Exploring the Impact of EEG Data Signal Fluctuations Based on the Time of Day

Jason Jones, Computer Science and Data Science School of Science
Mentor: Dr. Mohammad Husain
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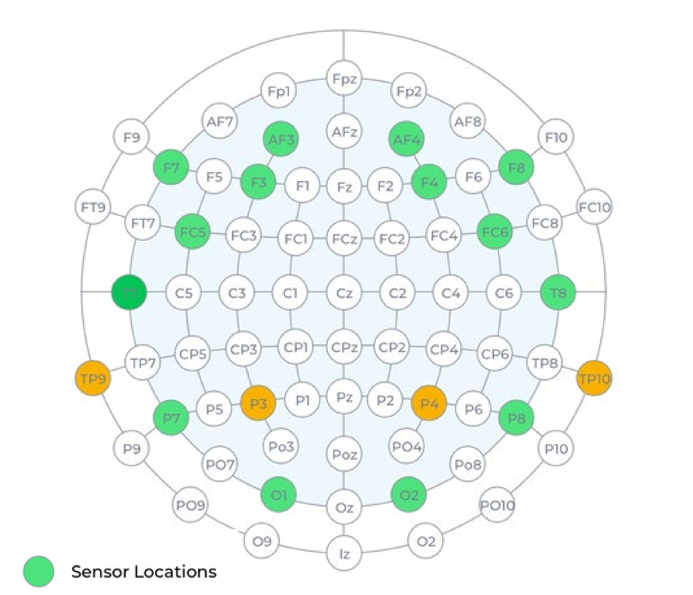
Abstract
This exploration delves into the intricate dynamics of the human brain by analyzing EEG data to examine the fluctuations band powers at different times of the day—specifically morning, midday, and night. The central objective is to elucidate the connections between our circadian rhythms—the internal processes that regulate the sleep-wake cycle—and neuronal activity. The aim is to highlight the existence of time dependent fluctuations in EEG signal data. In doing so we can ensure that the time dependent fluctuations can be taken into consideration when conducting further studies. By leveraging the advanced sensing capabilities of the Emotiv EPOC X devices, the study captures the ebb and flow of brain activity that may correspond to the natural rhythms dictated by the time of day. Employing rigorous statistical methodologies that provides a comparative analysis of the mean band powers. These statistical tools pave the way for identifying not just variations, but statistically significant differences that could suggest deeper biological underpinnings.

Methodology
Data Acquisition
Utilizing the Emotiv EPOC X, a sophisticated EEG device, brainwave data was systematically captured from a single participant during three sessions mapped to distinct circadian stages: morning, midday, and night, lasting from 50 minutes up to 1.5 hours. This approach was meticulously designed to compile a dataset representative of the full spectrum of daily physiological rhythms.

EEG Sensor Placement and Naming

The electrode placement adhered to the international 10-20 system, a universally accepted method to describe and apply the location of scalp electrodes in the context of an EEG test. Sensors on the left side of the scalp are designated with odd numbers, while those on the right carry even numbers. 10/20 system fig 01



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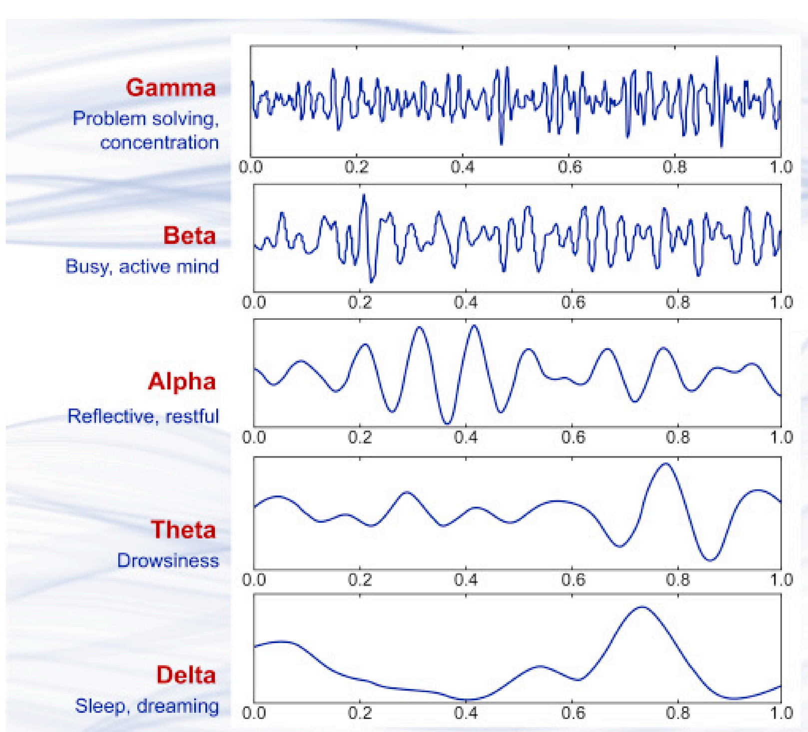


