qEEG of NREM sleep in recovery of consciousness in traumatic brain injury: A longitudinal study.

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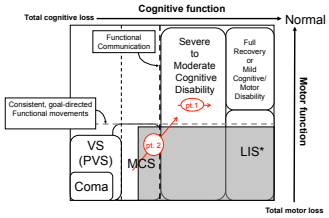
Introduction

- Transitions from wakefulness to sleep in humans are accompanied by dramatic changes in the electroencephalogram (EEG).
- The study of brain-injured patients often employs a qualitative EEG approach to assessing sleep-related processes.
- Here, we employed quantitative EEG (qEEG) methods to identify potential biomarkers of sleep recovery after brain injury; specifically, power spectra and coherence analyses.



EEG Methods

Patients

Pt 1 - TBI; severe closed head injury
1st visit - 20 yrs post-injury
2nd visit - 18 months after 1st visit

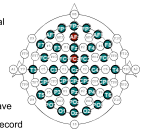
Neurological Improvements
•Some functional recovery of left upper extremity
Behavioral Improvements
•Increase in baseline arousal level
•Improvement in attentional focus/response persistence
•Improvement in speech (more intelligible; no paraphasic or dysnomic errors; no errors in confrontation naming)

Pt 2 - Hypoxic ischemic encephalopathy; fat emboli
1st visit – 1 yr post-injury
2nd visit – 7 months later
3rd visit – 1 yr after 2nd visit

Neurological Improvements
•Improved motor control
Behavioral Improvements
•Consistent, fluent verbal communication
•Emotional reactivity
•Spontaneous humor

Recording

- 32+ hrs of recording with video
- Augmented longitudinal bipolar recording montage (International 10/10 system)
- 200 or 256 Hz sampling rate
- XLTEK data acquisition system (XLTEK, Ontario, CN LH65S1)



electrode placements

AFz = ground
FCz = reference

Analysis

Segments of artifact-free, slow wave sleep (SWS) were selected from consecutive nights of each EEG record based on visual review and video.

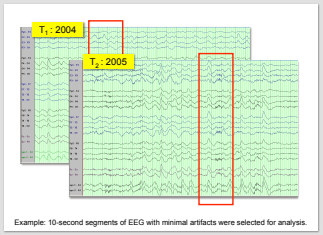
Power spectra (bandwidth 1Hz, with confidence limits) and coherence were estimated using multi-taper methods, implemented in MATLAB with Chronux toolbox

Patient 1

DTI: reduced L-R connectivity*

MRI: enlarged ventricles

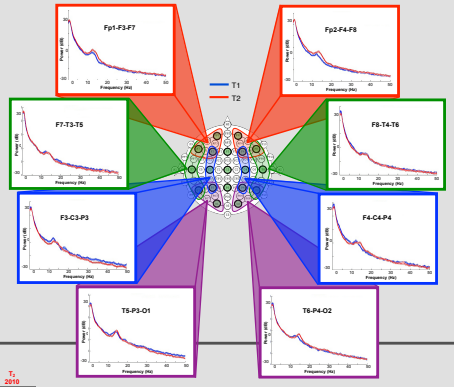
Background
- 40 yr old male
- TBI at age 19 due to MVA in 1984
- Coma for 6 weeks → brief period in VS →19 yrs in MCS
- T_1 = 2004; T_2 = 2005



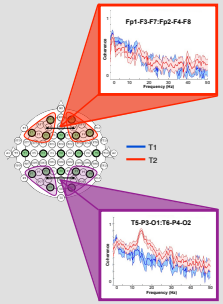
Example: 10-second segments of EEG with minimal artifacts were selected for analysis.

