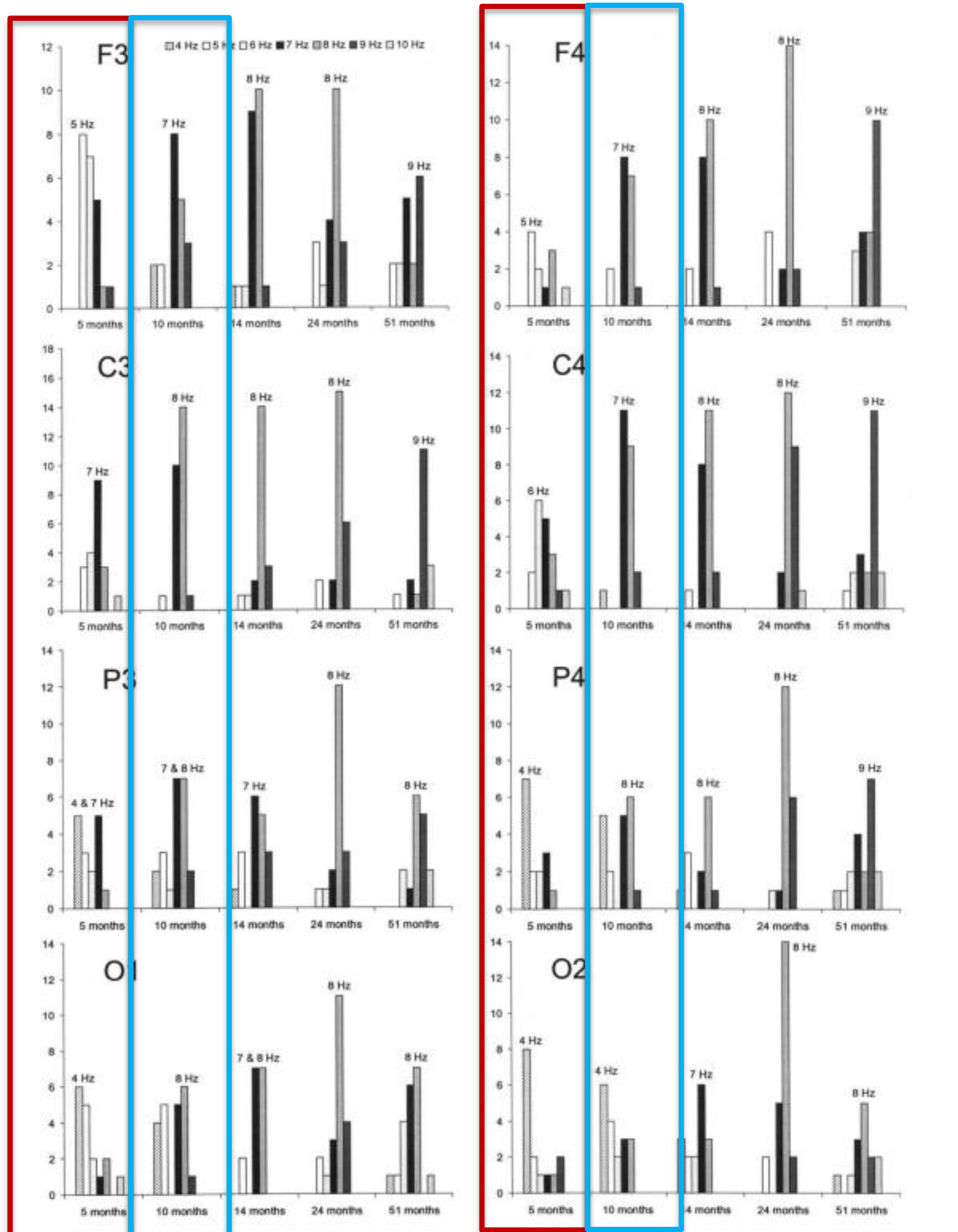
the developmental trajectory of mu rhythm modulations

- locked to an **alpha component** that peaked at
  - **7 to 8 Hz at 12 months,**
  - **8.5 to 10 Hz at 4 years**
  - **10 to 12 Hz in adults.**
- Topographic analysis: **distributed frontoparietal patterns**, which were consistent across age groups.
- the infant/child central rhythm ➔ **a developmental analogue** of the adult mu rhythm with the same functional dependence on behaviour.
- In children with spastic **CP**: SM1 cortex activities recorded in most patients but with frequent variations in frequency, topography and task-induced modulations as compared with typically developing children ➔ **alternative (maladaptive?) patterns** regarding the mechanisms of plasticity that take place after brain injury and after rehabilitation

Marshall PJ, Bar-Haim Y, Fox NA.
Development of the EEG from 5 months to 4 years of age.
Clin Neurophysiol. 2002 Aug.

- **PEAK FREQUENCY**:
  - The majority (80%) of individual spectra showed **single peaks**. The number of spectra showing no peak declined with age and did not show differential patterns among electrode sites.
  - **At 5 months of age**, modal peak frequencies tended to be **lower at parietal and occipital sites** than at frontal and central sites. The modal peak frequency at parietal and occipital sites at 5 months of age was **4 Hz**, with the exception of P3, which showed equally frequent peaks at 4 and 7 Hz. Across **frontal and central sites**, the modal peak frequency varied between **5 and 7 Hz** at 5 months of age.
  - **At 10 months of age**, there was **less variation between anterior and posterior sites** in terms of the modal peak frequency, although **posterior sites** tended to show **a more diffuse pattern (lack of a clearly dominant frequency) compared to frontal and central sites**, which showed clear modes at **7 or 8 Hz**.



The distribution of the peak frequency of relative power within the 3–10 Hz range for each electrode site at each age point. The bars indicate the number of participants whose peak frequency fell in each 1 Hz bin. Modal frequencies are indicated for each site and age.

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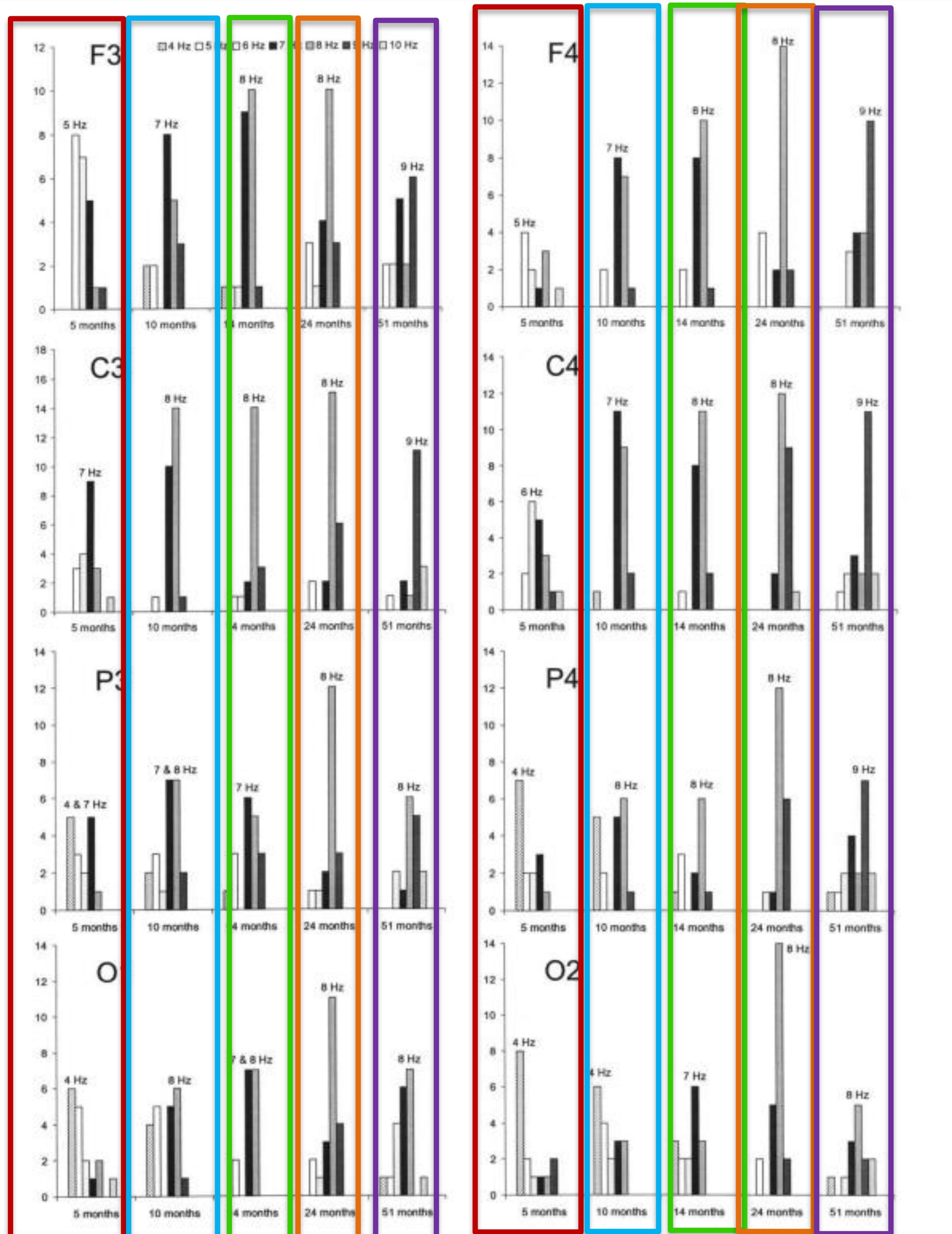
- **PEAK FREQUENCY**:
  - At 14 months of age, the modal peak frequency was **8 Hz at frontal and central sites**, and **7 or 8 Hz at parietal and occipital sites**
  - At 24 months of age, the dominant peak frequency at **all sites was 8 Hz**. At this age, **parietal and occipital sites showed less variability**, with the majority of toddlers showing peaks at 8 Hz.
  - At 51 months of age, all of the 4 **frontal and central sites** showed modal peak frequencies of **9 Hz**. At **parietal and occipital** sites, the modal peak frequency was **8 Hz** except for P4, which showed a modal frequency of 9 Hz.



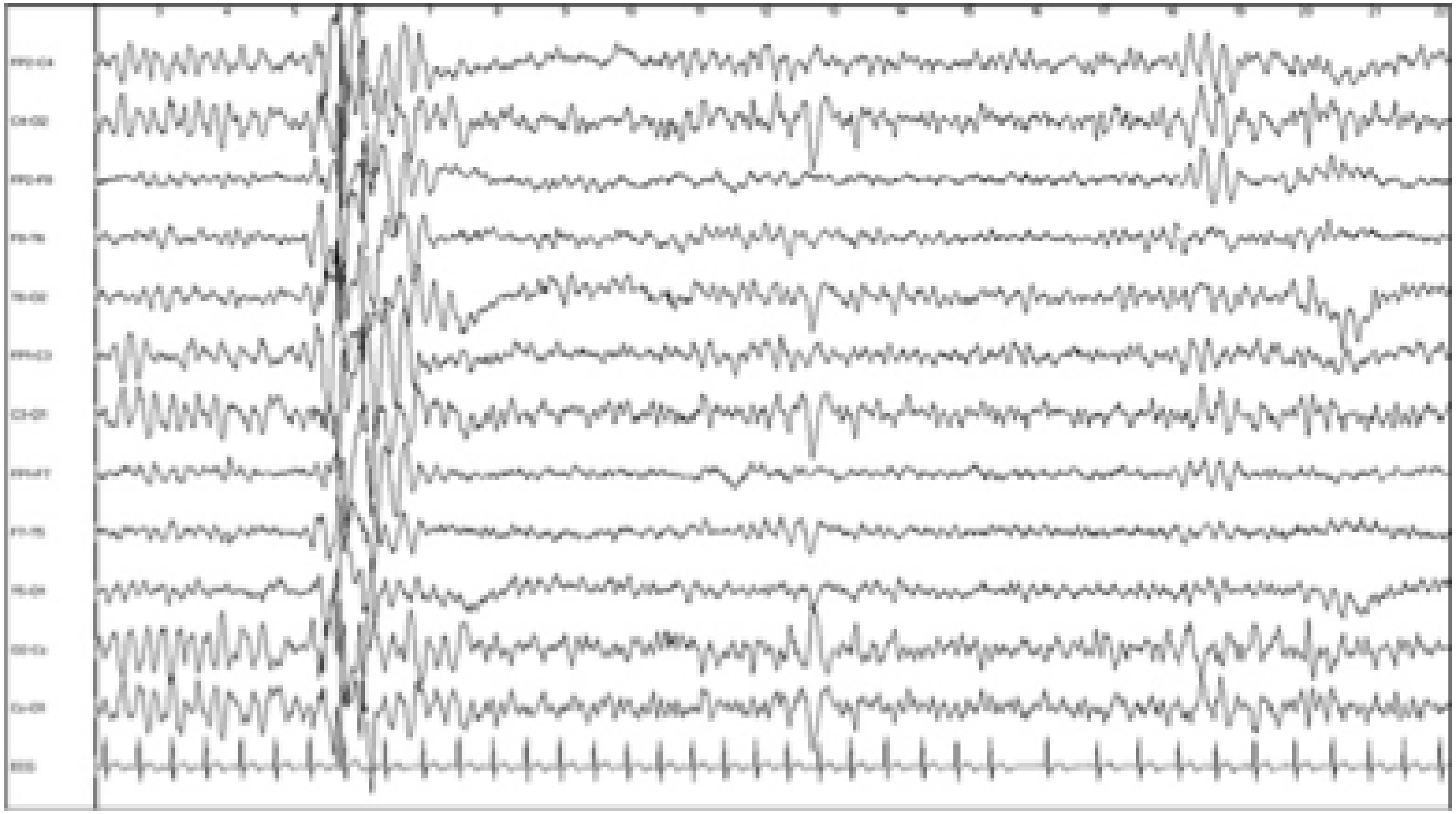
The distribution of the peak frequency of relative power within the 3–10 Hz range for each electrode site at each age point. The bars indicate the number of participants whose peak frequency fell in each 1 Hz bin. Modal frequencies are indicated for each site and age.

