INTRODUCTION
Like many complex dynamic systems, the brain has been shown to exhibit scale-free dynamics that follow power-law scaling. Broad-band power spectral density of ECoG exhibits power-law scaling in the range of approximately 1-100 Hz with a log frequency exponent close to -2\textsuperscript{1, 2}. Further, this scaling is state-dependent, being much lower during slow wave sleep (SWS) than in wake\textsuperscript{3}. Thus, we hypothesize that the shift in global neural dynamics represented by this shift in slope of the log-frequency exponent is predictive of global neural state changes. We report the development of a suite of tools designed to allow us to validate the ability of this measure to accurately and reliably predict neural state differences represented by wake, stage 2 and stage 3 (slow wave sleep, SWS) sleep.

METHODS
Subjects.
Following informed consent under a protocol approved by the Institutional Review Board of Washington University, eight pediatric subjects (4-18 years, 3m/5f) undergoing invasive monitoring for the surgical treatment of intractable epilepsy provided awake and asleep data across 1-7 days, uncontrolled for behavior. Data were collected using a research EEG amplifier (2 subjects, 64 sensors, Synamps\textsuperscript{2}a, Compumedics Neuroscan, 1kHz, DC-200 Hz) or the clinical amplifier for long term and broader coverage (6 subjects, 72-116 sensors, Pro Amp, LaMmont Medical, 500 Hz, 0.1-200 Hz).

Preprocessing.
Bad channels and artifact-filled time periods were identified and removed from further processing. Five minute continuous segments were identified using standard criteria\textsuperscript{4} for wake, N2, N3 (deep slow wave sleep: SWS) and REM sleep episodes and by time stamp for periods of task performance (2 subjects). Data were then partitioned into uniform 10-30 second intervals.

Sensor Arrays.
Arrays varied in their placement, number and configuration, with two subjects additionally implanted with depth electrodes. Depth electrode and strip data were excluded from these analyses, which focus on sensor grids. Grid arrays consisted of 20-64 sensors in three configurations, shown above right. Electrode data were segmented from CT and co-registered onto MRI volume rendering of the brain for each subject (Bix, Subject 2 shown).

Sleep Staging.
Representative short segments of data collected during wake and three stages of sleep, 10 second segments are shown (cyan, Subject 6). Epileptiform interictal slowing accounts for some similarity between N2 and REM, confounding discrimination of stages.

RESULTS
Maximum likelihood state discrimination (MLSD) was used to find those frequencies that maximally discriminated between a wake and SWS with no a priori assumptions as to the band limits most likely to meet criteria. Our task was complex as our sensors detected different EEG features above. In the space shown above, 100 Hz was used to compute the log frequency range between f1 and f2 as indicated in the Table (bottom).

MLSD
Unlike Gaussian models for frequency occurrence of slopes, a Maximum Likelihood State Discriminator (MLSD) with threshold slope s* (See Table) is readily calculated. The probability of correct state classification is illustrated in the MLSD figures. The horizontal lines extend over the frequency ranges used to calculate PSDs and the slopes of PSDs. Note that the maximally discriminative frequency ranges VARY from subject to subject.

CONCLUSIONS
An initial step toward methods validation indicates that we can correctly classify neural state as wake, N2 or SWS sleep based on the global dynamics of the system as assessed by the log spectral density exponent. Unlike the MLSD technique, state discriminations are based on a set of frequency bands that is data driven rather than assumed. This data-driven approach indicates that discrimination is strongly subject-specific. It is highly likely that, however strong the discrimination is in specifically chosen states, discrimination on a single measure when accomplished on continuous data will require that more factors be included. Future work will examine this hypothesis.

REFERENCES

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[1038]