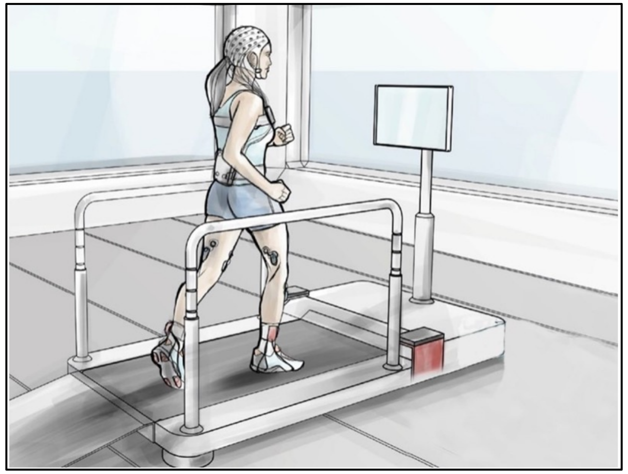
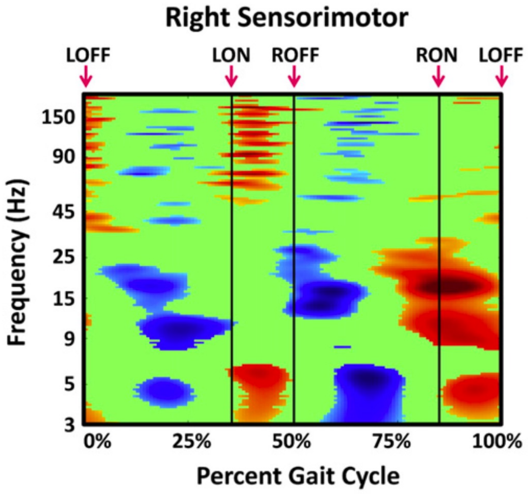
Electro-encephalography (EEG): Movement-related time-frequency modulations





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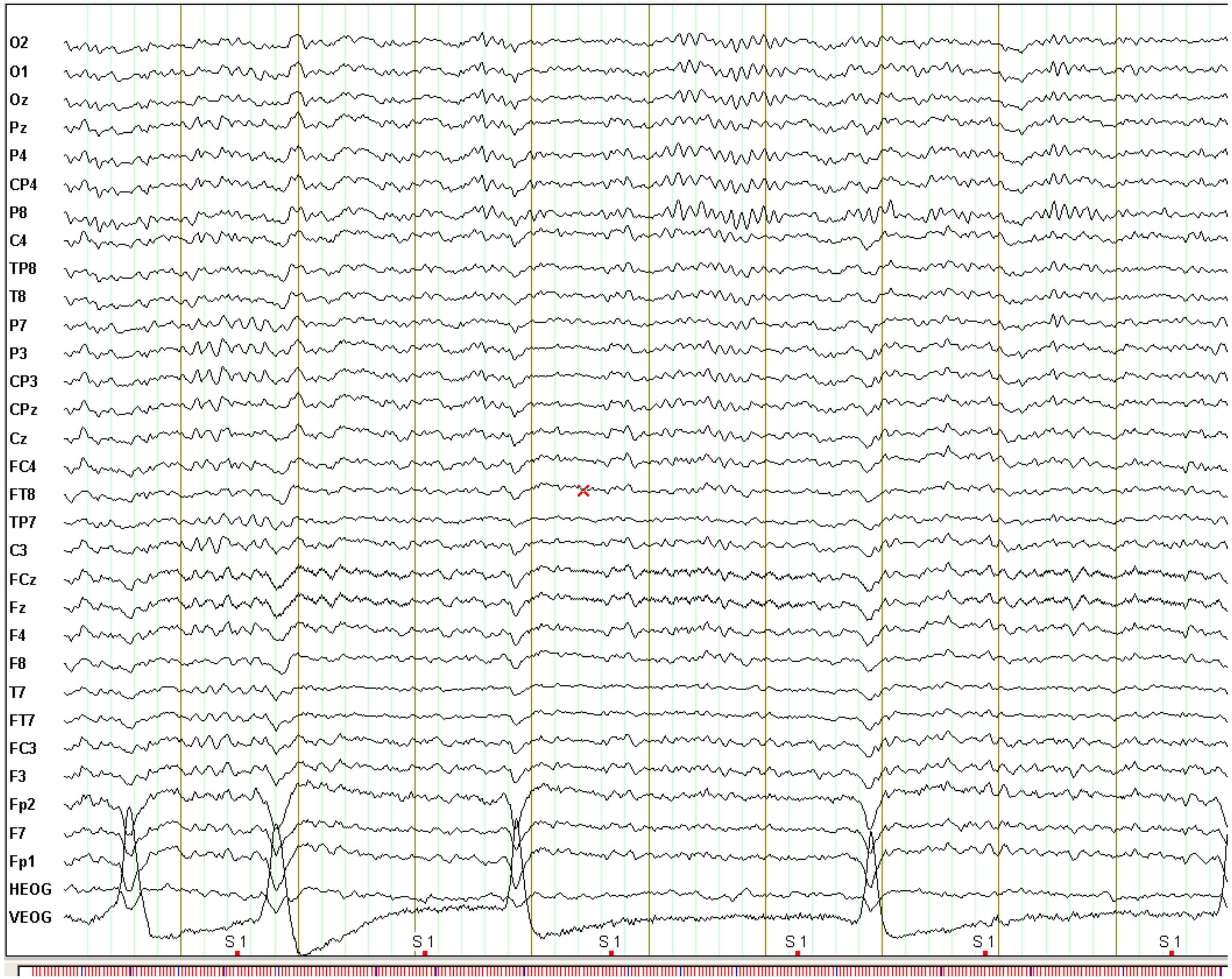
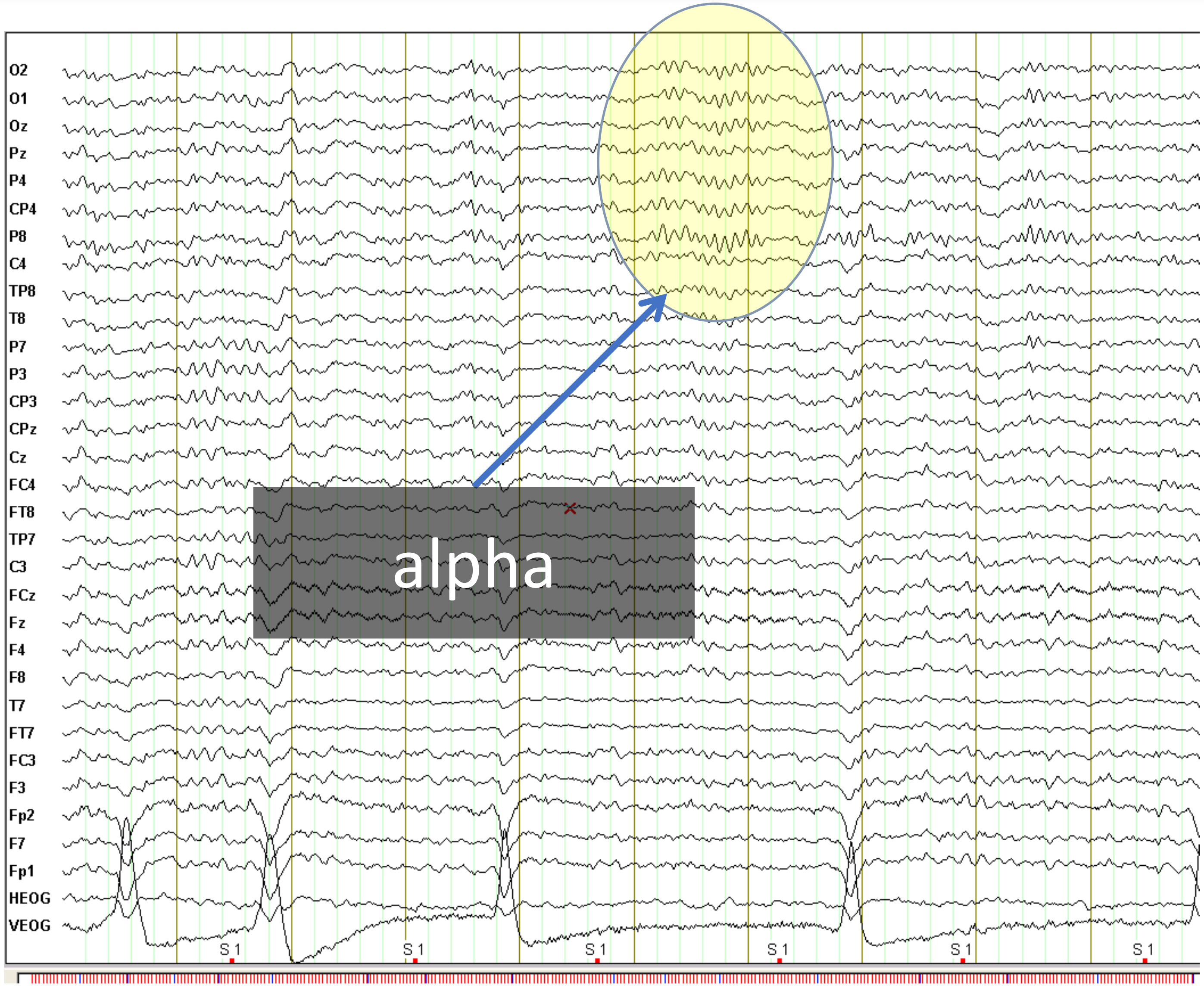
Example recording