Normal EEG between **12 and 36 months**

- **Somnolence**
  - **hypnagogic hypersynchrony** when falling aspleep decreases progressively
    - 75% between 1 and 2 years
    - 57% between 2 and 3 years
  - **Anterior theta**: monomorphous fronto-central rhythms of variable duration (9-10% of children)
  - **Bursts of theta slow waves and spikes**: physiological on falling asleep

Normal EEG between **12 and 36 months**

- **Somnolence**

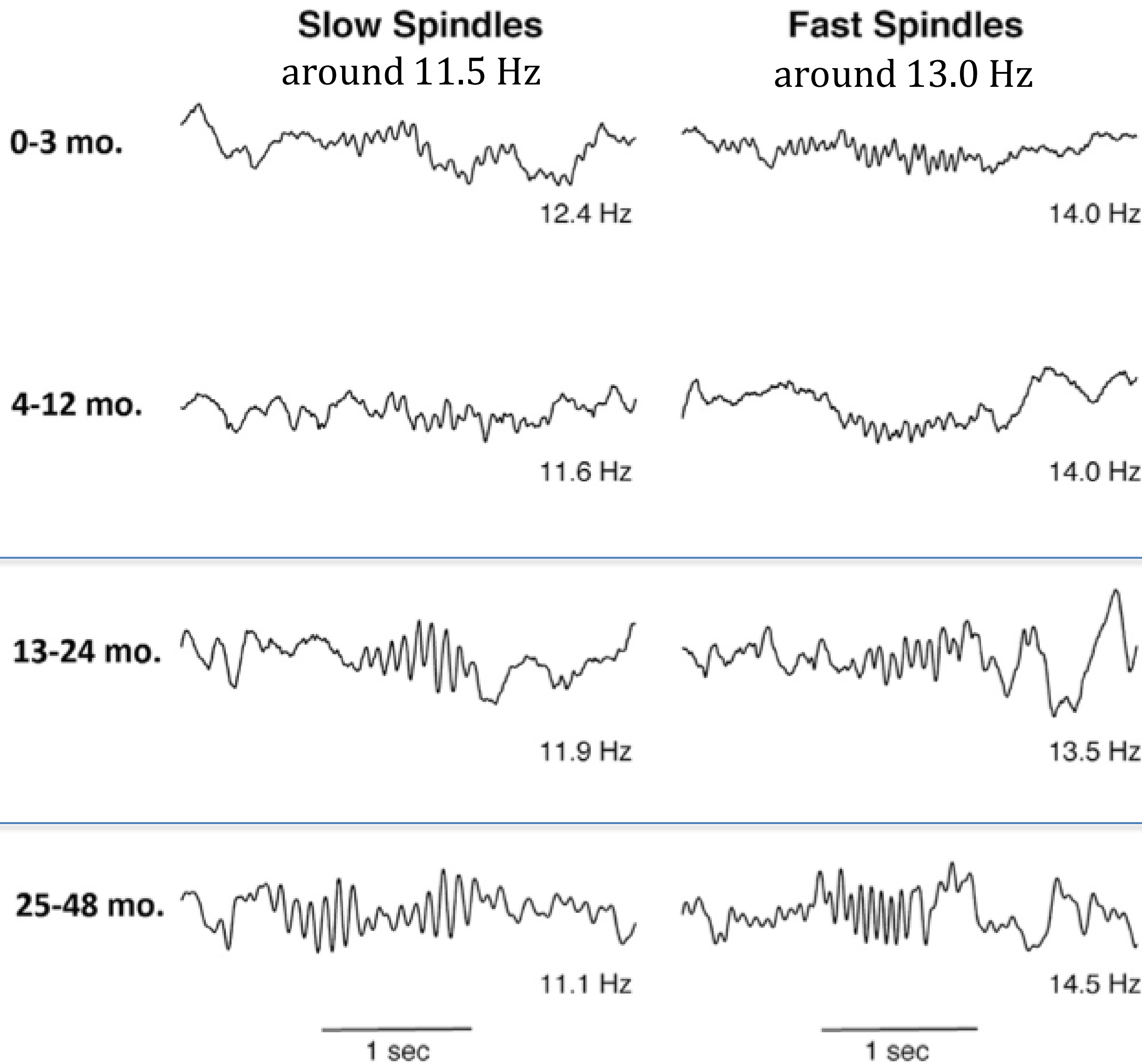


Normal EEG between **12 and 36 months**

- **Sleep**
  - **Sleep spindles**
    - **Symmetrical**
    - Located in the **central areas (from centroparietal area)**
    - In **frontal** areas in stage II-III of SS

Normal EEG between **12 and 36 months**

different topographical distributions



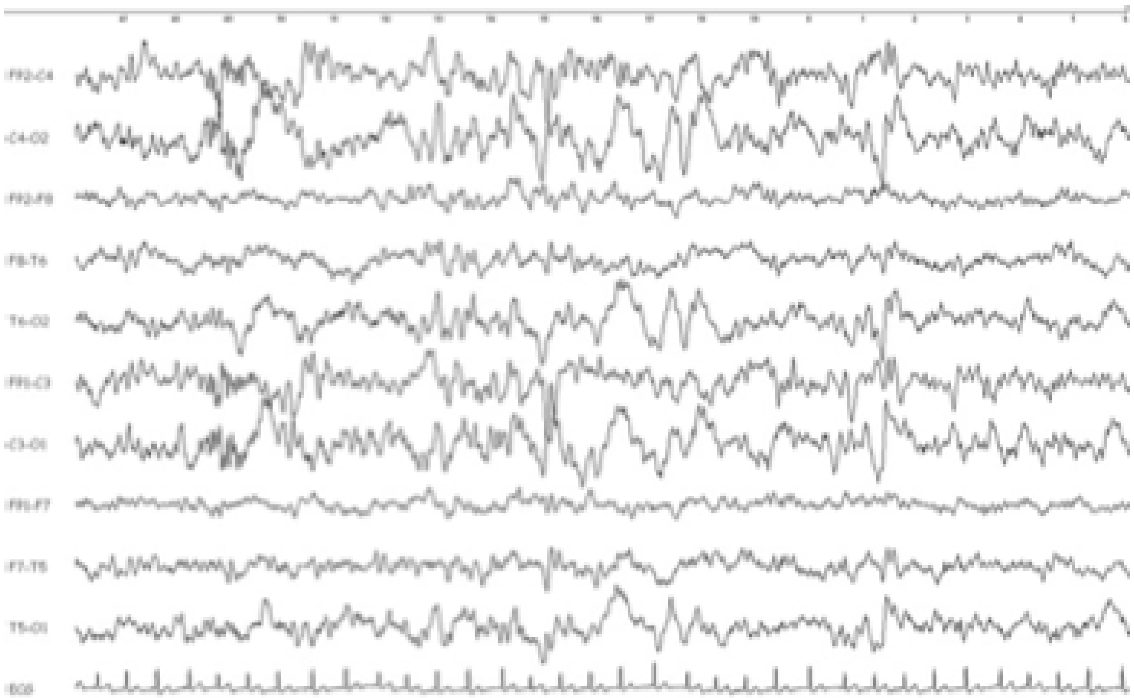
Density of slow spindles declines over consecutive **NREM sleep** episodes,

while **density of fast spindles** linearly **increases** across consecutive **sleep cycles**

D'Altri et al Sleep Medicine 42 (2018) 73e82

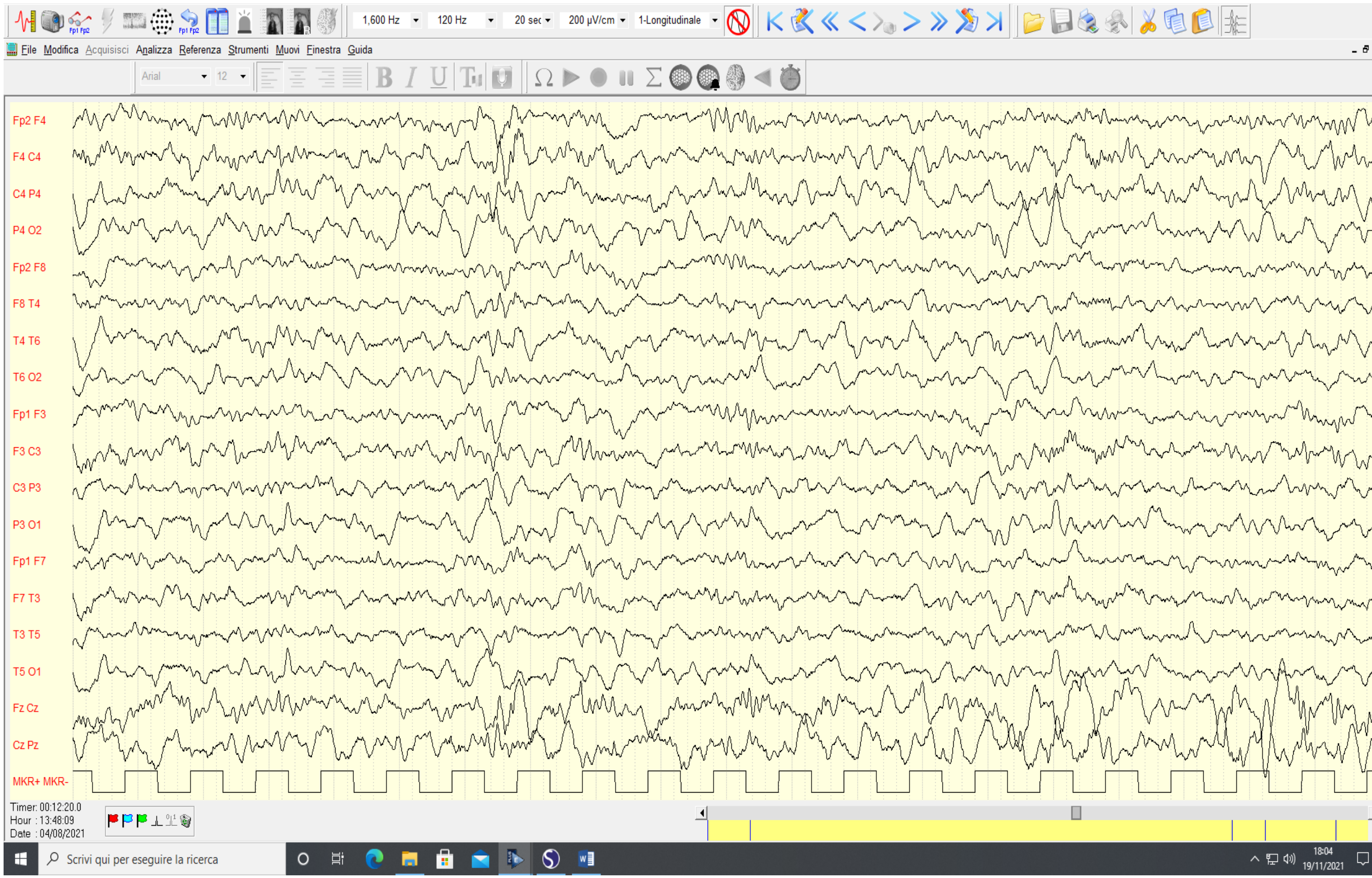
Normal EEG between **12 and 36 months**

- **Sleep**
  - **Vertex spikes**
    - Isolated or in clusters of 3 to 4 with a frequency around **1 Hz**
    - **Central** location
    - 12 months: may occur in **bursts**



