High-frequency oscillations

High-frequency oscillations (HFO) are brain waves of frequency faster than ~80 Hz, generated by neuronal cell population. High-frequency oscillations can be recorded during an electroencephalogram (EEG), local field potential (LFP) or electrocorticogram (ECoG) electrophysiology recordings. They are present in a physiological states during sharp waves and ripples - oscillatory patterns involved in memory consolidation processes.

HFOs are associated with the pathophysiology of the brain like epileptic seizures and are often recorded during seizure onset. It makes a promising biomarker for the identification of the epileptogenic zone.

HFO is generated by different cellular mechanisms and can be detected in many brain areas.

In hippocampus, this fast neuronal activity is the effect of the population synchronous spiking of pyramidal cells in the CA3 region and dendritic layer of the CA1, which give rise to a characteristic oscillation pattern (see more in sharp waves and ripples).

The HFO occurrence during a memory task (encoding and recalling images) was also reported in human patients from intracranial recordings in primary visual, limbic and higher-order cortical areas.

Another example of physiological HFO of around 300 Hz, was found in the subthalamic nucleus, which partially explains, why high-frequency deep brain stimulation treatment helps patients with Parkinson's disease.

Sharifshazileh et al. from Zurich present a neuromorphic system that combines a neural recording headstage with a spiking neural network (SNN) processing core on the same die for processing intracranial EEG (iEEG), and show how it can reliably detect High-Frequency Oscillations (HFO), thereby achieving state-of-the-art accuracy, sensitivity, and specificity. This is the first feasibility study towards identifying relevant features in iEEG in real-time using mixed-signal neuromorphic computing technologies [1)].

High frequency oscillations in scalp EEG

HFOs have also been found in scalp EEG, but an overview of all studies is lacking. In a systematic review, Noorlag et al. assessed the methodology to detect scalp HFOs and their clinical potential.

They searched PubMed, Embase and the Cochrane Library for studies on HFOs in scalp EEG, and extracted methodological and clinical data.

They included 60 studies with data from 1149 unique individuals. Two-thirds of studies analyzed HFOs visually in the time or time-frequency domain, and one-third automatically with visual validation. Most studies evaluated interictal ripples during sleep in children. Pathological HFOs were overall better than spikes in localizing the epileptogenic zone and predicting outcome, correlated negatively with

cognition and positively with disease activity and severity, and decreased after medical and surgical treatment.

The methodologies of the 60 studies were heterogeneous, but pathological scalp HFOs were clinically valuable as biomarkers in various situations, particularly in children with epilepsy.

This systematic review gives an extensive overview of methodological and clinical data on scalp HFOs, establishing their clinical potential and discussing their limitations [2)].

Cserpan et al. selected 16 whole-night scalp EEG recordings of paediatric patients with a focal structural epilepsy. They used an automated clinically validated High-frequency oscillations (HFO) detector to determine HFO rates (80-250 Hz). They evaluated the reproducibility of HFO detection across intervals.

HFO rates were higher in N3 than in N2 and REM (rapid eye movement) sleep and highest in the first sleep cycle, decreasing with time in sleep. In N3 sleep, the median reliability of HFO detection increased from 67% (interquartile range: iqr 57) to 78% (iqr 59) to 100% (iqr 70%) for 5-, 10-, and 15-min data intervals, improving significantly ($p = 0.004$, $z = 2.9$) from 5 to 10 min but not from 10 to 15 min.

They identified the first N3 sleep stage as the most sensitive time window for HFO rate detection. At least 10 min N3 data intervals are required and sufficient for reliable measurements of HFO rates.

The study provides a robust and reliable framework for scalp HFO detection that may facilitate their implementation as an EEG biomarker in paediatric epilepsy [3)].

Interictal High-frequency oscillations

see Interictal High-frequency oscillations.

Pathological High-Frequency Oscillations

Pathological High-Frequency Oscillations.

1)
Sharifshazileh M, Burelo K, Sarnthein J, Indiveri G. An electronic neuromorphic system for real-time detection of high frequency oscillations (HFO) in intracranial EEG. Nat Commun. 2021 May 25;12(1):3095. doi: 10.1038/s41467-021-23342-2. PMID: 34035249.
2)
Noorlag L, van Klink NEC, Kobayashi K, Gotman J, Braun KPJ, Zijlmans M. High-frequency oscillations in scalp EEG: A systematic review of methodological choices and clinical findings. Clin Neurophysiol. 2022 Jan 20;137:46-58. doi: 10.1016/j.clinph.2021.12.017. Epub ahead of print. PMID: 35272185.
3)
Cserpan D, Rosch R, Lo Biundo SP, Sarnthein J, Ramantani G. Variation of scalp EEG high frequency oscillation rate with sleep stage and time spent in sleep in patients with pediatric epilepsy. Clin

Neurophysiol. 2022 Jan 12;135:117-125. doi: 10.1016/j.clinph.2021.12.013. Epub ahead of print. PMID: 35085923.