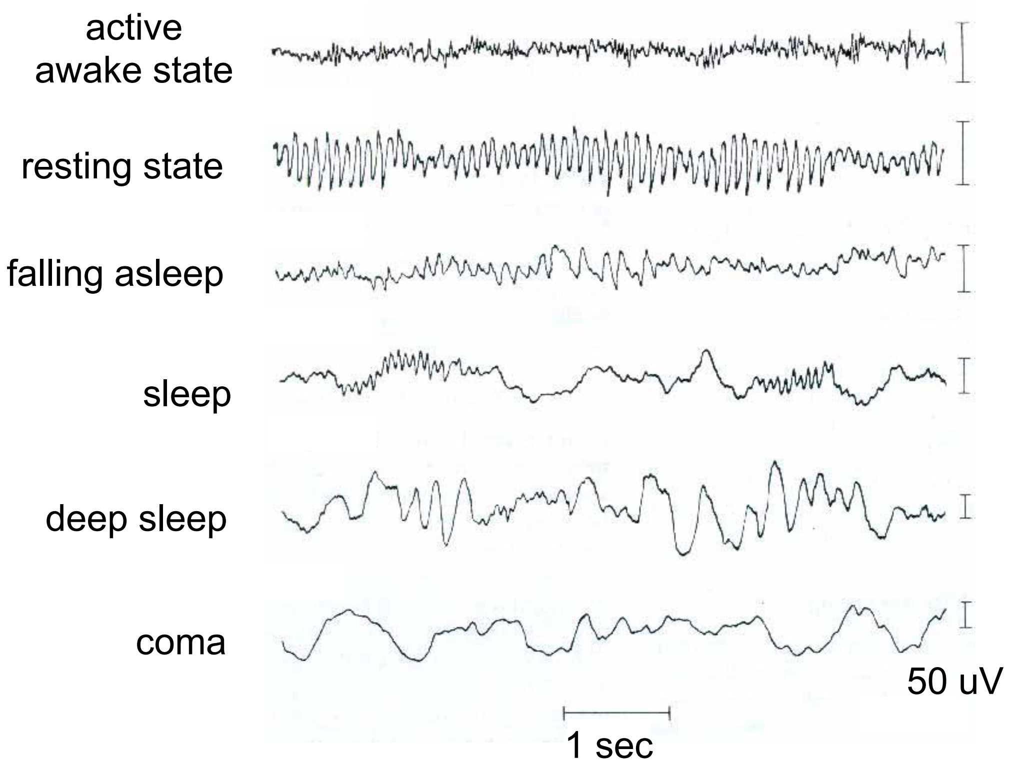


Example recording



Oscillations in EEG time series

EEG recordings comprise different frequency bands ('oscillations') with specific functional roles



ongoing rhythms

Fourier decomposition

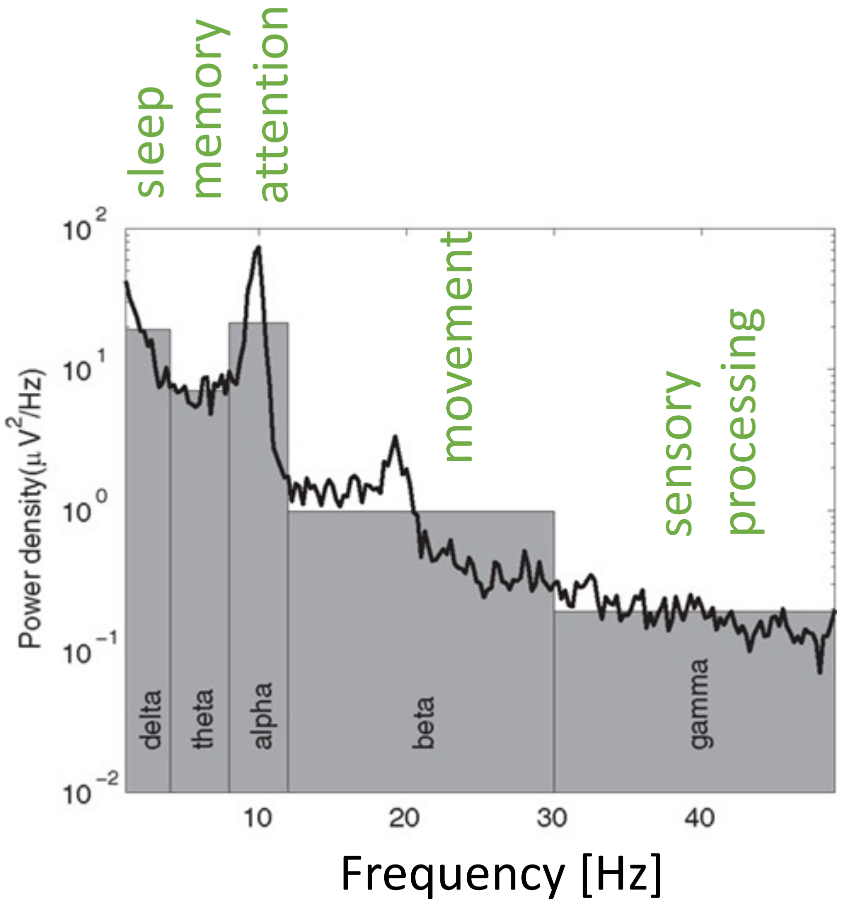
Any complex time series can be broken down into a series of superimposed sinusoids with different frequencies

