Brain dynamics at rest following concussion in adolescent athletes: changes in spectral power and functional connectivity

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Legend
Concussed
Control

BACKGROUND

Concussions are a common injury that often have long term impacts on cognitive health. Exactly what short and long term effects they have on cognitive processes is still not entirely known. Quantifying structural and functional changes in the brain is an important, active area of research. If significant and reproducible effects can be found it will increase our understanding of concussions and may be a first step towards developing objective diagnostic tools. We investigate the power spectrum, phase locking measures and functional connectivity of resting state EEG signals in order to identify any differences between the brain dynamics of healthy controls and concussed patients.

GENERAL METHODS

Five minutes of resting state EEG time-series data was collected from 27 concussed patients and 33 control (healthy) adolescents with 64 channel EEGs. All participants had subacute concussion and were tested in under 3 months since their concussion. This data was interpolated to 27 channels, which are more representative of signal source locations. Data was cleaned through an automatic cleaning algorithm and three separate analyses were conducted:

i) Power Spectrum Density
ii) Graph Theory
iii) Phase Locking Value

Figure 2: EGI EEG caps used

POWER SPECTRUM DENSITY

The power spectrum looks at the strength of a signal at each distinct frequency. For our analysis we divided the power spectrum into five distinct bands (measured in Hz): Delta (2-4), Theta(4-8),Alpha(8-12), Beta-Low(12-20), Beta-High(21-30) and Gamma (30-50).
The signals were filtered to remove noise, then the power was computed for each subject in each of the frequency bands.
The power spectrum was obtained at each of the 27 channels . It was averaged over all the channels to get one measure of mean power for each subject within each frequency band.

A mixed linear model was fit by regressing power onto concussion status , frequency band, and the interaction between these variables. The null hypothesis of no interaction was strongly rejected. The beta bands (high and low) were most significantly different with power significantly lower for concussed than control.

Results: The power spectrum analysis showed that the relationship between power and frequency band was influenced by concussion status