*Voss, H.U., et al., (2006) Possible axonal regrowth in late recovery from the minimally conscious state. J Clinical Investigation 16: 2005-2011

Spectra in the Sleep State



Coherence

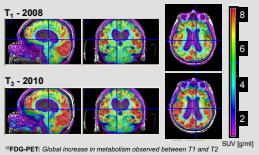


Summary

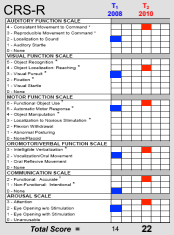
- Visual inspection of the EEG record revealed an increase in spindle activity present in the second visit compared with the first during NREM sleep.
- Comparison of spectra between the two visits reflected an increase in amplitude and shift towards a higher frequency in the 10-13 Hz range.
- The most dramatic difference between the two visits was an observed increase in inter-hemispheric coherence across the temporal-occipitoparietal regions; specifically in the beta band around 14 Hz (corresponding to typical spindling frequencies.
- There were no significant differences in intra-hemispheric coherence at 14 Hz.

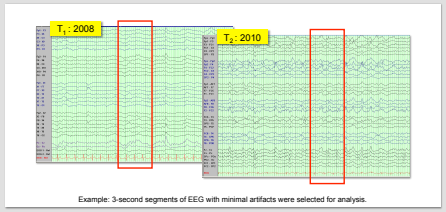
Patient 2

Background
- 58 yr old woman
- Diffuse encephalopathy following fat emboli in 2007
- Baseline exam at one year after injury: eyes open, consistent visual tracking



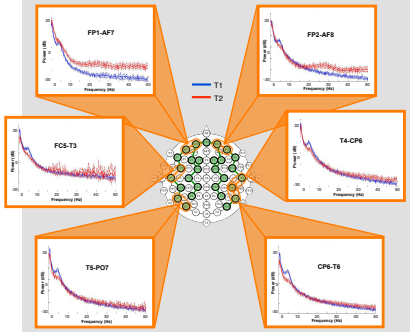
*FDG-PET: Global increase in metabolism observed between T1 and T2



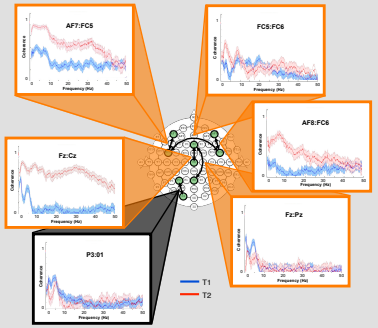


Example: 3-second segments of EEG with minimal artifacts were selected for analysis.

Spectra in the Sleep State



Coherence



Summary

- Visual inspection of the EEG record shows primarily stage 2 sleep at the 1st visit, whereas a combination of sleep stages 2 and 3 are seen at the 2nd visit. An increase in low-frequency power in some channels recorded at the 2nd visit may reflect this shift towards more typical stage 3 SWS.
- Comparison of spectra between the two visits shows a prominent peak in spectral power around 4-6 Hz across all channels in T1 that is not present in the spectra from T2.
- At visit 1, *intra*-hemispheric coherence shows a peak around 4-6 Hz. *Inter*-hemispheric coherence of long-range frontal pairs (FC5:FC6) shows a dip in the same range. Together, these suggest the presence of independent oscillators in the two hemispheres.

Conclusions

- Both patients show significant longitudinal changes in power spectra and coherence associated with behavioral recovery and metabolic change.
- Atypical sleep profiles were observed, namely the intermittent disruption of SWS delta waves by sleep spindles (Pt 1) and the global presence of aberrant low-frequency oscillations (Pt 2).
- An increase in sleep spindling has been proposed as a biomarker for functional recovery from stroke, in that it is highly correlated with sleep efficiency, improved learning and memory, and brain plasticity (Gottselig et al., 2002). In Pt 1, we see increased spindle frequencies and a marked increased in *inter*-hemispheric coherence at the spindle frequency at ~14 Hz, suggestive of a similar recovery process. These findings may also be linked to evidence of structural reorganization seen via DTI (Voss et al., 2006).
- Independent, highly coherent low-frequency oscillations dominate the sleep record in 1st visit for Pt 2. The disappearance of these oscillations at the 2nd visit may be correlated with neurological and behavioral improvements and global increases in cerebral metabolism measured by ^{18}FDG-PET.
- In both patients, the EEG became more typical of SWS from visit 1 to visit 2, mirroring the neurological and behavioral improvements clinically observed.
- Combined qEEG assessment of sleep, MRI and neurobehavioral assessments may be used to gauge functional recovery in TBI patients.

Acknowledgments

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