Hierarchical decomposition (HD) of resting-state EEG in recovery following severe brain injury identifies causal influence of high frequency activity (beta band) over anterior forebrain

Mary M. Conte, Jonathan D. Drover, Jonathan D. Victor, Nicholas D. Schiff

Department of Neurology and Neuroscience, Weill Cornell Medical College, NY

553.17
SFN2012

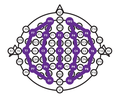
mmconte@med.cornell.edu

Motivation

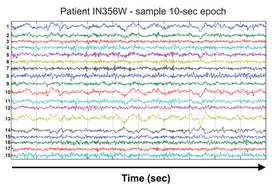
The normal background electroencephalogram (EEG) typically shows a dominance of high frequency (15-35Hz, 'beta band') activity over the anterior forebrain (frontal/prefrontal cortices) in the awake state. Restoration of this high-frequency power as characterized in the power spectrum (PS) of the EEG is a common finding among patients who show recovery after a severe brain injury across a wide range of etiologies and patterns of structural injury (Conte et al., 2010, Williams et al., 2009). This activity has been suggested as a general marker for the recovery process and likely reflects changes in overall cerebral background activity and the afferent input to neocortical neurons within the anterior forebrain mesocircuit (Schiff 2010). To examine the possible causal role of recovered high-frequency activity over anterior forebrain structures, we applied hierarchical decomposition analysis (HD) of the EEG (Repucci et al., 2001) to EEG data obtained from a single patient subject studied longitudinally over an 18 month period and 6 normal subjects. In contrast to principal component or independent component analysis, HD seeks to identify EEG components that drive others. HD components are linear recombinations of the original EEG signal for which an autoregressive model demonstrates a simple causal structure.

Methods

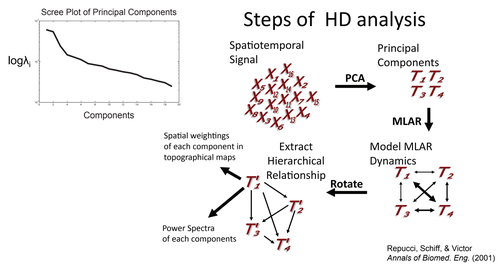
Data Acquisition



10-20 Bipolar montage
Digitization at 200 - 1024 Hz
Bandpass filtering, 1 - 55 Hz
Selection of 30 artifact-free epochs, 10 sec each from eyes-open, awake state



For Patient IN356W, continuous CCTV EEG was recorded during separate 5- and 6-day inpatient visits over an 18 month period.



Hierarchical Decomposition

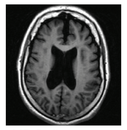
Projection into first 5 principal components
Downsampling to 100 – 128 Hz
Lags selected by Akaike Information Criterion (AIC)

Spectral Analysis

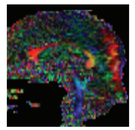
Multitaper method; 19 tapers
carried out in MATLAB with Chronux Toolbox

Patient IN356W

The patient subject (40 yr. old male) demonstrated a spontaneous recovery of consciousness 19 years after sustaining a severe traumatic brain injury.



MR findings: enlarged ventricles



DTI findings: reduced L-R connectivity

Between evaluations, functional & behavioral improvements were documented including:

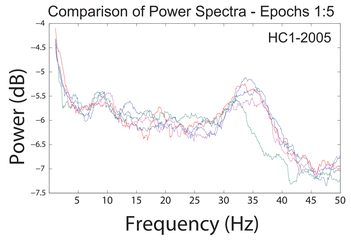
Neurological: Some functional recovery of left upper extremity motor function

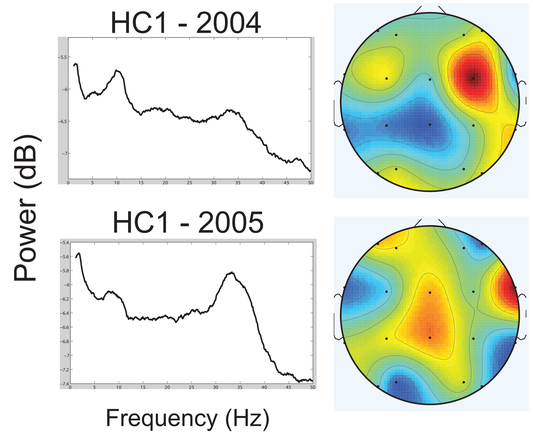
Behavioral: Increase in baseline arousal level
Improvement in attentional focus/response persistence
Improved speech; more intelligible
no paraphasic or dysnomic errors
no errors in confrontation naming