Joseph **Fourier**
(1768-1830)

Figure from: http://en.wikipedia.org

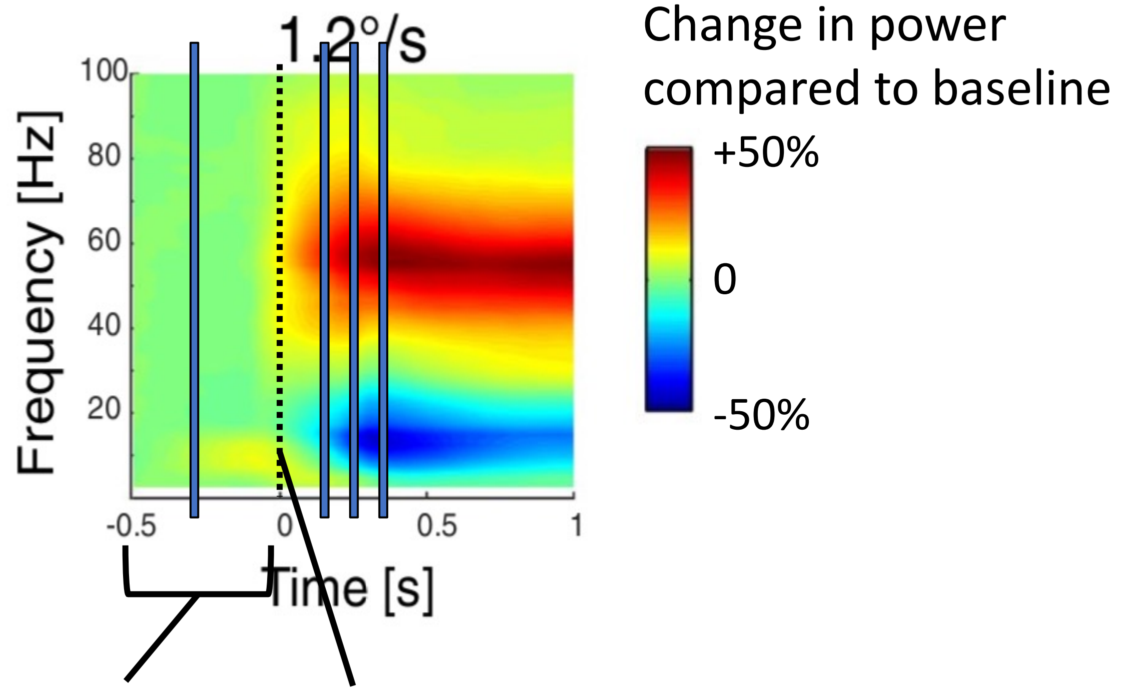
EEG Spectral power

A **power spectrum** shows the average amplitude of each frequency in the signal



Task-related modulations in spectral power

A **time-frequency spectrum** shows how the power spectrum changes over time



Baseline
time window

Time = 0s: Event of interest
(e.g. stimulus presentation, movement onset)

Event-related desynchronisation (ERD)

Decrease in power

Event-related synchronisation (ERS)

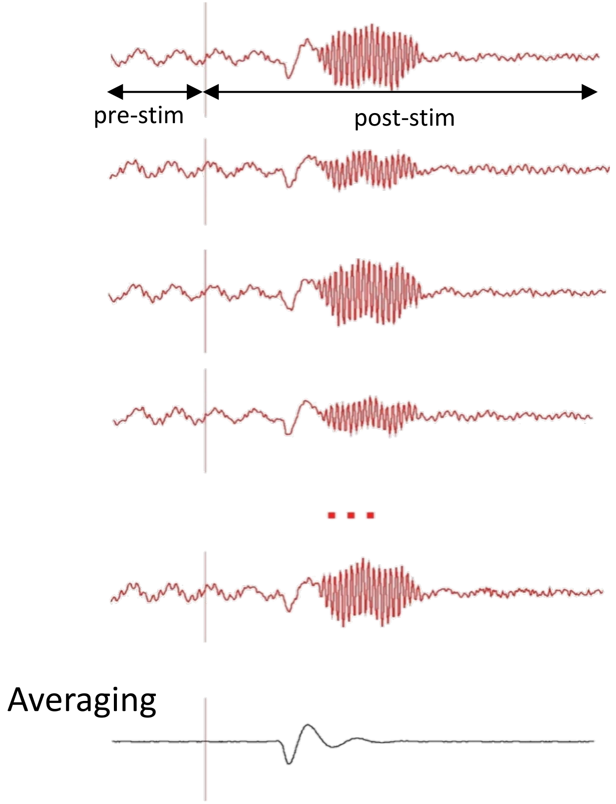
Increase in power

Both ERD and ERS could be meaningful

Evoked versus induced responses

Frequency analysis captures changes in the amplitude of oscillations that may cancel out by averaging in the time domain