Normal EEG between **12 and 36 months**

- **Sleep**
  - **14 months**



Patterns Specific to Pediatric EEG

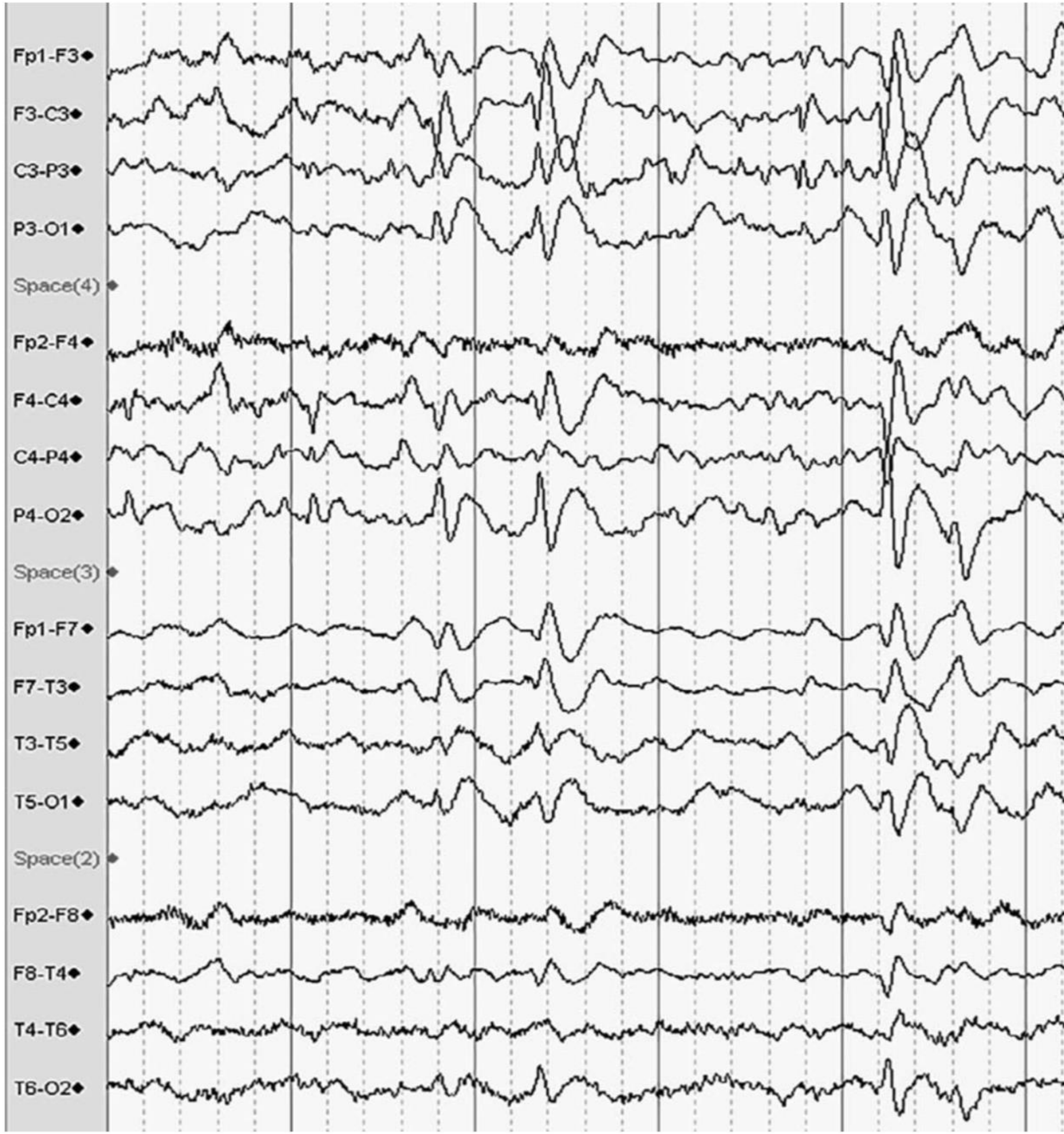
Raj D. Sheth

Mayo Clinic College of Medicine, Nemours Children Subspecialty Clinic, Jacksonville, Florida, U.S.A.

- **Vertex Waves**
  - **Vertex waves** can be **high voltage and "spike-like"** in appearance and can be **asymmetric with spread to the central regions**
  - can be misidentified as **centrotemporal Rolandic spikes**.
  - Generally, vertex spikes should only be diagnosed, **as epileptiform** if **they are also seen when present on the awake record**.
  - **Shifting asymmetries** are often present suggesting a non-epileptiform nature to the discharges.
  - drowsy patterns that can be particularly difficult in children are **14 and 6 per second positive spike discharges**.

Patterns Specific to Pediatric EEG

Raj D. Sheth
Mayo Clinic College of Medicine, Nemours Children Subspecialty Clinic, Jacksonville, Florida,



Normal EEG between **12 and 36 months**

- **Sleep**
  - **Delta waves increase in amplitude and number**
    - **Occipital** predominance
  - The proportion of time spent in **SS continue to increase**

Slow-wave activity and sigma activities are associated with psychomotor development at 8 months of age

Satomaa et al SLEEPJ, 2020, 1–10

- Accordingly, **topographical SWA features** during daytime sleep have been associated with the **development of expressive language** and **fine motor skills** in toddlers aged **12–30 months**.

- In both hemispheres, the **highest SWA** and sigma powers were found **occipitally** and centrally, respectively, with higher powers in the **right** hemisphere than in the left.

- **the occipital SWA and centro-occipital sigma correlated with cognitive scales,**
- **the frontal and occipital SWA and centro-occipital sigma correlated with language and fine motor scales.**

- **In 8-month-old infants, the NREM sleep quality shows local differences that are mostly attributable to the topical phase of brain maturation. The local NREM parameters correlate with psychomotor development.**

Normal EEG between **12 and 36 months**

- **Sleep**
  - **In REM sleep** there are diffuse, eventually **rhythmic theta waves**

Normal EEG between **12 and 36 months**

- **Awakening**
  - **Major Variability**
  - **Anterior theta activity lasting about 10 sec**

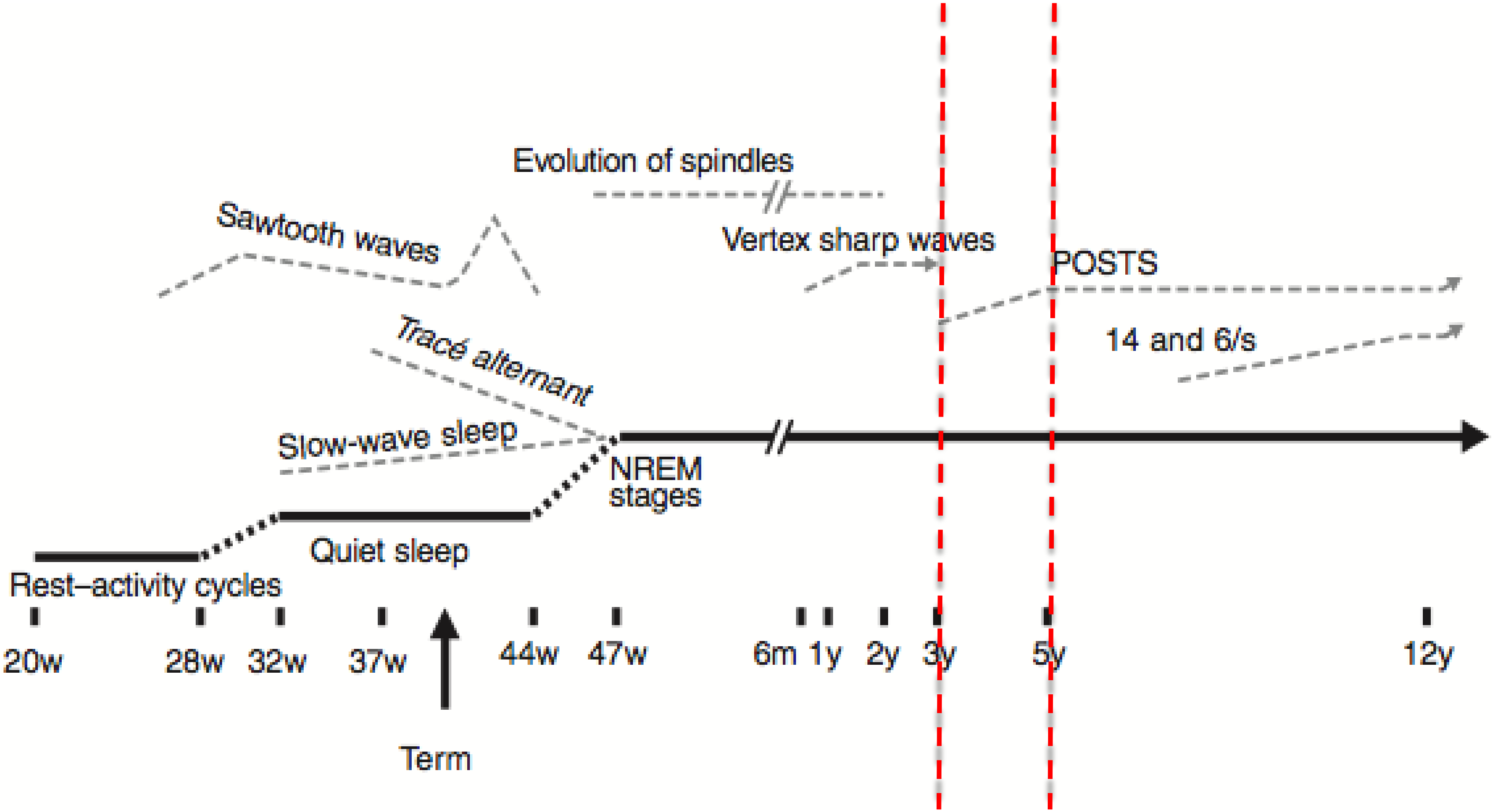


Figure 1: *Schematic diagram of temporal evolution of main neurophysiological features of sleep in infancy and early childhood. Black lines indicate periods of appearance of main behavioural stages. Ascending dotted lines indicate periods of transition between stages. Grey dashed lines indicate occurrence and maturational trends of distinctive electroencephalographic features (ascending lines=increase in occurrence, descending lines=decrease in occurrence, horizontal lines=stability, and arrows=continuation). POSTS, positive occipital sharp transients of sleep; 14 and 6/s, 14 and 6 per second positive spikes; NREM, non-rapid eye movement.*

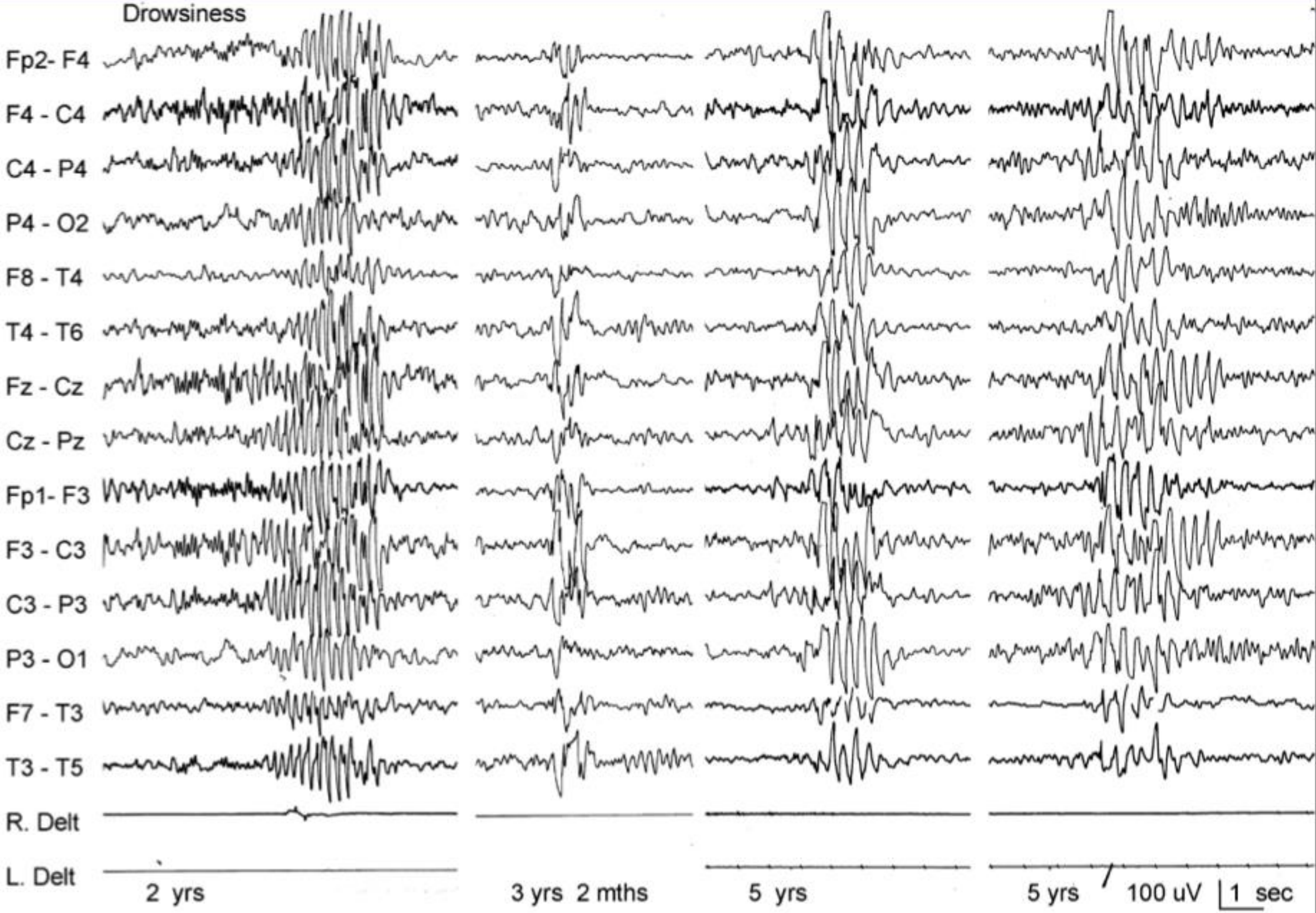
774 *Developmental Medicine & Child Neurology* 2006, 48: 773–779

Normal EEG between 3 and 5 years of age

- **Wakefulness**
  - The occipital background activity exhibits **rising frequency in the alpha band (8-9 Hz)**
  - Intermingled with **theta or even delta** (1.5 – 4 Hz) activities that also involve **posterior** areas