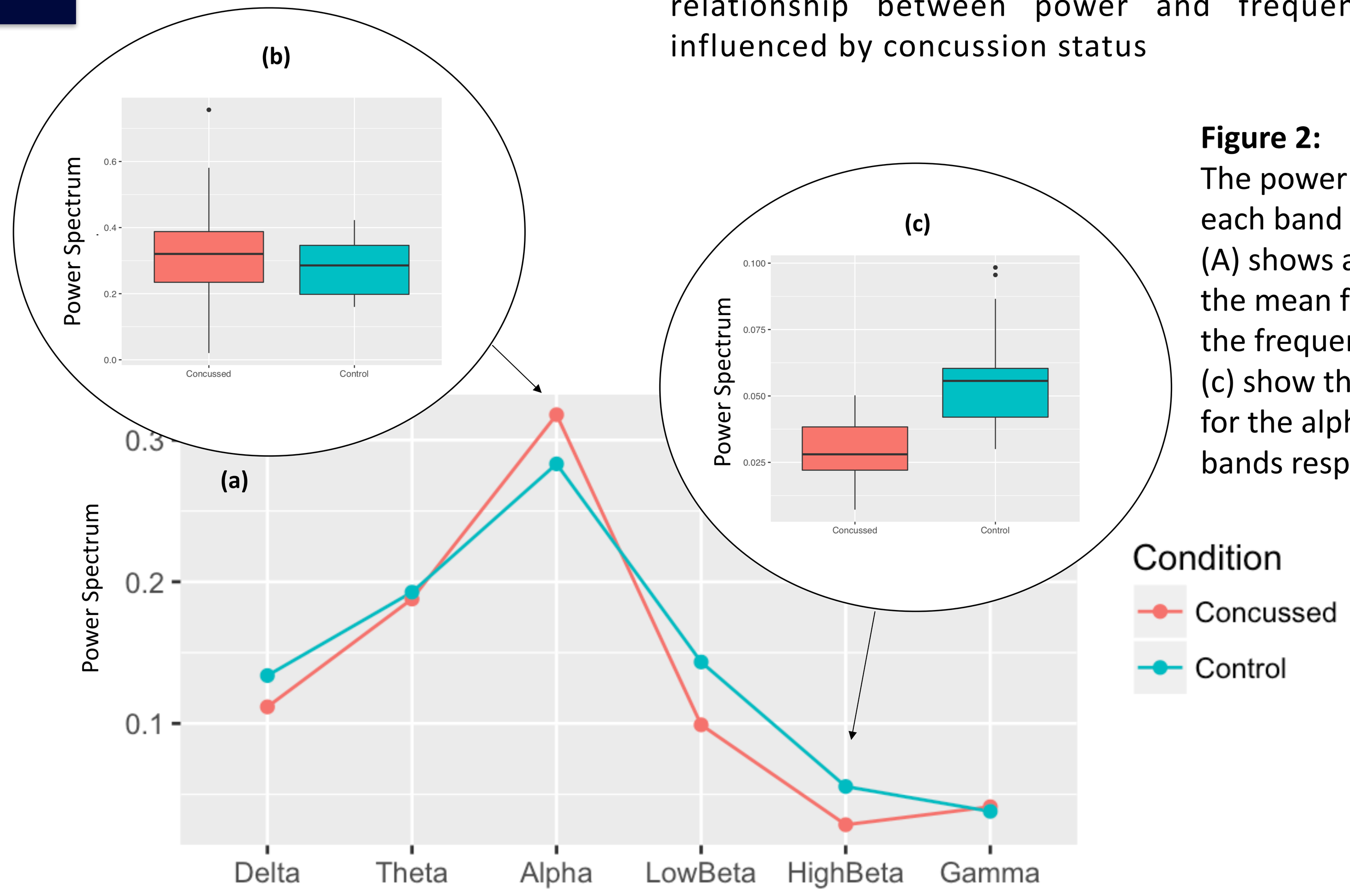

Figure 2:
The power for each subject in each band has been plotted. (A) shows a line graph with the mean frequencies across the frequency bands. (b) and (c) show the power spectrum for the alpha and high beta bands respectively.

GRAPH THEORY

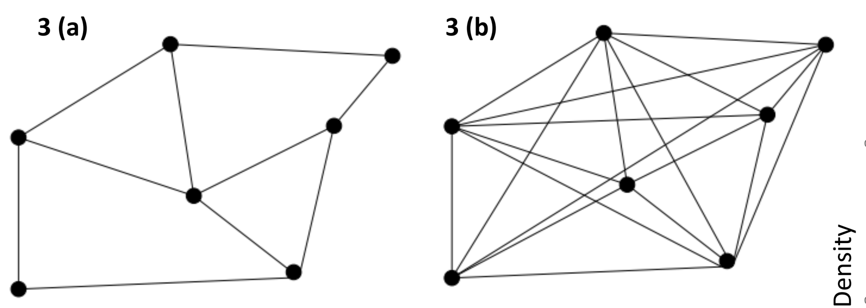

Figure 3: 3 (a), above, shows a graph with low global density and 3 (b) shows a graph with high density