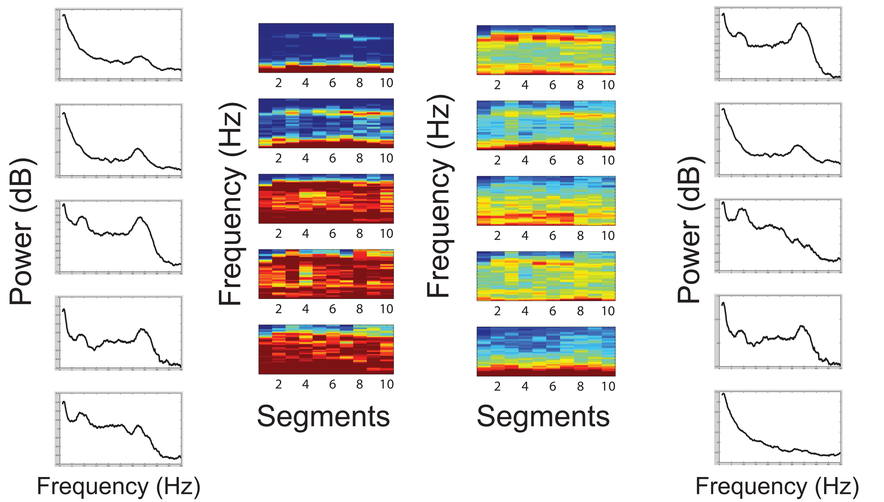
Corresponding evidence of structural and metabolic change (Voss et al., 2006) and prominent increases in ~15-35 Hz power over the anterior forebrain (Conte et al., 2010) were observed.

Results - Patient IN356W

- HD of the resting awake EEG in 2004 & 2005 shows a strong similarity in the power spectra.
- Increased beta power in HC1 in 2005 correlates with increased beta power over R frontal cortex as measured in individual EEG leads (Conte et al., 2010).
- Consistent spatial weightings of the 1st HC suggests the interaction of R frontal activity with a midline source.

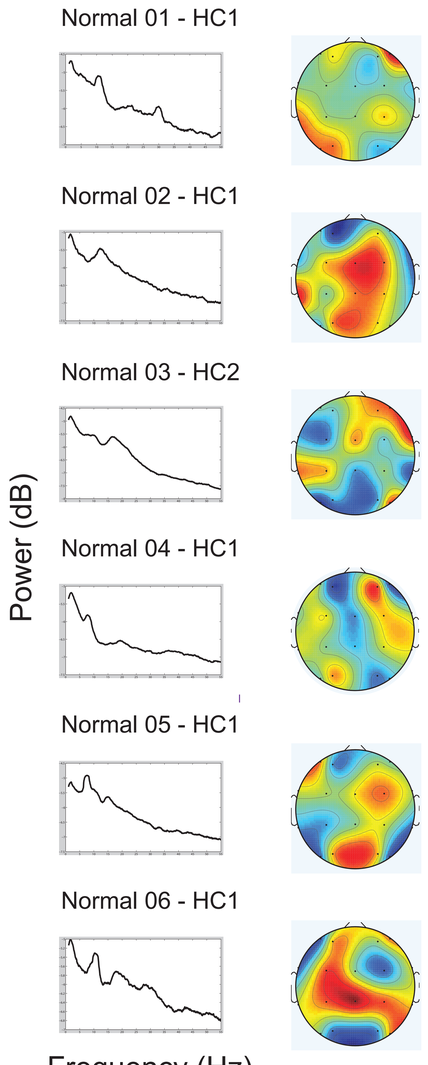






Results - Normal Subjects

Hierarchical Components (HC1 or HC2) at the causal end of the hierarchy for all normal subjects



Summary and Conclusions

- Hierarchical decomposition analysis of both normal subject and patient EEG records reveals a consistent finding of a component with strong alpha (~8-11Hz) and beta (~15-35Hz) peak in the power spectrum that is at or near the origin (causal side) of the hierarchy resolved by this analysis method.
- The analysis highlights the distinction between decompositions based on accounting for variance, and decompositions based on identifying causal relationships.
- An apparent similarity in the spatial weighting of the first (or second) hierarchical components for all subjects suggests a common biological generator, possibly related to the default mode network. Further characterization using source localization methods is necessary to test this possibility.
- Collectively, these findings suggest the utility of HD analysis to resolve global EEG dynamics and further development of the technique's use in the study of recovery of brain function following severe injuries (see Drover et.al., SFN2012, 553.15)

References

Conte, MM, Williams, ST, Goldfine, AM, Voss, HU, Victor, JD, and Schiff, ND. (2010) Longitudinal changes in the EEG spectrum during recovery after severe brain injury. Society for Neuroscience 40th Annual Meeting. Abstract 659.8.

Repucci, M.A., Schiff, N.D., and Victor, J.D. (2001) General strategy for hierarchical decomposition of multivariate time series: implications for temporal lobe seizures. Annals of Biomedical Engineering 29(12):1135-49.

Schiff, ND. (2010) Recovery of consciousness after brain injury: a mesocircuit hypothesis. Trends in Neuroscience 33(1):1-9.

Williams, ST, Conte, MM, Kobylarz, EJ, Hersh, JE, Victor, and Schiff, ND. (2009) Quantitative neurophysiologic characterization of a paradoxical response to zolpidem in a severely brain-injured human subject. Society for Neuroscience 39th Annual Meeting. Abstract 541.6.

Voss HU, Ulug AM, Dyke JP, Watts R, Kobylarz EJ, McCandliss BD, Heier LA, Beattie BJ, Hamacher KA, Vallabhajosula S, Goldsmith SJ, Ballon D, Giacino JT, and Schiff N.D. (2006) Possible axonal regrowth in late recovery from minimally conscious state. Journal of Clinical Investigation 116: 2005-2011.

Supported by:

NIH RO1 HD051912
The Charles A. Dana Foundation
The James S. McDonnell Foundation