Normal EEG between 3 and 5 years of age

- **Somnolence**
  - **hypnagogic hypersynchrony disappears** progressively
  - Replaced by **anterior rhythmic high-amplitude theta activity**
  - Intermingled with **burst of sharp waves**



Drowsiness
Fp2- F4
F4 - C4
C4 - P4
P4 - O2
F8 - T4
T4 - T6
Fz - Cz
Cz - Pz
Fp1- F3
F3 - C3
C3 - P3
P3 - O1
F7 - T3
T3 - T5
R. Delt
L. Delt
2 yrs
3 yrs 2 mths
5 yrs
5 yrs
100 uV
1 sec

Normal EEG between **3 and 5 years of age**

- **Sleep**
  - **Stage I-II of SS**
    - **High amplitude vertex spikes** or sharp waves and spindles
    - **Disappear**: occipital predominance of delta slow waves

Normal EEG between **3 and 5 years of age**

a faster negative component develops which continues to increase well into adolescence. During adulthood, there are changes observed at around 30 years of age. There is a decrease in the frequency and amplitude of the K-complex in those more than 50 years of age, seen especially in the elderly

- **Sleep**
  - **Stage III of SS**
    - Increasing abundance of **delta slow waves**
    - **K complex** predominate at the **vertex**, which appear spontaneously or are triggered by auditory stimulation
  - **All stages of sleep can be identified at that age**

Normal EEG between **3 and 5 years of age**

- **Awakening**
  - **Awakening reactions** are similar to those of the younger child

Normal EEG between 6 and 12 years of age

- **Awake**
  - The occipital **ALPHA RHYTHM**:
    - has increasing **frequency, reaching around 11 Hz by 10-11 years of age**
    - **Amplitude may reach 100 uV** with a maximum by 8-9 years then decreases
    - Often **higher in the NON dominant hemisphere**
  - **Theta rhythms**
    - Still present in the **occipital areas**
    - **Reacting to opening of the eyes** but decrease from the age of 12 years

Behavioural Brain Research 359 (2019) 56–65

Contents lists available at ScienceDirect

Behavioural Brain Research

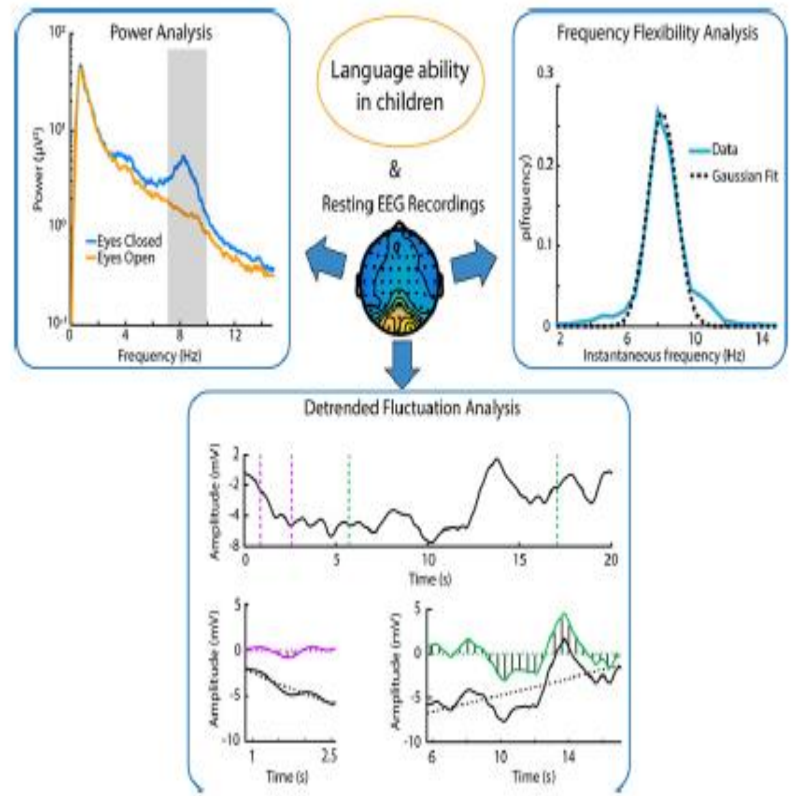
journal homepage: www.elsevier.com/locate/bbr

ELSEVIER

Dynamics of spontaneous alpha activity correlate with language ability in young children

Elaine Y.L. Kwok[a,*], Janis Oram Cardy[a,b,c], Brian L. Allman[c,d], Prudence Allen[a,c], Björn Herrmann[b,e,*]

Early childhood is a period of tremendous growth in both **language** ability and brain maturation. **Higher language scores correlated with lower alpha power, greater flexibility of the alpha frequency, and longer temporal correlations in the alpha-amplitude time course.**



Lyakso E, Frolova O and Matveev Y (2020)

Speech Features and Electroencephalogram Parameters in 4- to 11-Year-Old Children.

Front. Behav. Neurosci. 14:30.

Children aged 9–11 years are characterized by **alpha rhythm** expression in the EEG pattern, **clear articulation, and use of complex sentences in speech** that indicates a high level of speech. It was revealed that the **alpha rhythm is asymmetrically localized in children with clear pronunciation of words**.

In children who have **mastered reading skills**—read words and phrases and understand the meaning of the text—the EEG pattern corresponds **to a more "mature" brain. Alpha rhythm is of average and low amplitude, mainly regular, with the left-sided dominance in the parieto-occipital areas.**

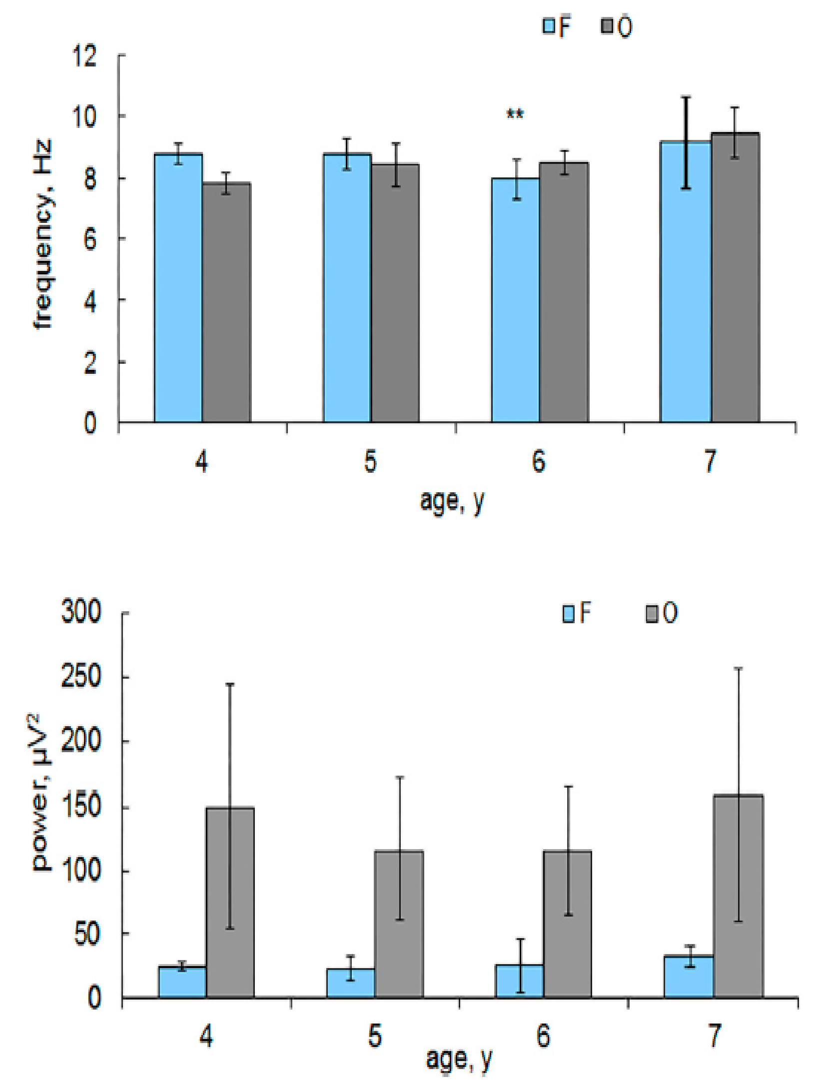


FIGURE 1 | The alpha peak frequency and power in the frontal and occipital areas depending on children's age. Horizontal axis, the average age of children; vertical axis, the alpha frequency, Hz; power, μV^2. Blue columns, frontal areas (F); gray columns, occipital (O). Vertical lines are the standard error bars. ** indicates the age when the frequency values are minimal, Mann-Whitney test.

Normal EEG between **6 and 12 years of age**

- **Sleep**
  - **NON REM**
    - **Spindle** bursts
      - do not last for more than 1 sec
      - Their topography moving from central to **FRONTAL** areas
    - **K complex**
      - vertex spikes are intermingled with the spindles
  - **REM sleep**
    - Comprieses low amplitude and desynchronized activity (theta, alpha and beta rhythms)

Slow oscillation-spindle coupling predicts enhanced memory formation from childhood to adolescence

Hahn et al. eLife 2020;9:e53730.

- patterns of **sleep spindles** and **slow oscillations** (SO) change dramatically between childhood and adolescence.
- **Memory consolidation** also improves in those formative years.
- **SO and spindles become more precisely coupled during brain maturation from childhood to adolescence.**
- Crucially, this increase indicated **improved recall performance and sleep-dependent consolidation in a declarative memory task**.

Normal EEG between **6 and 12 years of age**

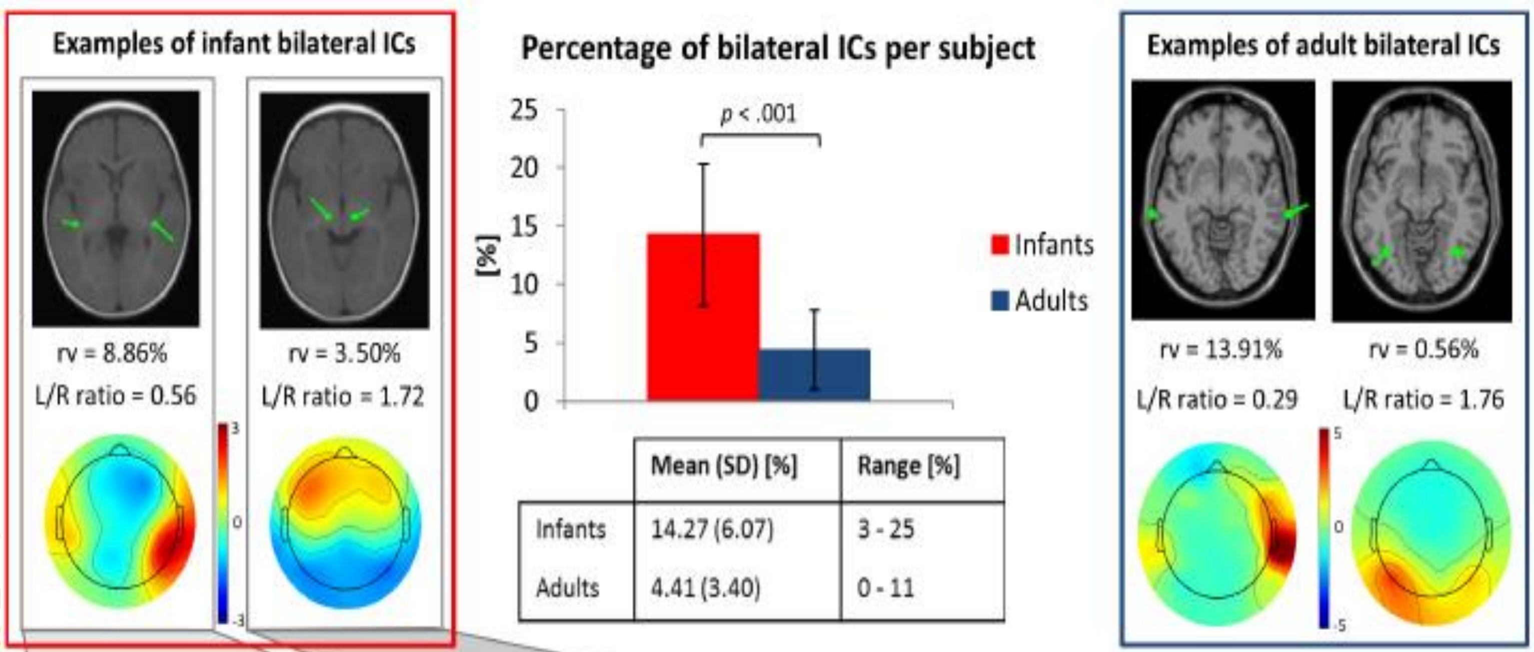
- **Awakening**
  - More **rapid transition** from sleep to wakefulness
  - Progressive **decrease in duration and amplitude of theta weaves**

EEG Effective Source Projections Are More Bilaterally Symmetric in Infants Than in Adults

Piazza et al 2020, Frontiers in Human Neuroscience 1 March 2020 | Volume 14 | Article 82

the immature brain features locally synchronous electrical activity patterns in bilaterally coupled cortical areas.