(02)

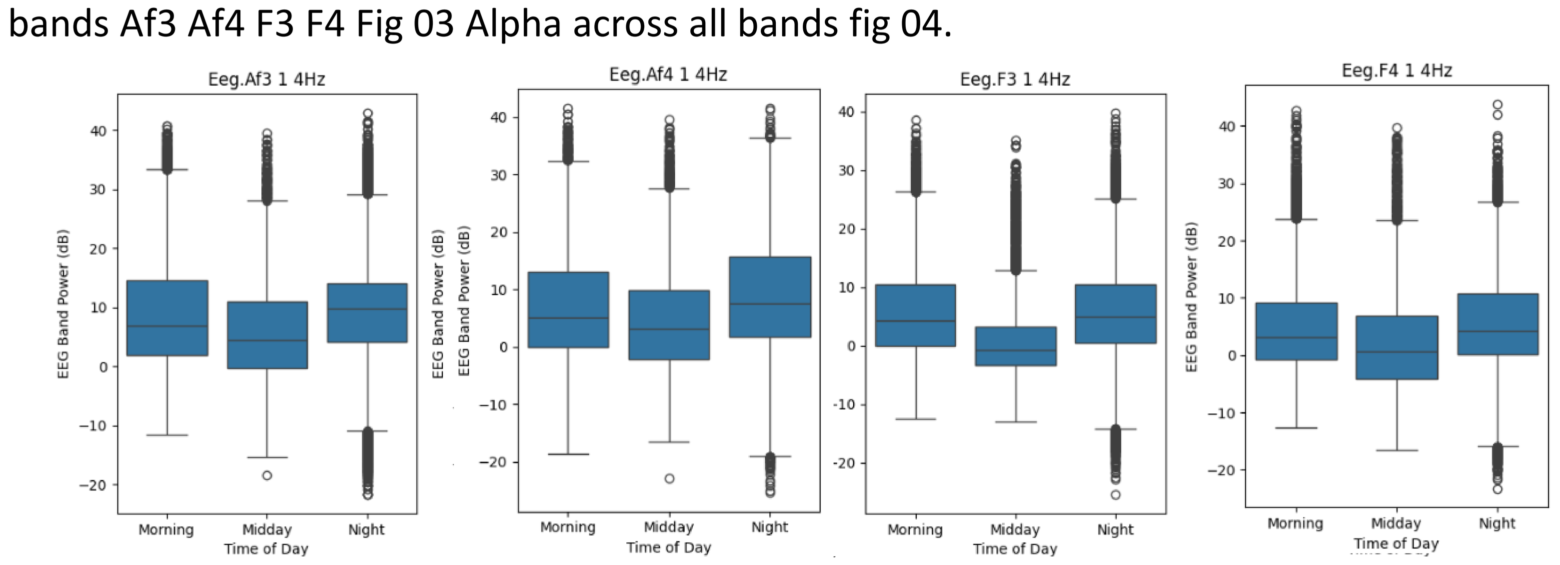
EEG Bands Analyzed
Delta Band: 1-4 Hz, associated with deep sleep
Theta Band: 4-8 Hz, linked to drowsiness and early stages of sleep
Alpha Band: 8-12 Hz, present in wakeful relaxation with closed eyes
Beta Band: 12-30 Hz, dominant during alert, attentive states
Gamma Band: 30-40 Hz, related to higher mental activity and consolidation of information