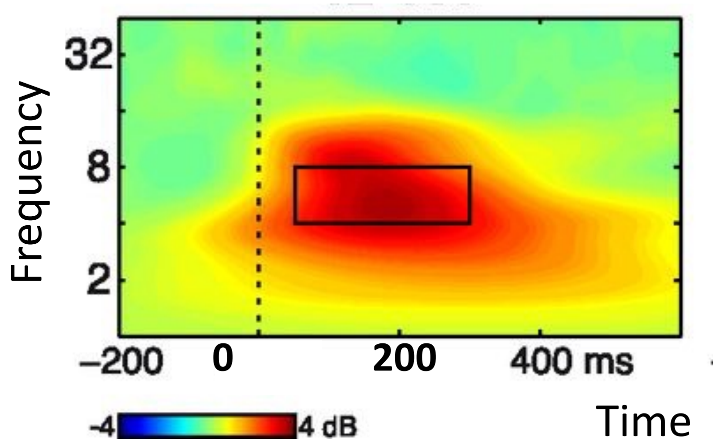
Raw time series



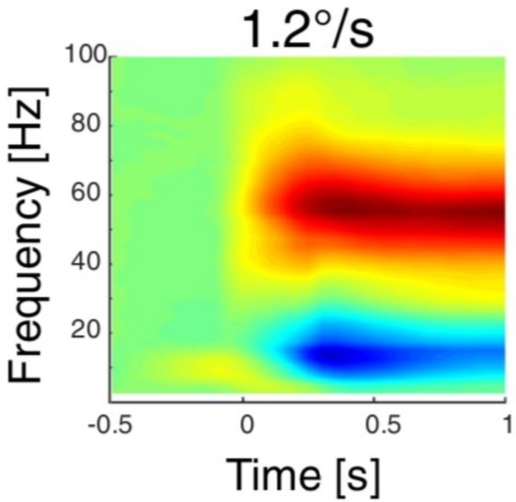
Evoked response

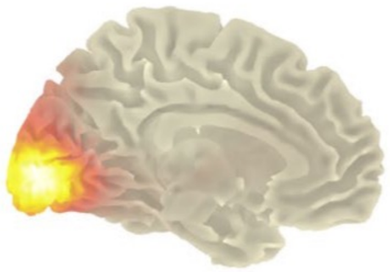
Induced response

Time-frequency spectrum



Example 1: Oscillations in visual perception





Visual input

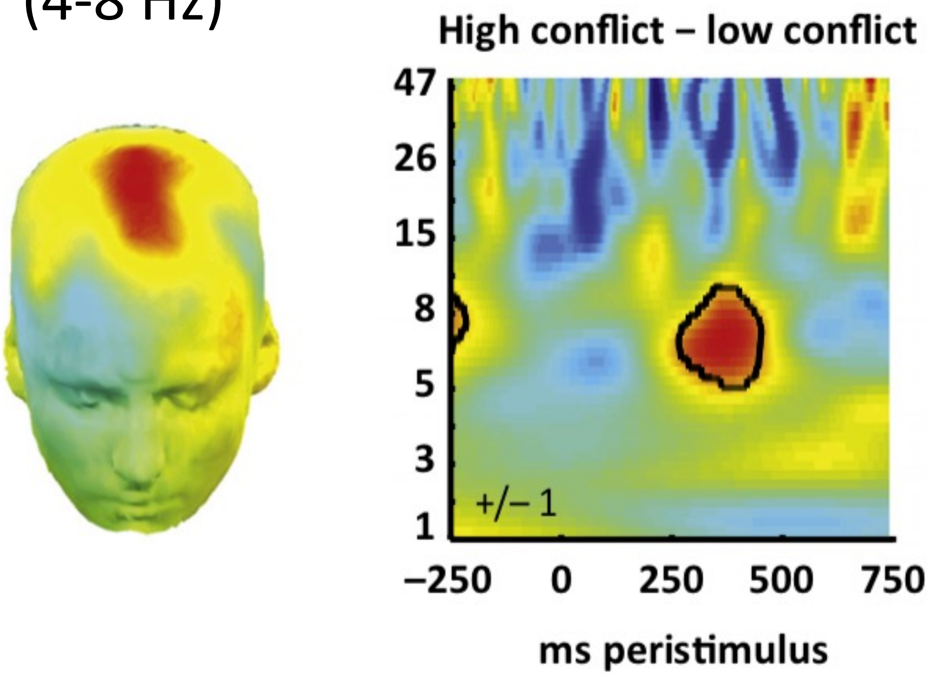
Increase in gamma power (ERS for ~30-100 Hz)

Decrease in alpha/beta power (ERD for ~8-30 Hz)

Orekhova et al. (2018) *Scientific Reports*

Example 2: Oscillations encoding cognition

Mid-frontal increase in theta power (4-8 Hz)

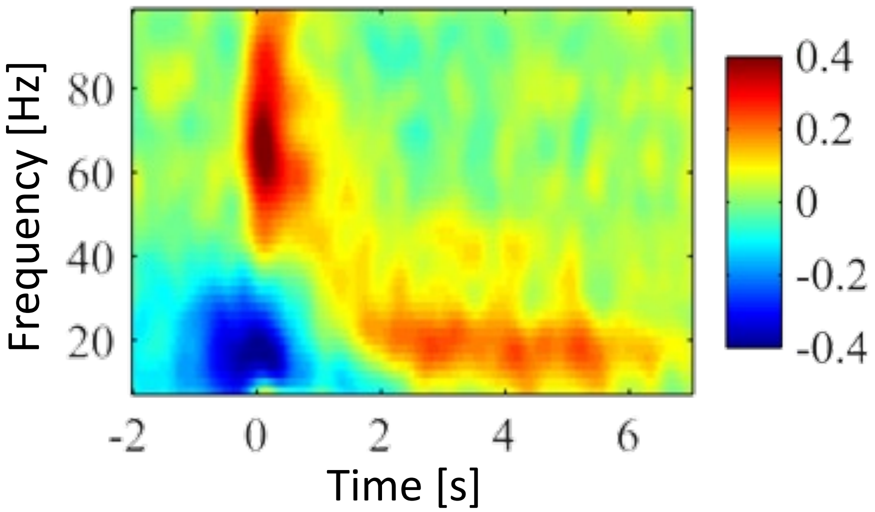


Novelty, conflict, error, etc.

Cavanagh & Frank (2014) *Trends in Cognitive Science*

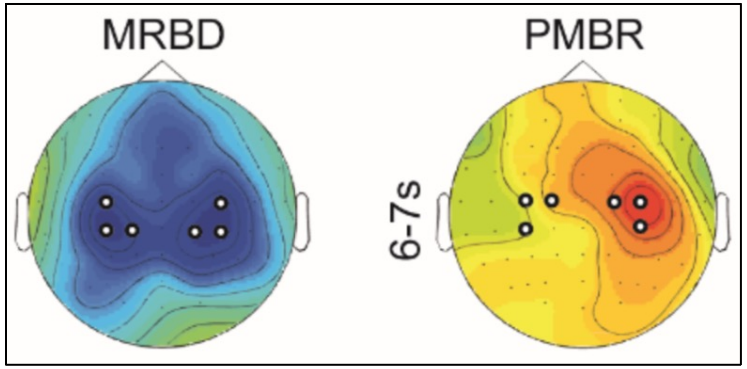
Example 3: Movement-related oscillations