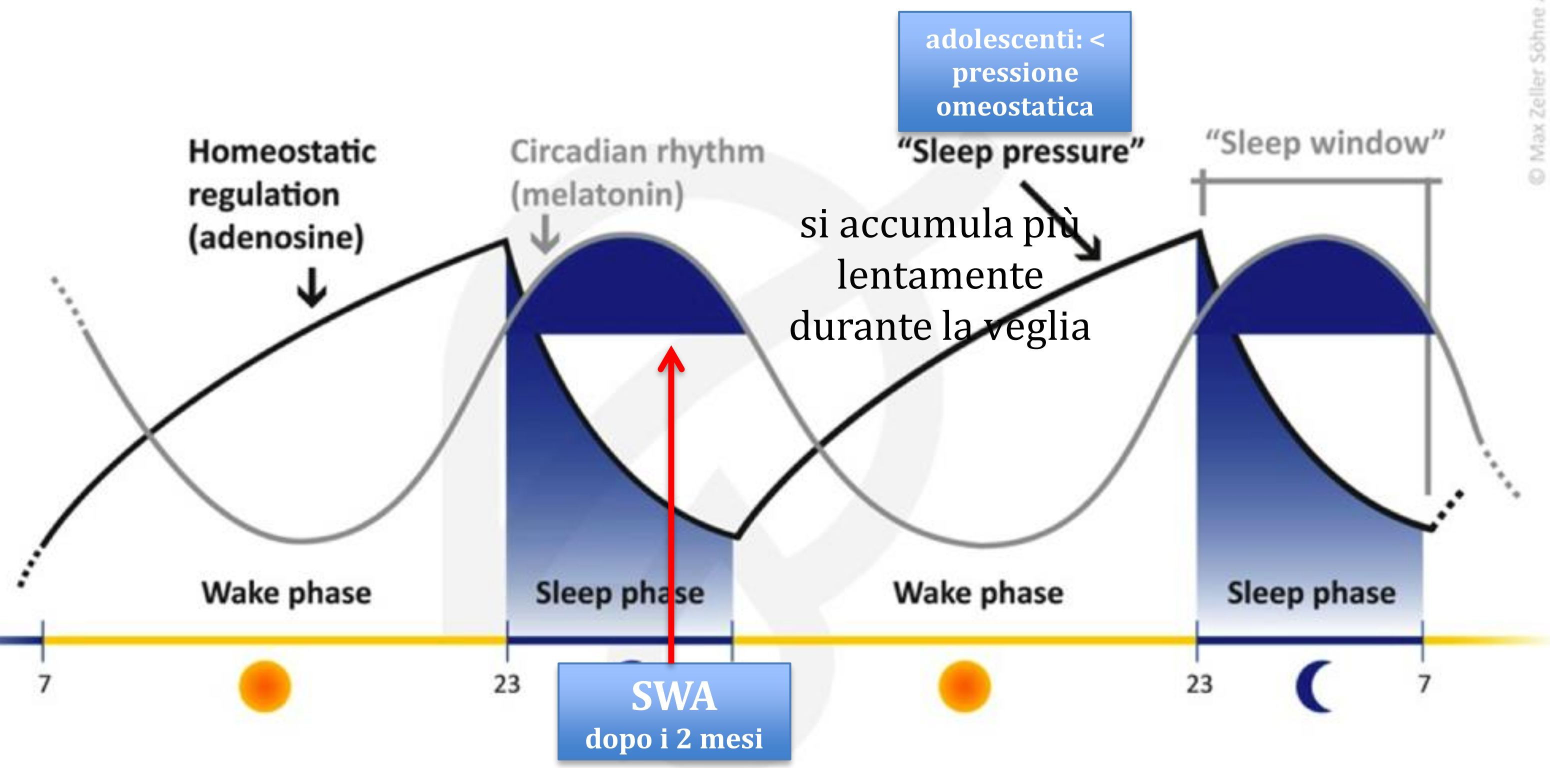
hemispheric asymmetry reduction in older adults, also referred to as de-differentiation, indicates deviation from hemispheric specialization of function, and is considered to possibly represent a compensatory mechanism to counteract functional decline during aging.



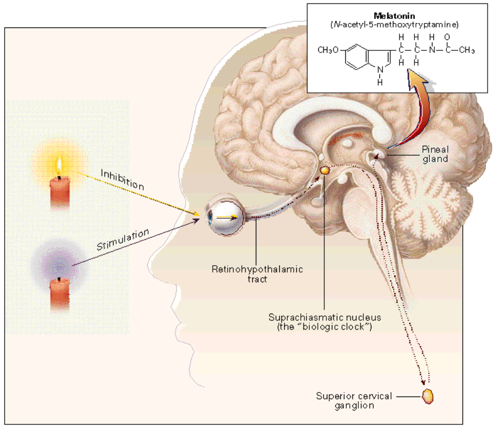
	Mean (SD) [%]	Range [%]
Infants	14.27 (6.07)	3 - 25
Adults	4.41 (3.40)	0 - 11

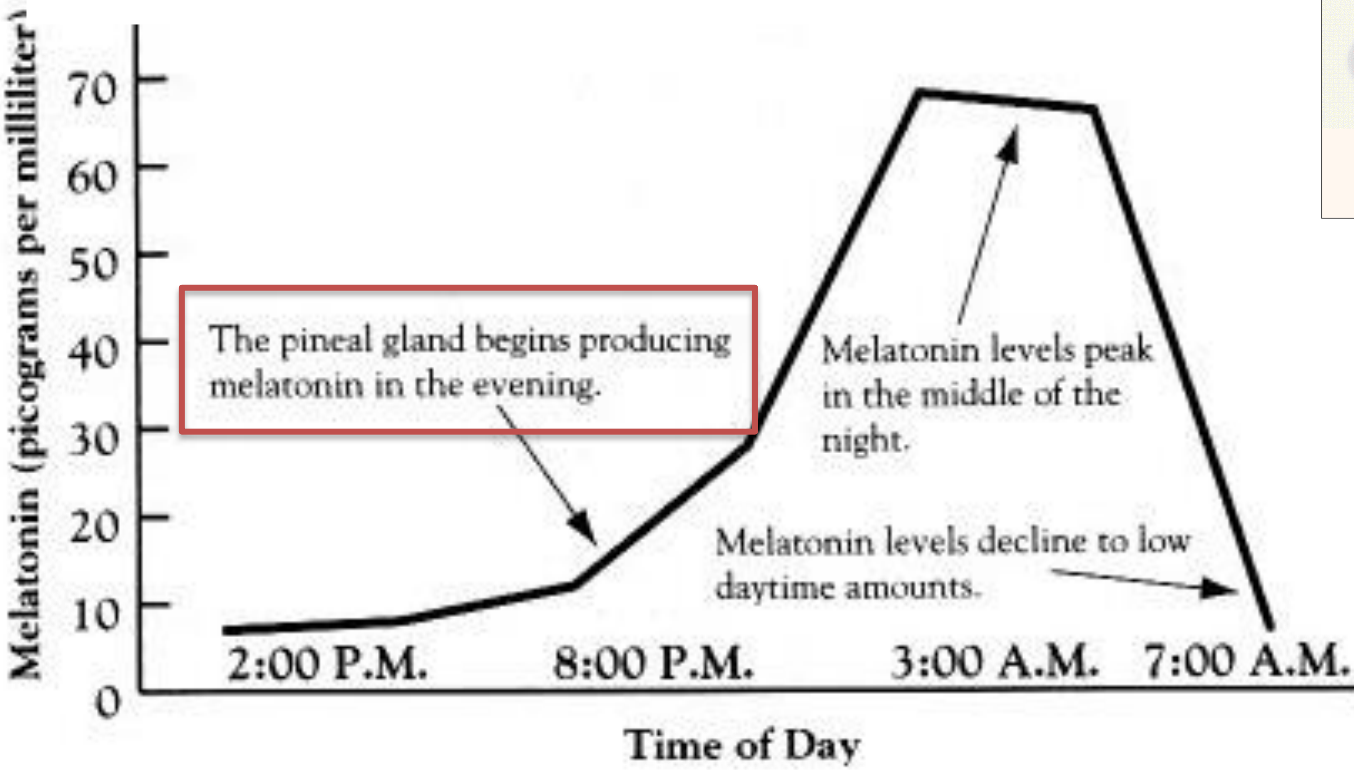
Regolazione ciclo sonno-veglia

un ritardo del ciclo sonno-veglia (ritardo di fase del ritmo circadiano)



Melatonina

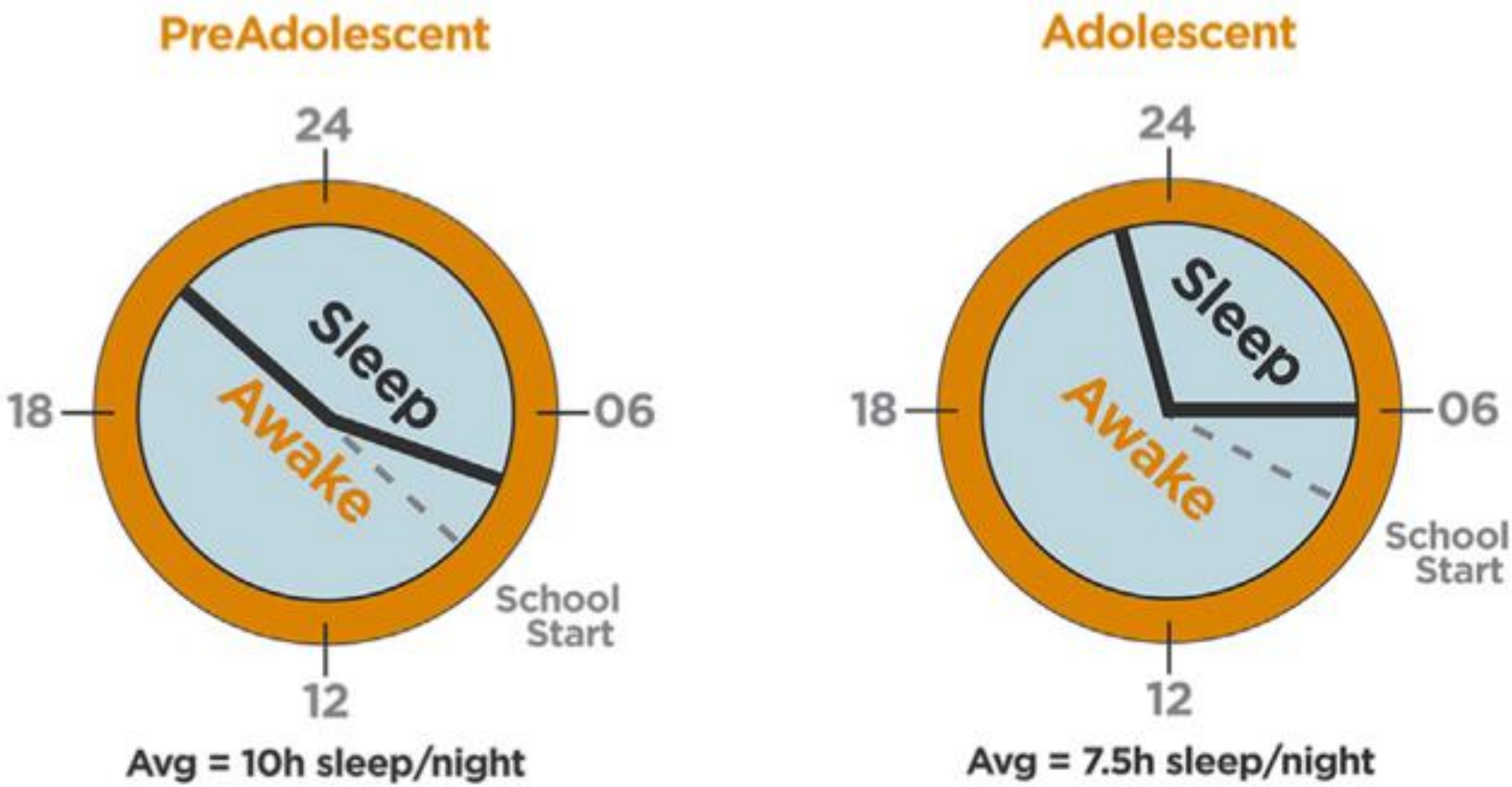




Circadian timing as measured **by dim light melatonin onset** (**DLMO**) and its temporal relationship to sleep show age-related changes.