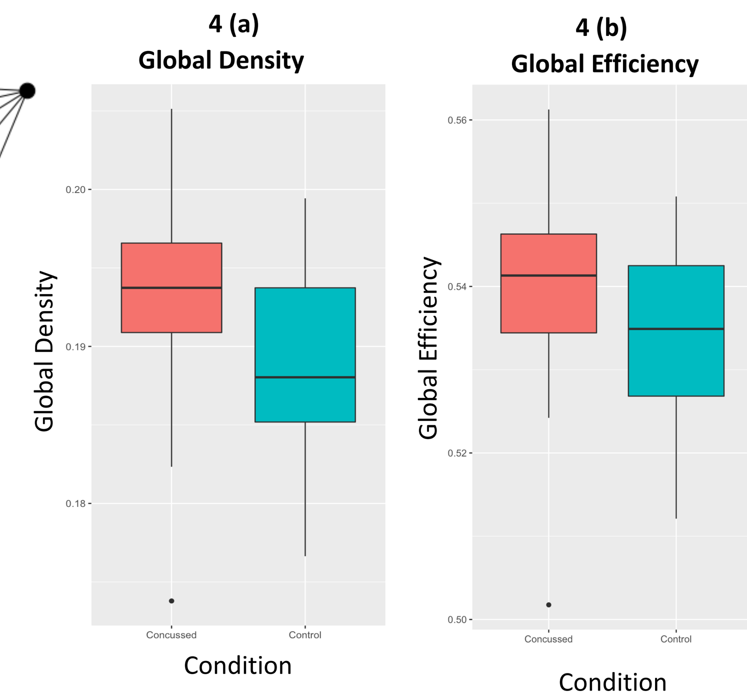

Figure 4: 4 (a), above, shows a bar graph with global density for concussed vs. control participants . 4 (b) shows global efficiency for concussed vs. control.

Graph Theory Background:
A graph is a series of nodes connected by edges. Graph theory models can hence be used to quantify the properties of nodal networks. This graph theoretic approach provides a way of describing changes in brain network organization following a concussion.

For our network analysis:
We considered each of the 27 interpolated channels as nodes. For each subject, a network was constructed using a PC FDR algorithm. Global measures for density, efficiency and modularity and clustering coefficient were computed. These measures deal with how efficiently information can travel between nodes throughout the network. channel-wise between groups as well. Local measures look at how integral a specific node is to the network.
Global and local measures were compared between groups for several different metrics. Wilcoxon rank sum was used to determine significance, and the results were controlled for multiple testing.

Results: At a global scale, the density and efficiency were both significantly higher for concussed individuals relative to controls. This means that there are a higher number of edges connected to each node. There were several local graph theory metrics that were different for concussed relative to controls, but changes were seen most often in the frontal regions. Figure 5 shows an example of degree in the Fz channel: concussed have significantly higher degree than controls.

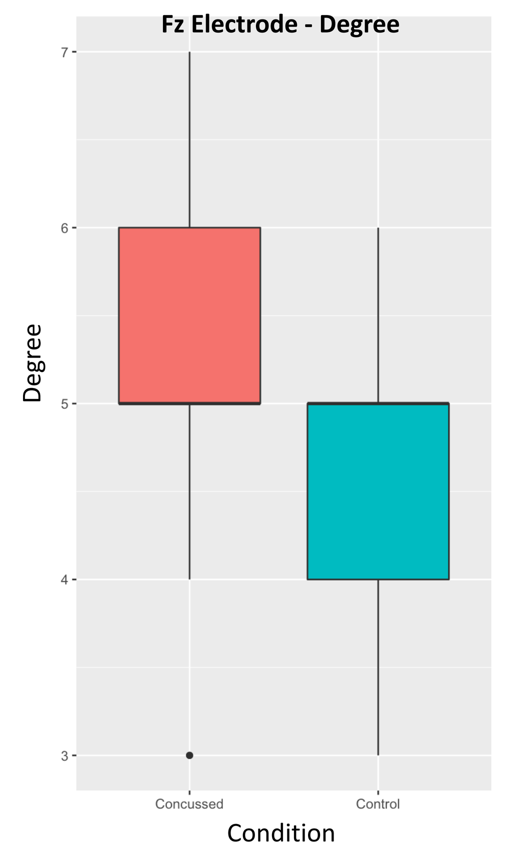

Figure 5: The local (Fz) degree is significantly higher for concussed than controls.

PHASE LOCKING VALUE

Connectivity within the brain was measured via phase synchronization of EEG signals.
The following method was employed:

- First the analytic signal of the EEG data is computed.
- The instantaneous phase of the analytic signal is calculated for each time point.

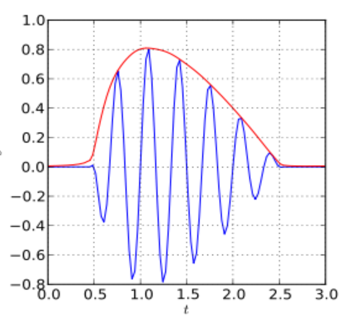

Figure 6: Transformation of our signal: Blue-original signal Red-analytic signal

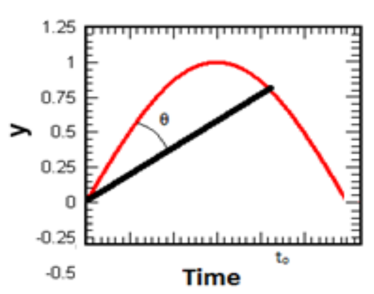

Figure 7: θ-the instantaneous phase of the signal at time t_0

- The relative phase (for each time point) of any two channels is the difference of their instantaneous phases.
- The relative phase is an angle and can be projected onto the unit circle.
  If two channels are not synchronized then their relative phase should be randomly and uniformly distributed about this circle.
- Our quantifier of connectivity, called the phase locking value (PLV), between two channels is derived from the distribution of the relative phase.