Motor cortex



Movement-related beta decrease

Post-movement beta rebound



Hand movement

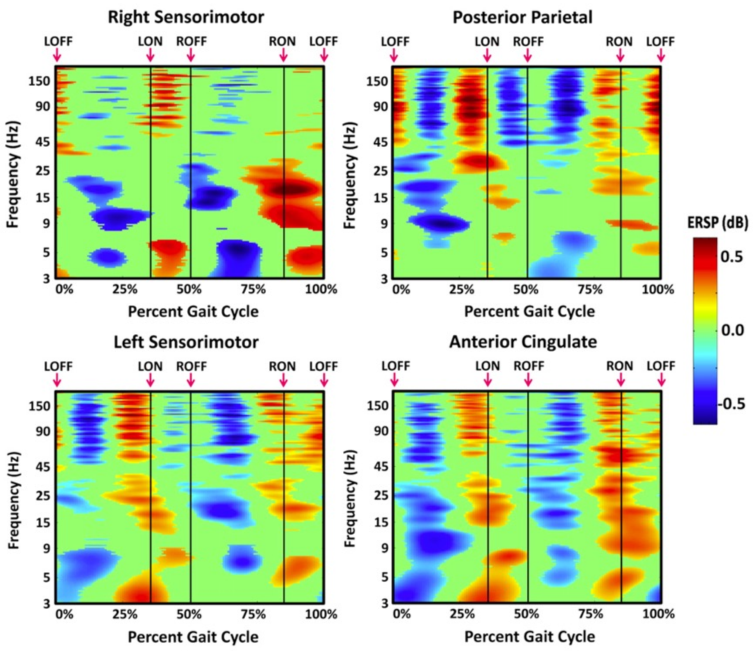
Beta ERD before & during movement (13-30 Hz)

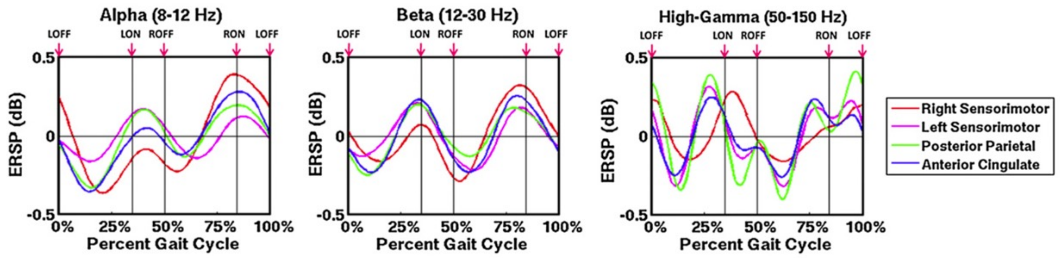
Beta ERS after movement (13-30 Hz)

Gamma ERS around movement onset (30 – 100 Hz)

Pfurtscheller et al. (1999); Litvak et al. (2012); Espenhahn et al. (2017)

Gait-related time-frequency modulations

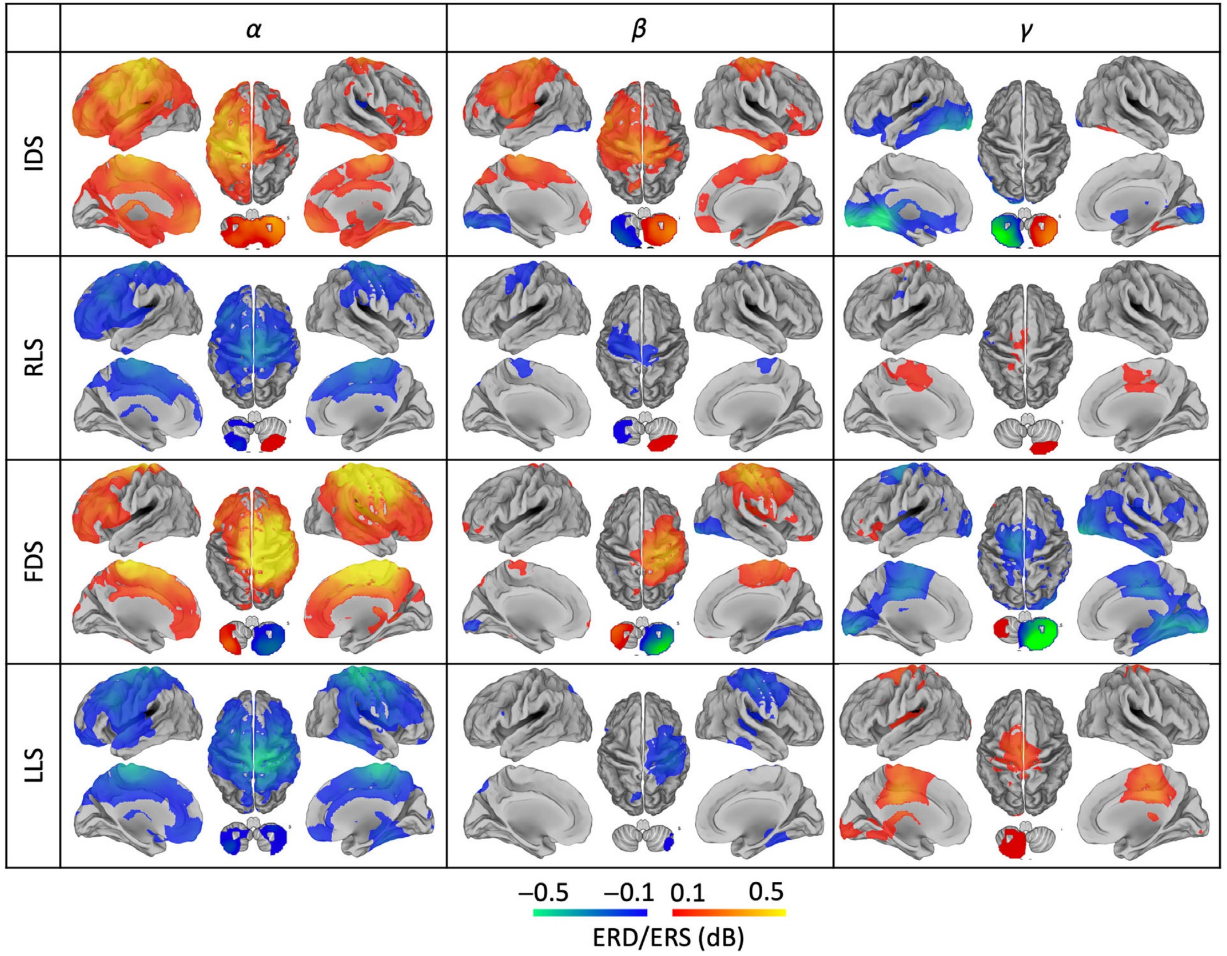




- Alpha/beta ERD during swing phase
- Alpha/Beta ERS during double support
- Gamma ERS before heel strike