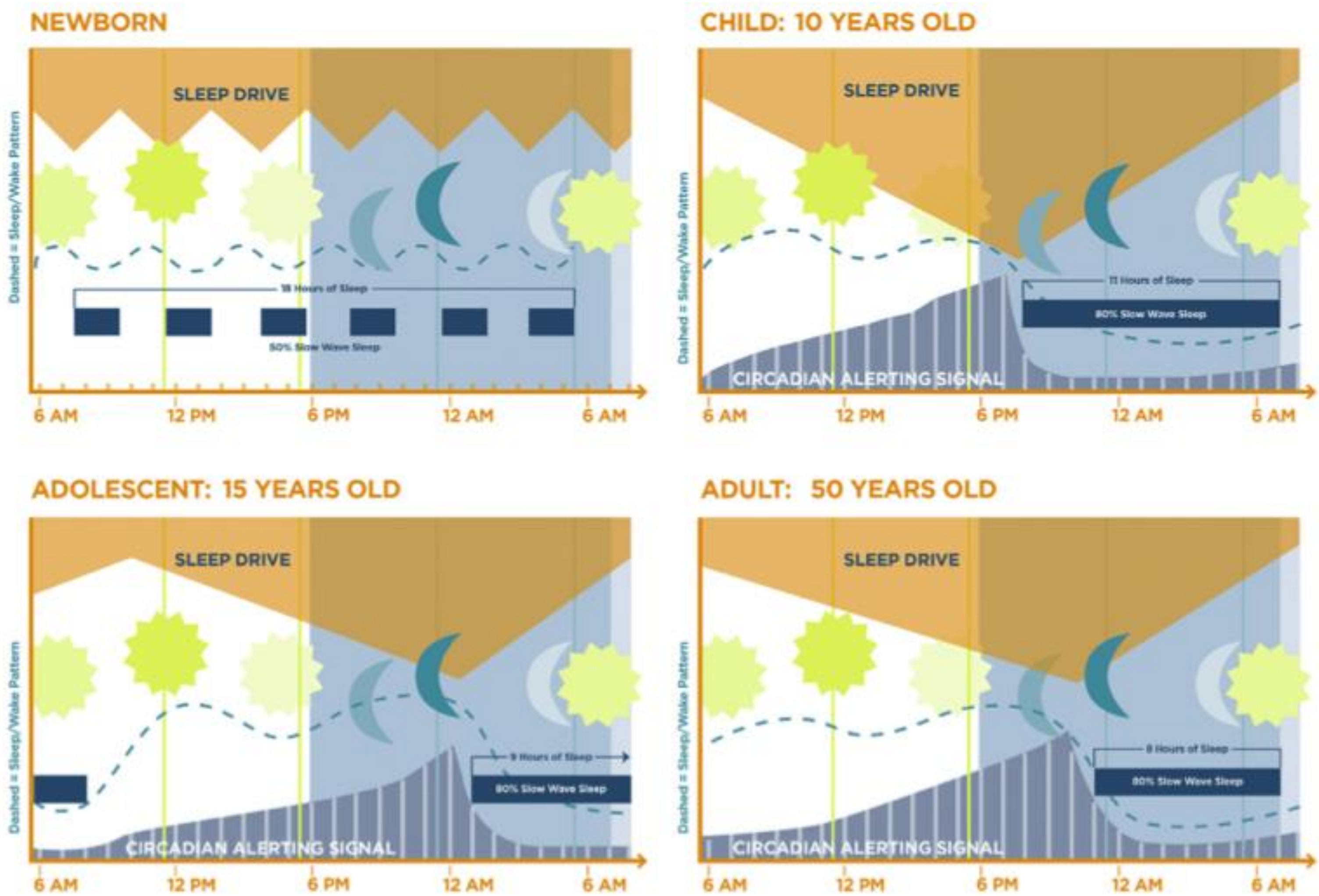
Toddlers	**19:29h**
9–12-year-old children	**20:28h**
13– 16-year-old adolescents	**20:41h**

Riduzione del sonno notturno dalle pre-adolescenza all'adolescenza



hormonal changes during puberty correlate with adolescent changes in the daily timing of sleep

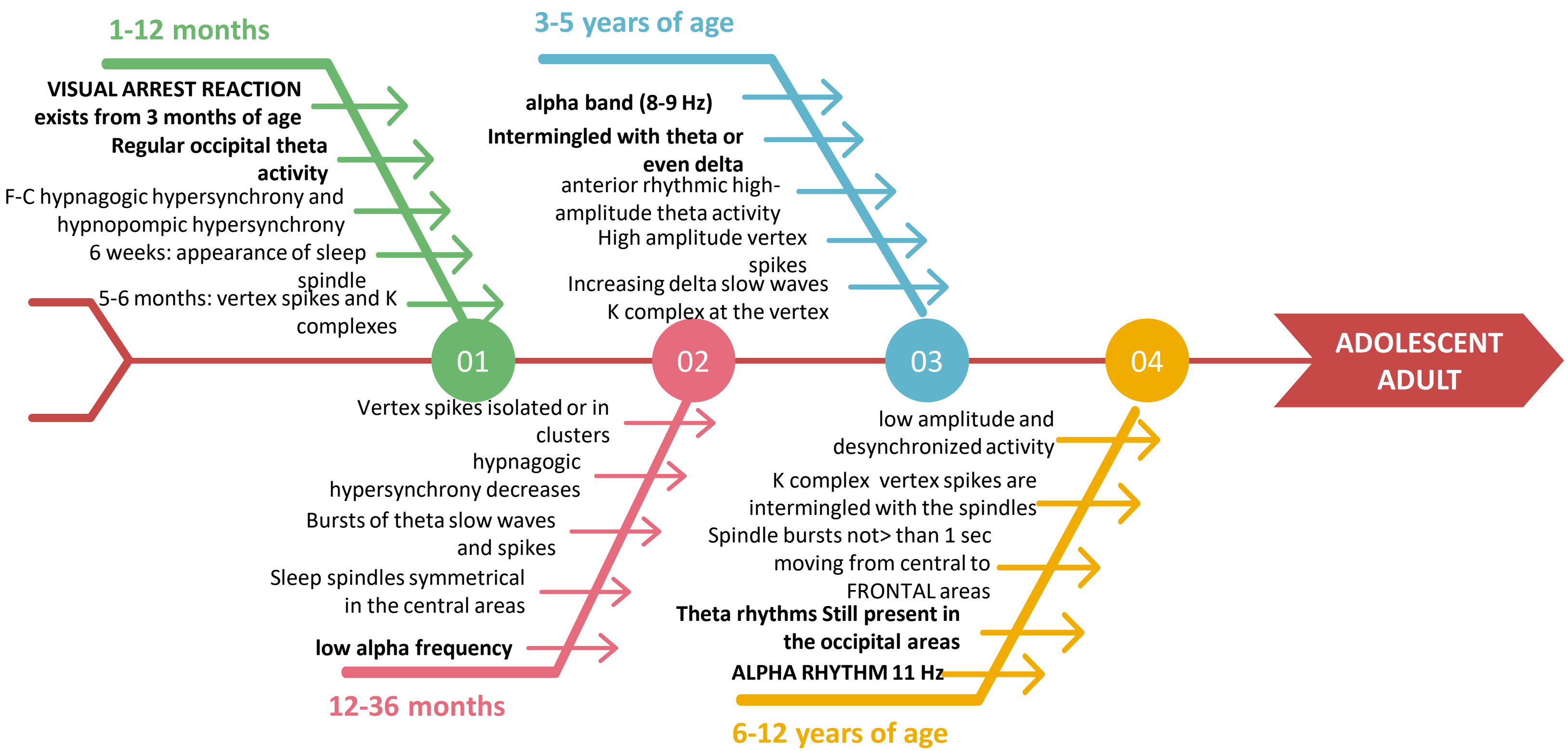
rate and timing of sleep drive accumulation varies by age



Fondazione I.R.C.C.S.
Istituto Neurologico Carlo Besta

Regione Lombardia

Milestones EEG wake and sleep



Normal EEG between 13 and 20 years of age

- **Little modification (???)**
  - **Alpha rhythm**: **lower amplitude** tha at younger age
  - Asymmetry of the amplitude is never more than **20%** in favor of the **nondominant hemisphere**
  - The **slow posterior component decreases** in adolescence
  - **Rapid rhythms** may be seen in **frontal areas**
  - **Hyperventilation modifies** the tracing in no more than **20%** of cases
  - **Photic driving** may be present for **rapid frequencies (6-20 Hz)**
  - Transition between wakefulness and sleep stage I is like in adults: **diffuse desynchronization of the background activity**

Theta and alpha oscillatory responses differentiate between six- to seven year-old children and adults during successful visual and auditory memory encoding

Güntekin et al Brain Research 1747 (2020) 147042

HIGHLIGHTS

- The young adults had higher memory performance than the children.
- Remembered items were represented by increased theta phase-locking in the children.
- There was an anterior-posterior shift between the young adults and the children.
- Children had increased post-stimulus alpha power in memory tasks.

- at the age of 15–16 years, the posterior alpha rhythm matured and became 8.9–11 Hz; the maturation of the alpha activity was completed at age 16 years.

Journal of Adolescence 66 (2018) 55–70

Contents lists available at ScienceDirect

Journal of Adolescence

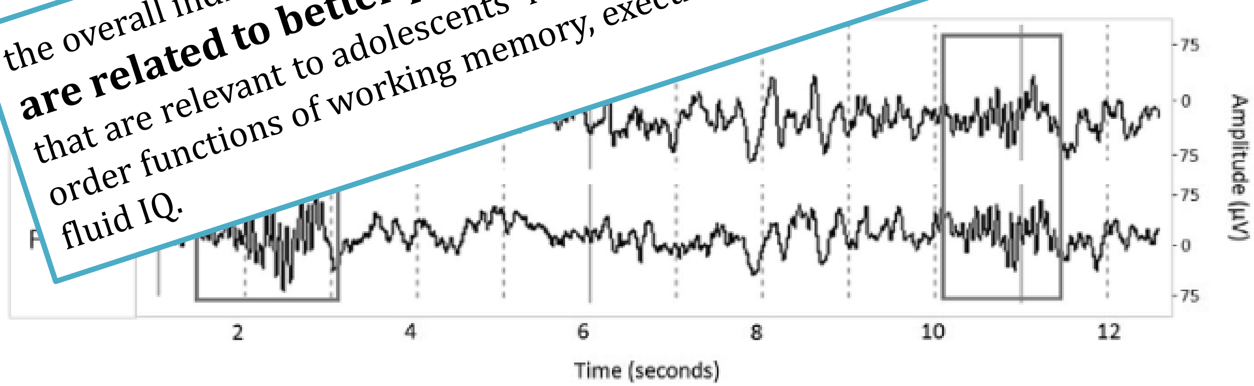
journal homepage: www.elsevier.com/locate/adolescence

Sleep spindles and cognitive performance across adolescence: A meta-analytic review☆

C.M. Reynolds*, M.A. Short, M. Gradisar

Spindles are associated with diverse **cognitive functions**, including learning and memory (Fogel, Nader, Cote, & Smith, 2007), intelligence (F... 2011; Geiger et al., 2011), synaptic plasticity (Urakami, Ionnides, & Koston... -dependent memory consolidation (Clemens, Fabo & Halasz... 2; Schabus et al., 2008).

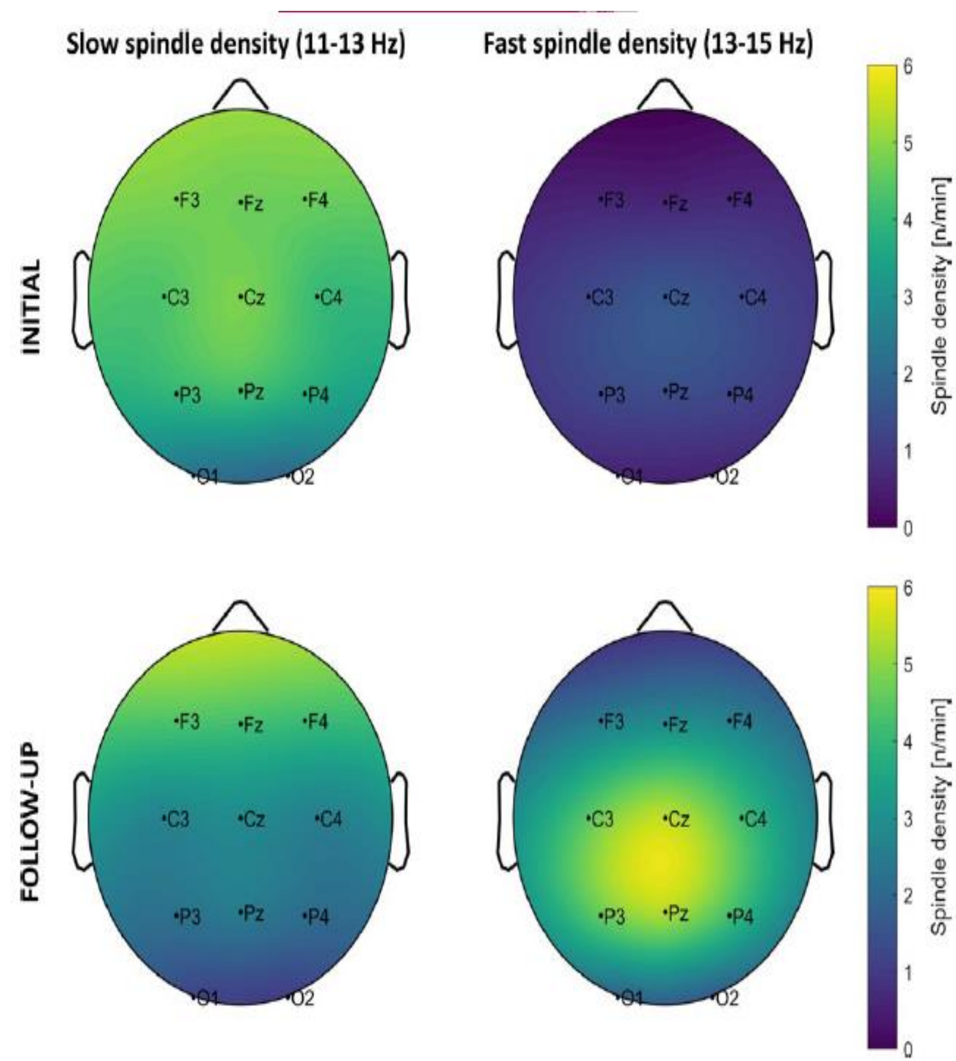
the overall indication is that **higher levels of spindle activity are related to better performance in cognitive areas** that are relevant to adolescents' learning, in particular, the higher-order functions of working memory, executive functioning and fluid IQ.