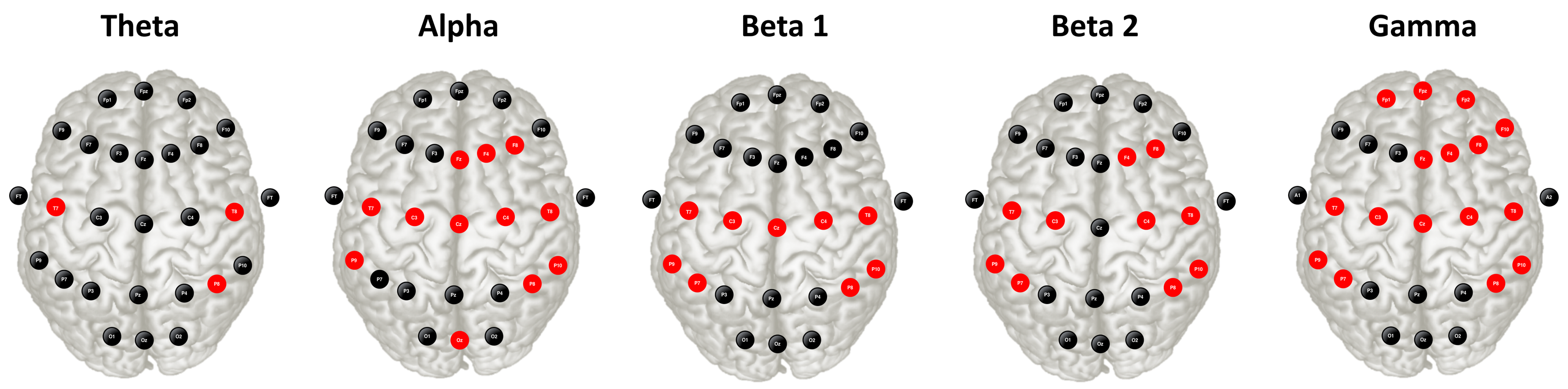

Figure 8: PLV of concussed relative to controls. The values that were significantly higher ($p<0.05$) for concussed relative to controls, after controlling for multiple testing, are shown in red. There were no channels in which concussed had significantly lower PLVs than controls.

Datasets were first separated into different frequency bands. After cleaning and filtering, PLVs were computed pairwise between all channels for each subject. The mean PLV for each channel was computed to get a value of overall connectivity for each. A group comparison of mean PLV was computed using a Wilcoxon rank non-parametric test. After adjusting for multiple testing, several channels were significantly different between concussed and controls (see Figure 8).

Results: Investigation of phase synchronization between EEG channels shows that there was increased connectivity in concussed patients. Changes are evident in frontal to central to occipital channels and effects are more pronounced in the alpha to gamma bands.

SUMMARY

Adolescents show increased brain connectivity overall. Frontal and occipital regions are particularly affected. Changes in brain organization can be seen even 3 months post injury.

- Power Spectrum Density: The relationship between power and frequency band is affected by concussion
- Graph Theory: measures show increased brain connectivity, and find significant network changes in the frontal regions following concussion.
- Phase Locking Value: PLVs are significantly higher for concussed than controls in all frequency bands, across multiple channels.

REFERENCES AND ACKNOWLEDGEMENTS

Quraan MA, McCormick C, Cohn M, Valiante TA, McAndrews MP (2013) Altered Resting State Brain Dynamics in Temporal Lobe Epilepsy Can Be Observed in Spectral Power, Functional Connectivity and Graph Theory Metrics. PLoS ONE 8(7): e68609. doi:10.1371/journal.pone.0068609