Gwin et al. (2011) *Neuroimage*

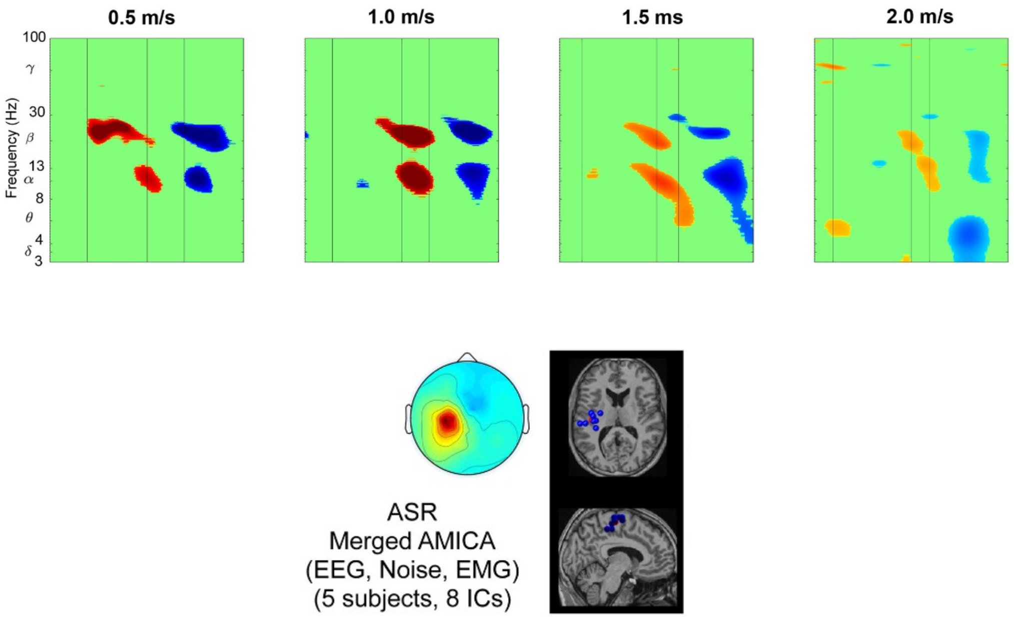
Gait-related time-frequency modulations



Zhao et al. (2022) *Human Brain Mapping*

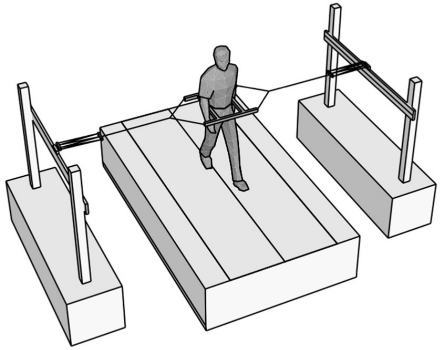
Gait-related time-frequency modulations

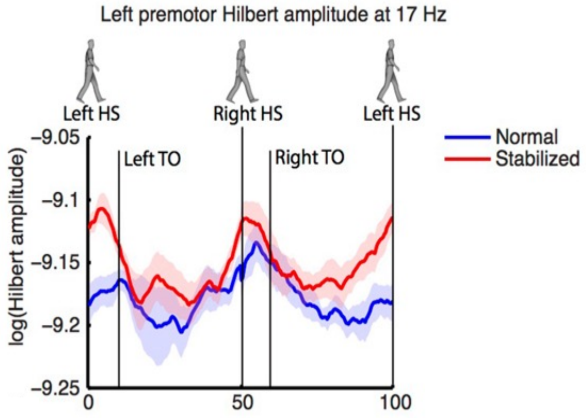
Size of ERD/ERS can be speed-dependent



Nordin et al. (2020) *IEEE Trans Biomed Engineering*

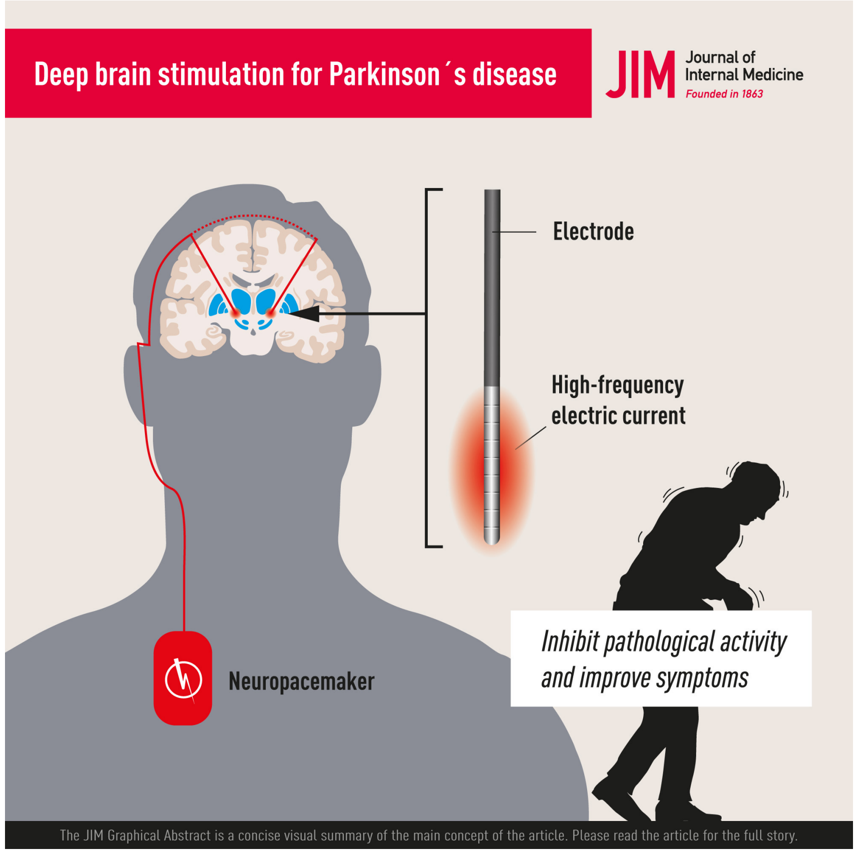
Stabilized walking associated with higher beta power in left premotor cortex





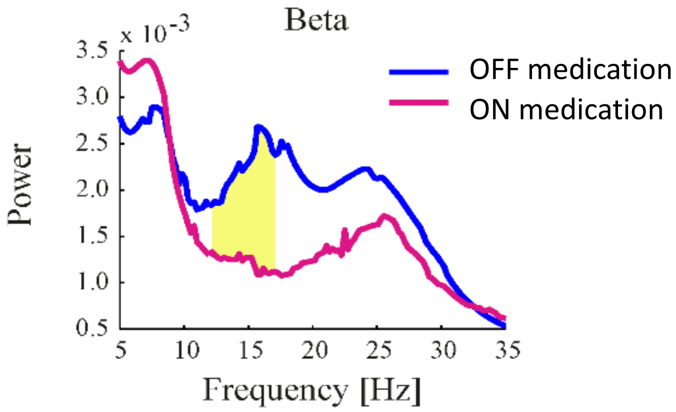
Bruijn et al. (2015) *Frontiers in Human Neuroscience*