Developmental changes of sleep spindles and their impact on sleep-dependent memory consolidation and general cognitive abilities: A longitudinal approach

Hahn et al Developmental Science. 2019;22:e12706

- **the typical mature spindle topography** develops throughout adolescence:
  - **slow spindles dominating frontal areas**
  - **fast spindles centro-parietal areas.**
- **Fast** spindles ➔ **sleep-dependent memory consolidation**
- **Slow** spindle ➔ generation of frontal brain networks relevant for **efficient cognitive processing.**

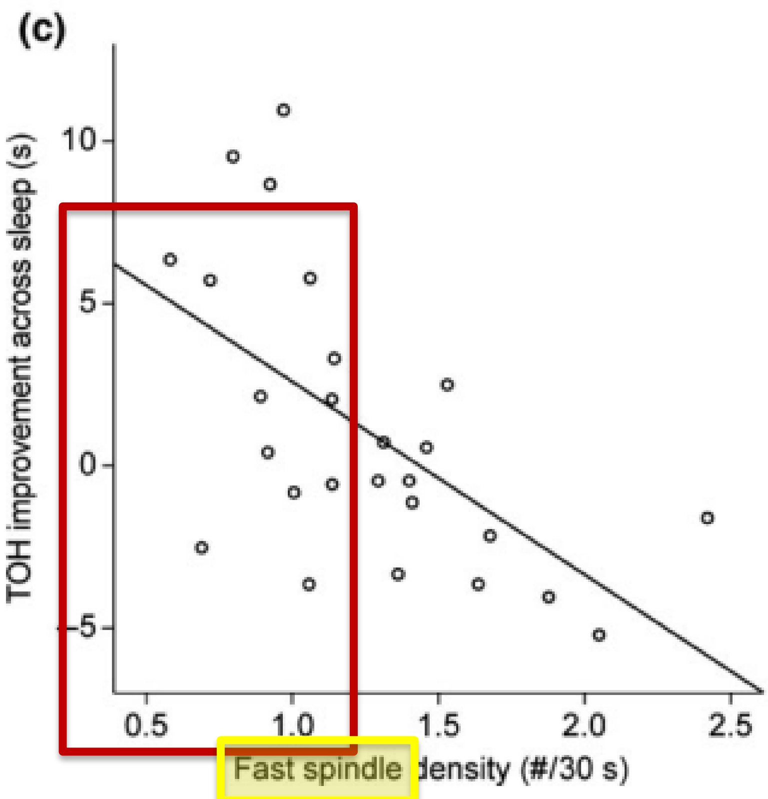


Received: 24 April 2018 | Revised: 6 September 2018 | Accepted: 17 September 2018
DOI: 10.1111/jsr.12779

REGULAR RESEARCH PAPER

Sleep spindle characteristics and sleep architecture are associated with learning of executive functions in school-age children

Marije C. M. Vermeulen[1,2] | Kristiaan B. Van der Heijden[2,3] | Hanna Swaab[2,3] | Eus J. W. Van Someren[1,4]



s epoch), $r = .49$, $p = .010$. A stronger improvement is associated with a lower density of fast spindles and a higher density of slow spindles

Clinical Neurophysiology 129 (2018) 448–454

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Local changes in computational non-rapid eye movement sleep depth in infants

Anna-Liisa Satomaa [a,*], Outi Saarenpää-Heikkilä [b], Eero Huupponen [a], Turkka Kirjavainen [c], Juhani Heinonen [d], Sari-Leena Himanen [a,d]

deep NREM is considered to be the most important sleep stage **for infants.**

SWA reflects the important function of NREM sleep in learning, synaptic plasticity, and in homeostatic brain restoration.

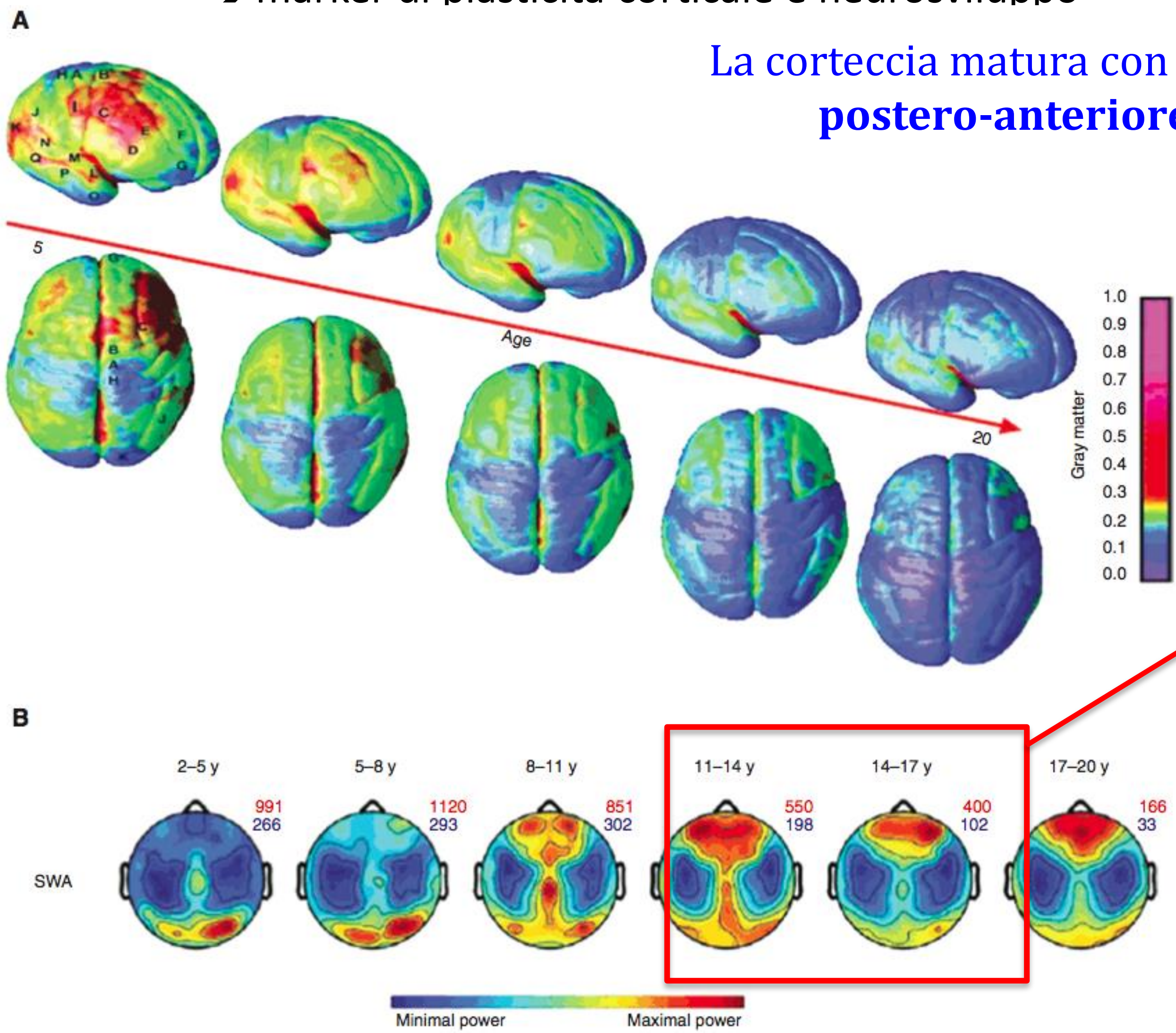
Moreover, in children, SWA is considered to reflect **brain maturation in terms of increased synaptic density and developing plasticity** (Kurth et al., 2010).

The maturation of the brain follows a **posterior-anterior trend** in that the occipital areas mature first and the frontal areas last (Kurth et al., 2010; Shaw et al., 2008).

Maturazione cerebrale e distribuzione topografica SWA

➔marker di plasticità corticale e neurosviluppo

La corteccia matura con una traiettoria **postero-anteriore ➔ SWA**



Importanti cambiamenti nell'adolescenza

Brain maturation in the first 3 months of life, measured by electroencephalogram: A comparison between preterm and term-born infants

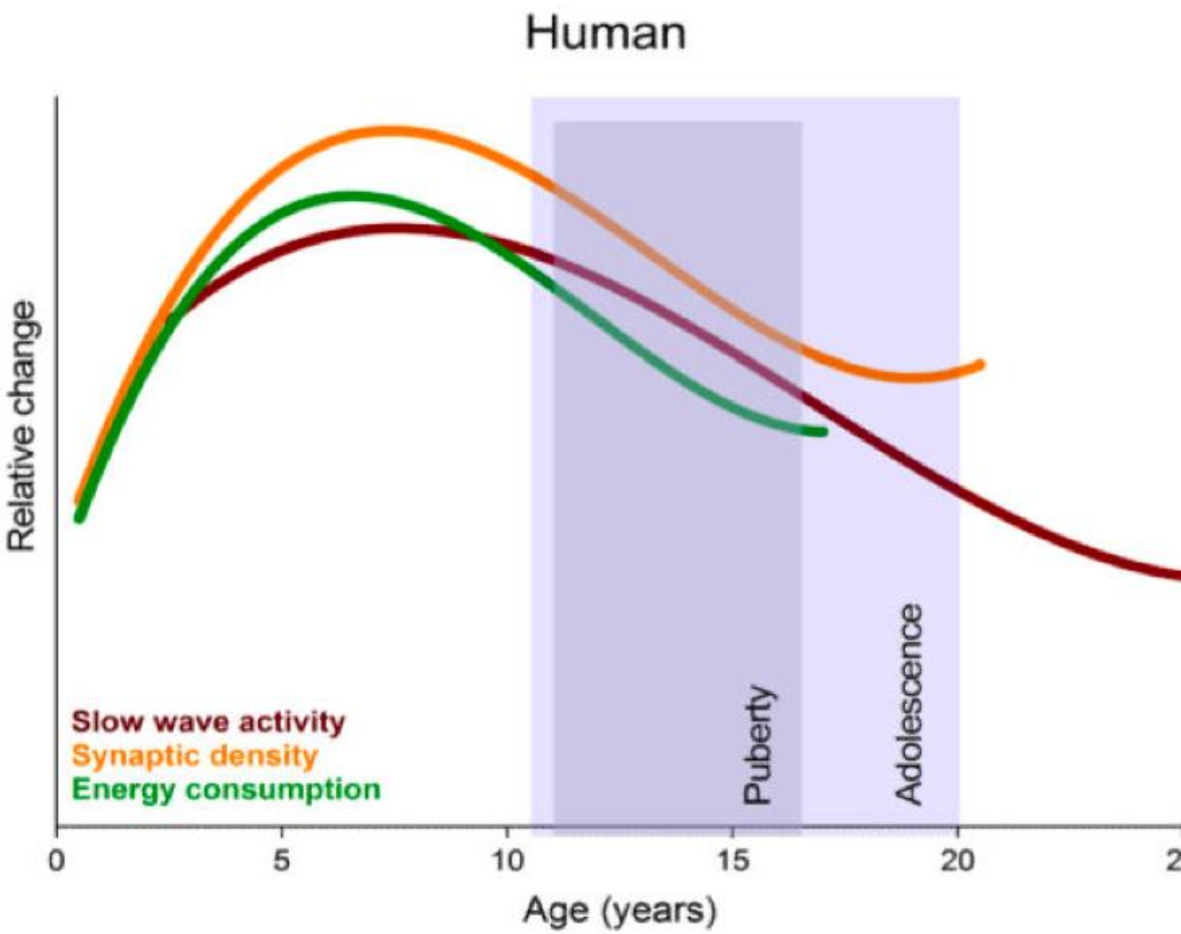
Guyer et al, Clinical Neurophysiology 130 (2019) 1859–1868

The topographical progression of **SWA from occipital to frontal areas** from childhood to adolescence parallels **cortical maturation**

a **posterior-anterior trajectory in theta and alpha activity** with age, which statistically most robust results within the **11 Hz frequency** range of so called **”slow spindles”**.

theta activity as an early sign of **brain maturation**

Time course of sleep and brain maturation variables in humans



synapse density increases across early childhood, reaches a maximum before adolescence, and decreases thereafter (pruning) ➔ to be important for the refinement of cortical networks**.**