Neural oscillations in Parkinson's disease: basal ganglia



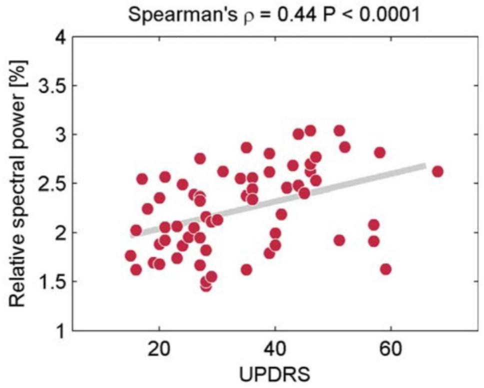
Hariz & Blomstedt (2022) *J Internal Medicine*

Levodopa medication reduces beta power in the subthalamic nucleus



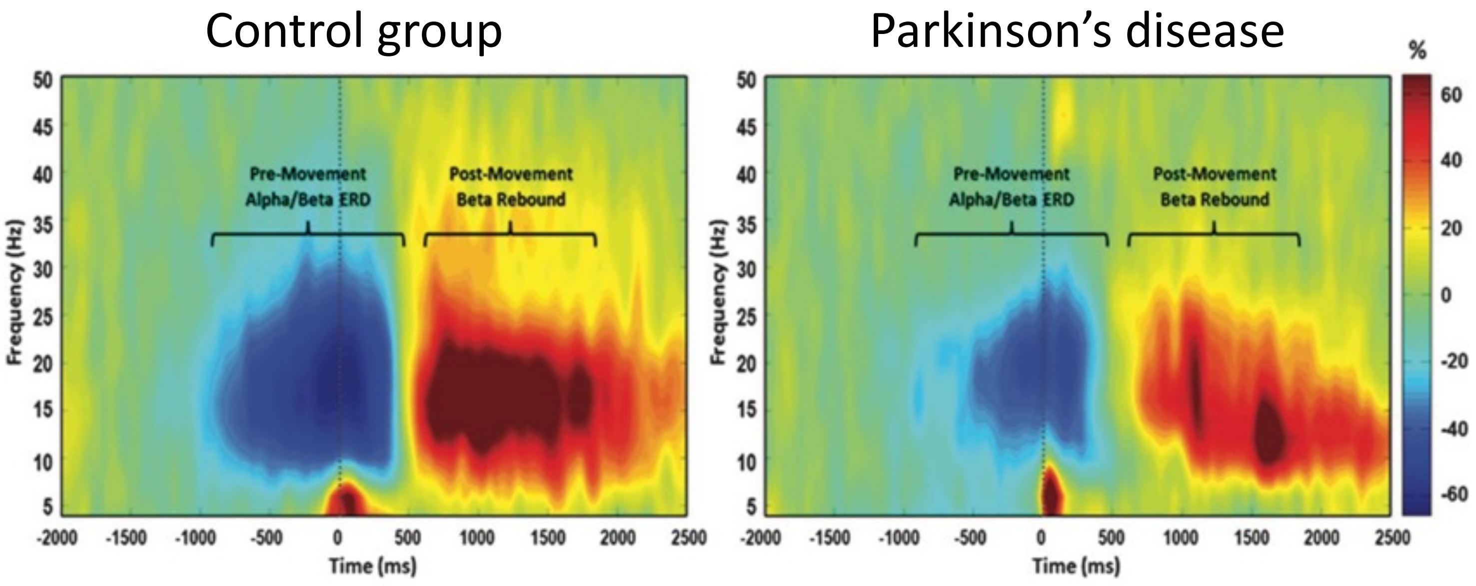
van Wijk et al. (2016) *Clin Neurophys*

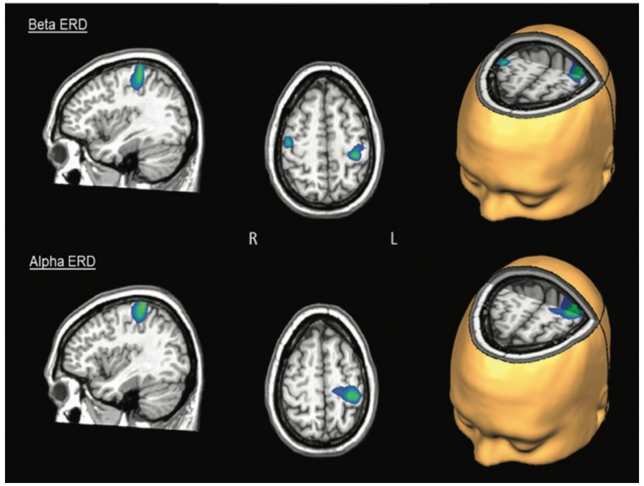
UPDRS scores correlate with beta power in the subthalamic nucleus



Neumann et al. (2016) *Movement Disorders*

Neural oscillations in Parkinson's disease: motor cortex



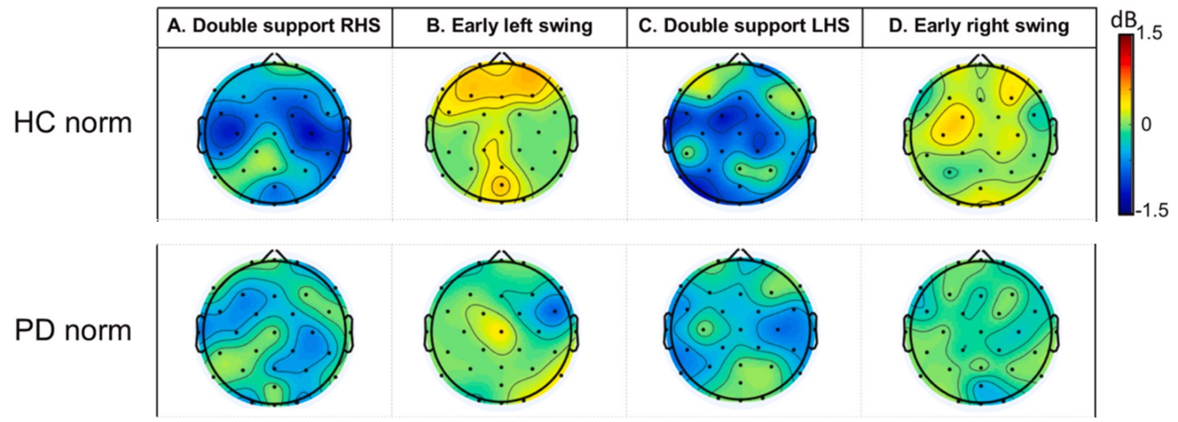


- Reduced and delayed beta ERD
- Reduced beta ERS
- Partially restored with medication