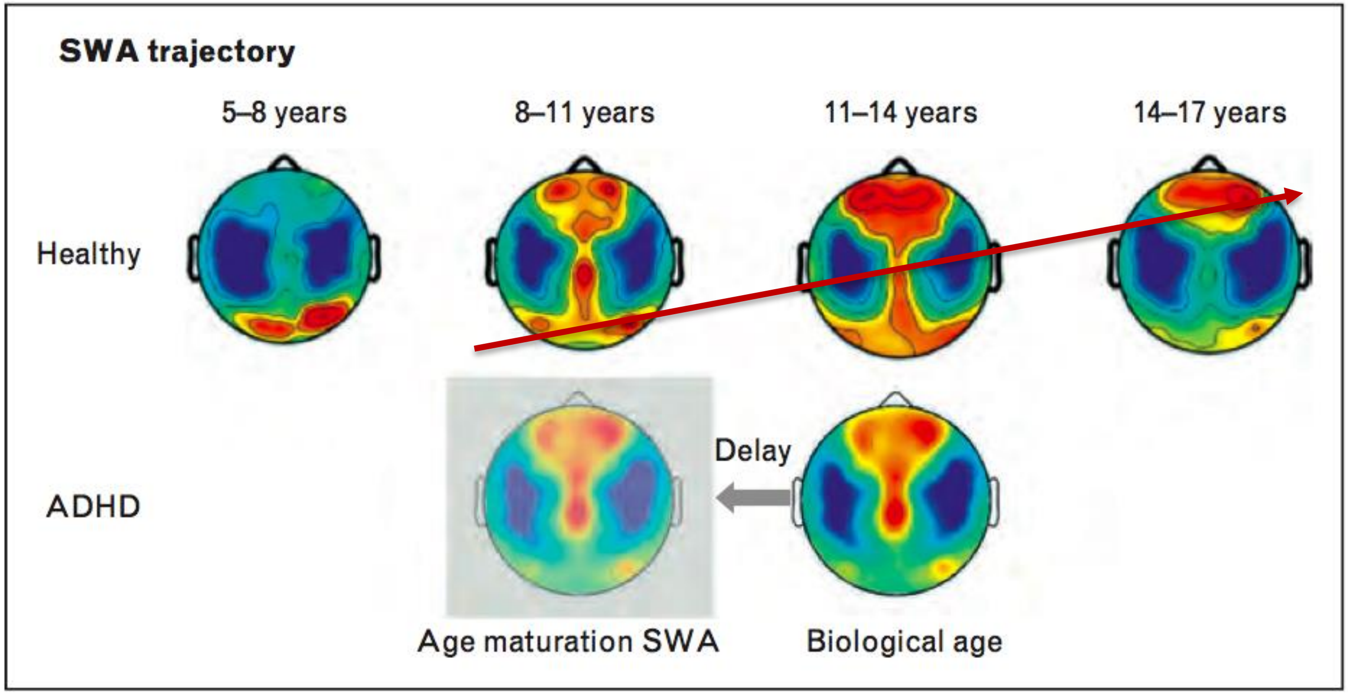
A similar preadolescent increase and postadolescent decrease have been observed in longitudinal recordings **of gray matter volume**.

Altered timing or magnitude of this process has been linked to a multitude of psychiatric diseases

↑ Sinapsi ↓ mielinizzazione
↑ consumo energetico

↓Sinapsi ↑ mielinizzazione
↓ consumo energetico

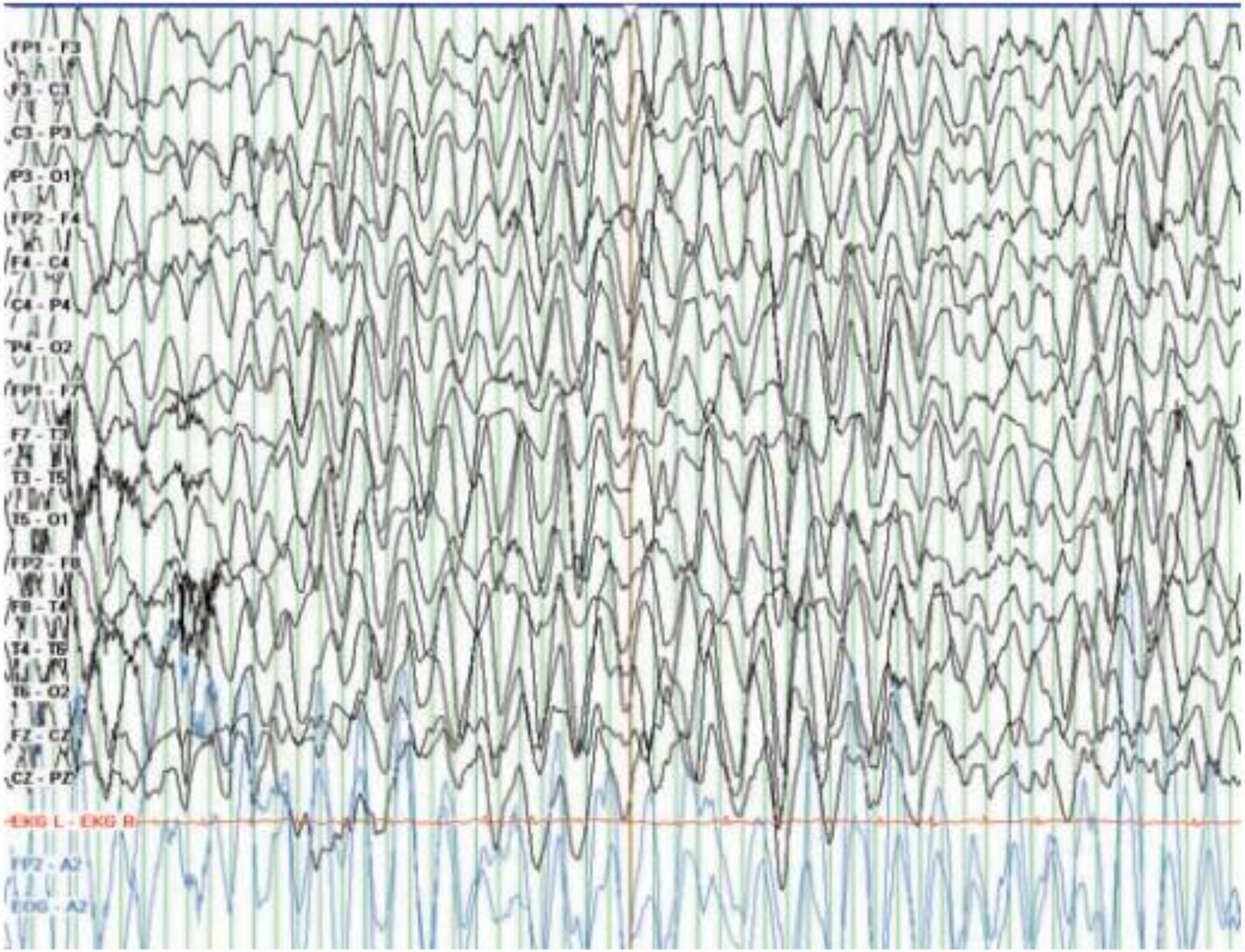
Un ritardo nella maturazione della distribuzione topografica della SWA si riscontra nei bambini con ADHD



Hyperventilation

- Can be performed from the age **of 5 years**
  - It modifies the tracing physiologically
  - May trigger pathological features
- The **alpha rhythm increases in amplitude and decreases in frequency**
- **Theta and delta slow waves** become more **abundant**, **monomorphous** and with posterior or anterior predominance
- These EEG changes may last over several seconds after the end of hyperventilation before they disappear.
- The physiological modification generated by HVN rises from **7 to 10 years of age**, and then **decreases and disappears** by the age of **15**
- Major interindividual variabiliry

Figure 4: Marked Hyperventilation Effect—Normal in Children and Not a Sign of Epilepsy



Patterns Specific to Pediatric EEG

Raj D. Sheth

Mayo Clinic College of Medicine, Nemours Children Subspecialty Clinic, Jacksonville, Florida, U.S.A.

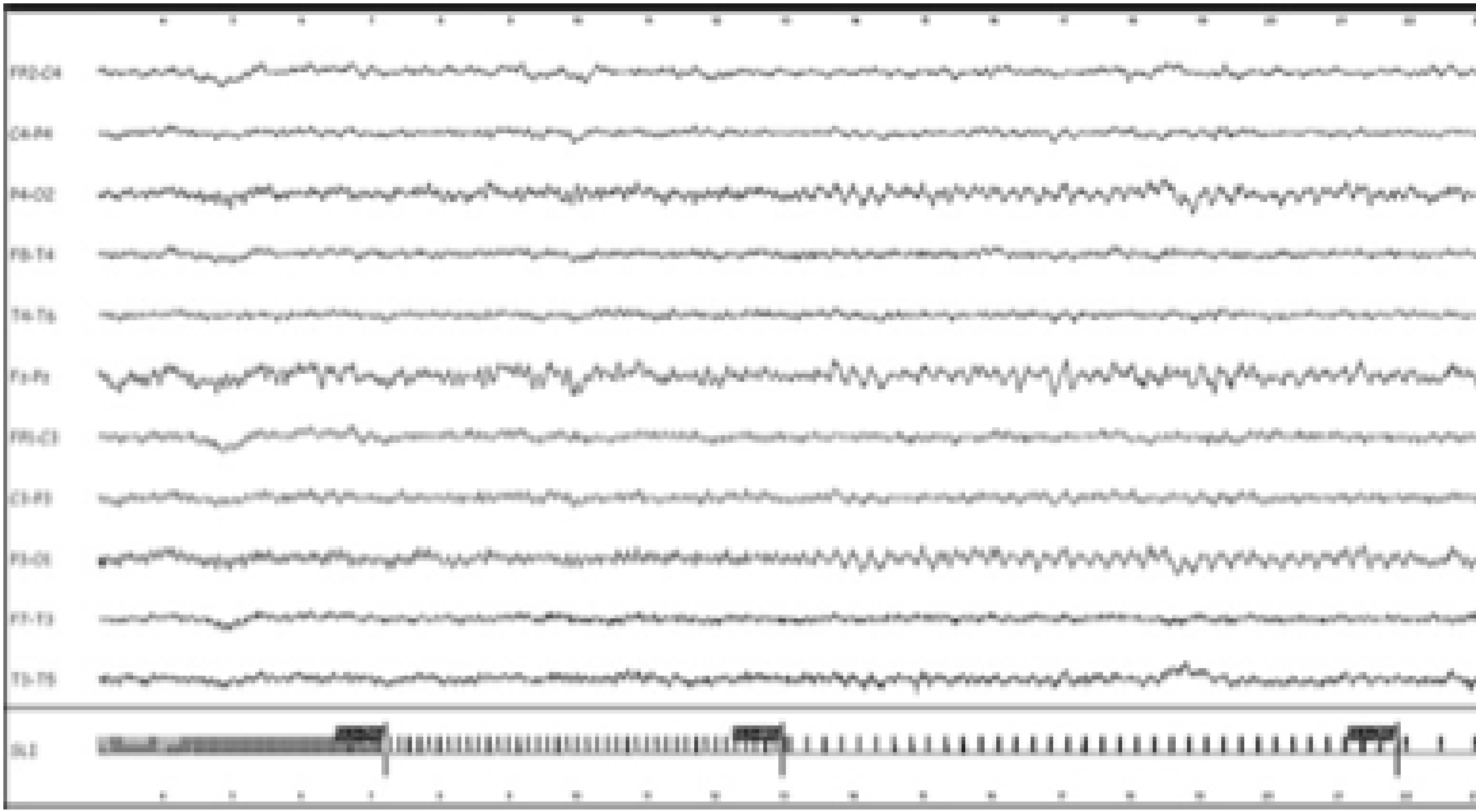
- Hyperventilation Patterns
  - hyperventilation-induced **3-Hz generalized spike–wave discharge** and misdiagnosed as **absence epilepsy**.
  - The young child who is **crying during EEG** recording can sometimes have a **breath-holding spell** that an unfamiliar technologist may **mark as a seizure**. The accompanying recorded EEG with **cyanosis** is helpful in correctly identifying this feature.

J Clin Neurophysiol 2019;36: 289–293

Intermitten Photic Stimulation

- **Photic driving** of the occipital rhythm for low stimulation frequencies (**4 to 5 Hz**) is present from **6 to 7 years** of age, then **increases progressively** with higher stimulation frequencies (**6-16 Hz)**
- Lack of Photic driving is not pathological **but asymmetrical** driving may be so

Intermitten Photic Stimulation



Normal Variants Are Commonly Overread as Interictal Epileptiform Abnormalities

Joon Y. Kang* and Gregory L. Krauss*

Normal Awake, Drowsy, and Sleep EEG Patterns That Might Be Overinterpreted as Abnormal

Ali A. Asadi-Pooya*† and Michael R. Sperling*

- One of the most challenging aspects of interpreting EEGs is distinguishing between **pathologic activity and similar appearing normal physiologic findings** called "normal" or "benign variants."
- When benign variants appear in small fragments with sharp morphology, the normal patterns can easily be **misinterpreted as epileptiform discharges.**

J Clin Neurophysiol 2019;36: 257–263

UNUSUAL EEG ACTIVITIES

	DURING	WHERE		AGE
EXTREME SPINDLES	sleep	frontal	6-18 Hz fast rhythms with higher amplitude than spindles	
THETA RHYTHMS	On falling asleep	temporal		From 3 y
VERTEX SPIKES	SS	Centroparietal areas	High amplitude, very sharp, sequences lasting several seconds = vertex spike trains	3-5 y
POSTERIOR SLOW WAVES	Awake phase		Variable frequency (theta or delta)	6-12 y
LAMBDA WAVES	When opening the eyes	Occipital	Bi- or triphasic spikes of low amplitude (20-50 uV) lasting 200-300 ms separated by 200-500 ms intervals	3 y
MU RHYTHM		Central bilateral or alternating (more controlateral)	Bursts of 7-11 Hz in sequences lasting a few seconds, blocked by voluntary movement	Adolesc 11-15 y
PSYCHOMOTOR VARIANTS*	Vigilance decreses	mid temporal uni-bilateral	Long sequences of rhythmic 5 Hz theta activity, synchronous or not	adolesc
FAST RHYTHMS	On falling asleep	anterior	15-30 Hz	Older child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