Heinrichs-Graham et al. (2014) *Cerebral Cortex*

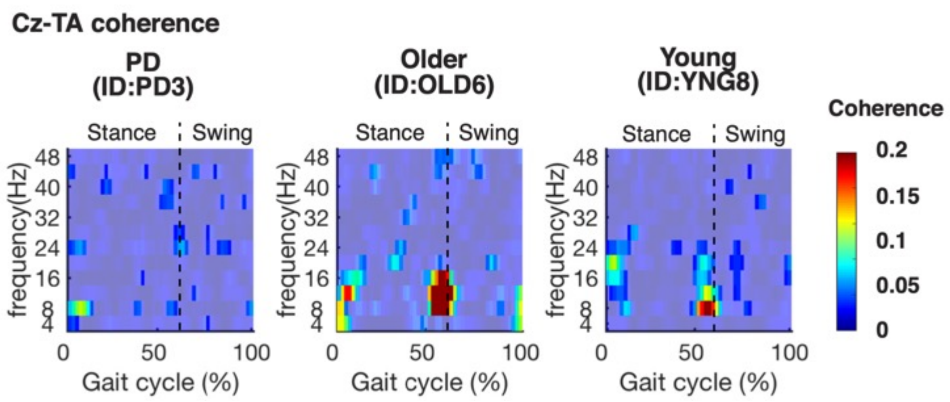
Gait-related time-frequency modulations in Parkinson's disease

Reduced cortical ERD & ERS



20-50 Hz

Reduced cortico-spinal coherence with Tibialis anterior muscle



Weersink et al. (2021) *Parkinsonism & Related Disorders*

Yokoyama et al. (2020) *J Neurophysiology*

The “Anti-kinetic” role of beta oscillations

- Beta power decreases before and during movement
  (Many studies)
- Presence of beta oscillations leads to slower or impaired movements
  (e.g., PD literature + Gilbertson et al. 2005; Chen et al. 2007; Zhang et al. 2009; Matsuya et al. 2013)
- Beta power can be up-regulated to resist upcoming perturbations
  (Gilbertson et al. 2005; Androulidakis et al. 2007; van Wijk et al. 2009)
- Deep brain stimulation at 20Hz slows movements
  (Chen et al. 2011)

- Movement-related rebound depends on afferent information
  (Cassim et al. 2001)
- Cortico-spinal coherence depends on both efferent and afferent information
  (Riddle & Baker, 2005)

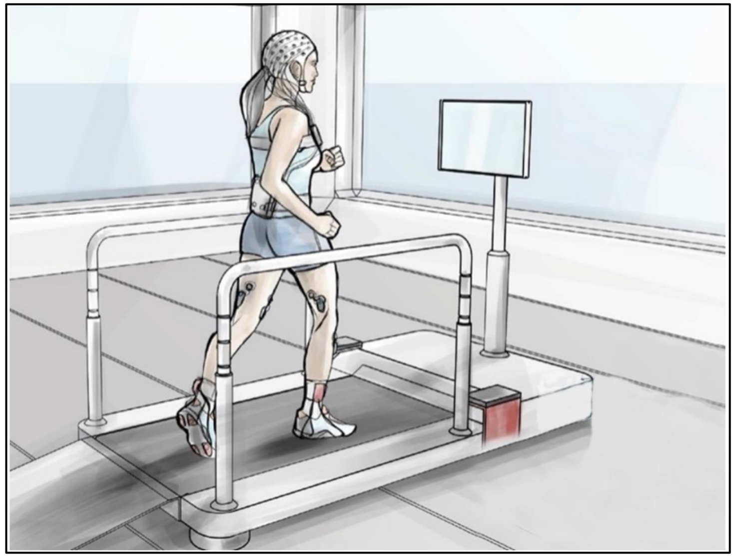
StepUp

? Reduced cortical ERD / ERS in Parkinson's patients?

? Reduced corticospinal coherence in Parkinson's patients?

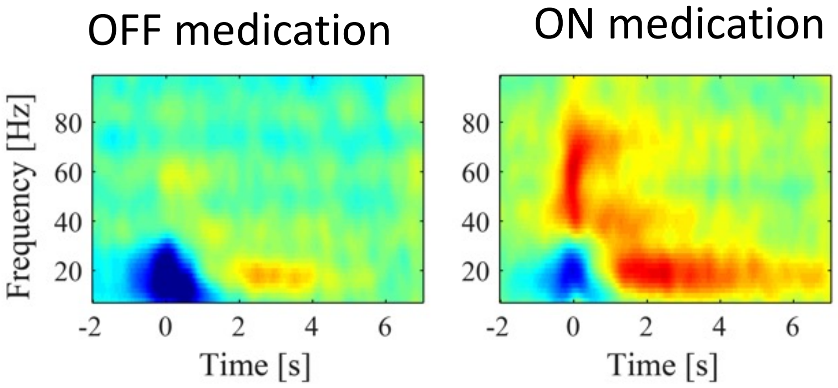
? (Partially) restored after training?

? Correlation cortical activity and gait parameters?

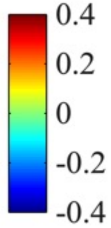


Movement-related oscillations in the subthalamic nucleus

Hand movement

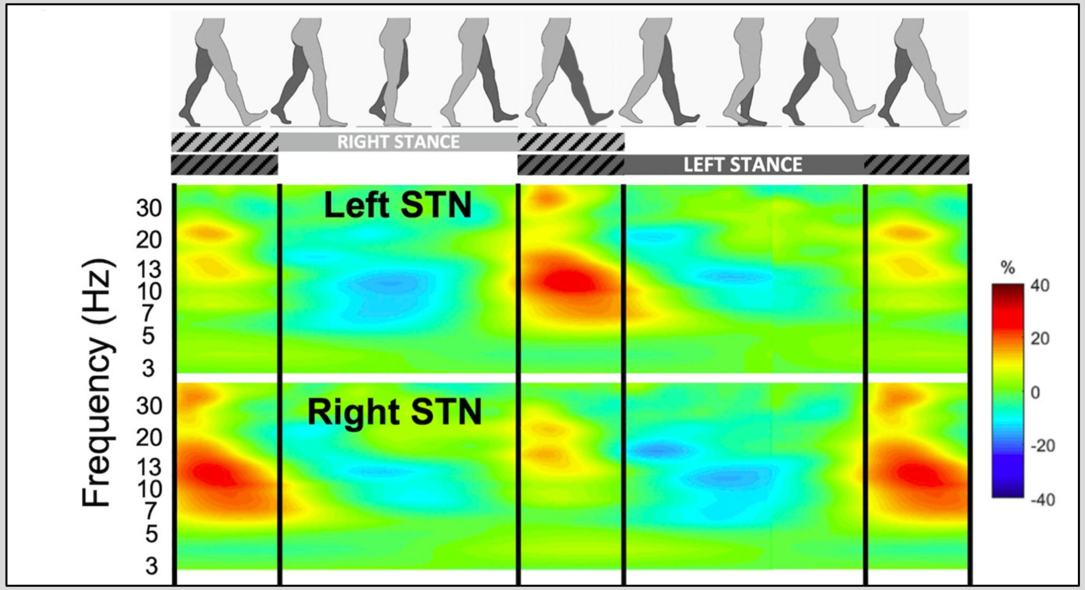


Change in Power relative to baseline [-4 to -2s]



Litvak et al. (2012) *J Neurosci*

Gait



Wang & Choi (2020) *Frontiers*
after Hell et al. (2018) *Neuroimage: Clinical*

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