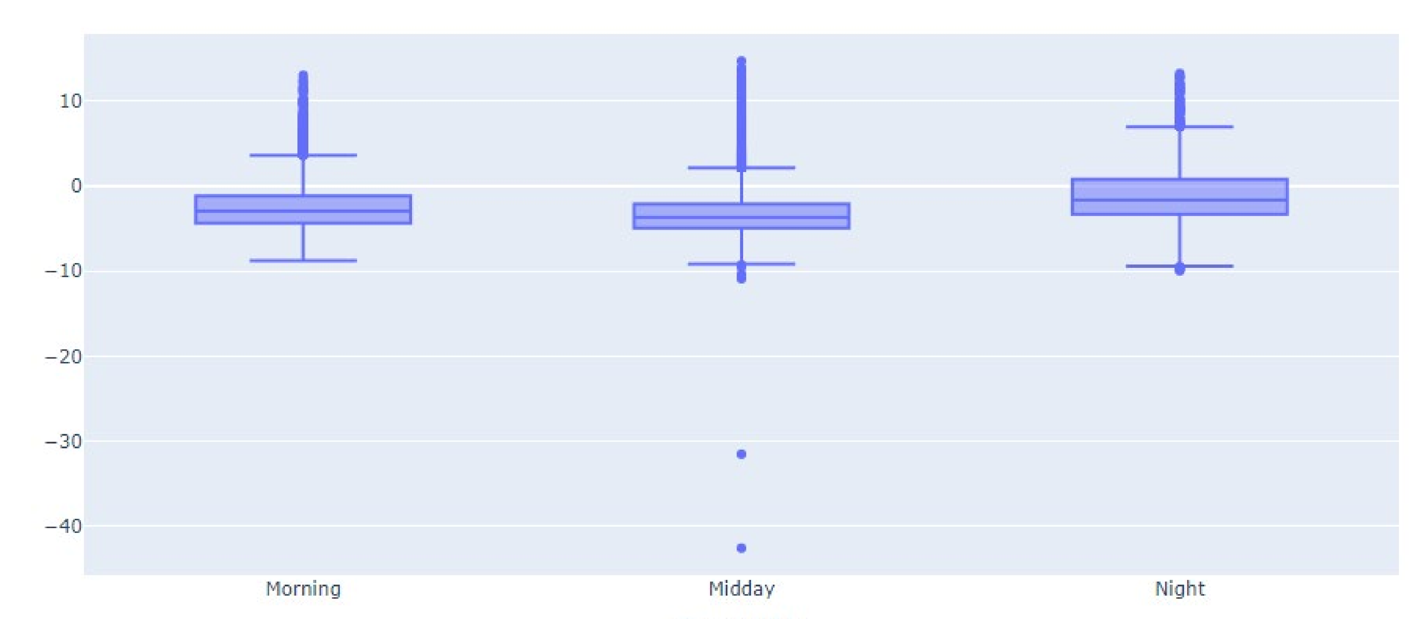
In the above, the 10-20 system is highlighted as a foundational element of EEG data collection, emphasizing the standardized approach to capturing brainwave data. This ensures the scientific rigor and reproducibility of the EEG methodology. Brain Sample Waveforms fig 02

Data Preprocessing
To ensure the reliability of EEG data, our preprocessing employs both hardware and software strategies in active and passive electrode processing, enhancing signal quality. This involves amplification to boost signal strength for clearer analysis and low-pass filtering to remove high-frequency noise, such as electromagnetic interference from the environment. Hardware filtering techniques ensure that only relevant brain signals are analyzed. The high-pass filter (HPF), set at 0.5Hz, excludes signal components moving slower than half a cycle per second, such as gradual changes in sensor contact. The slew rate limit further ensures data accuracy by restricting the maximum allowable change between consecutive data points to 30 µV, preventing abrupt, non-physiological spikes from influencing the data. A 256-sample window Fourier transformation translates the EEG data from the time domain, where it shows voltage changes over time, into the frequency domain, revealing the presence and strength of different brainwave frequencies. The sliding window technique overlaps consecutive data windows by 64 samples to ensure continuity and stability in the frequency domain data. This method aids in capturing transient brain activities more accurately. Advanced algorithms, including machine learning and deep neural networks, are utilized to distinguish true brainwave signals from artifacts—unwanted variances caused by physical movements or eye blinks. These algorithms learn from the data to predict and eliminate such distortions without losing valuable information. Finally, the power within specific EEG frequency bands is calculated, quantifying the intensity of different types of brain activity. These values are typically expressed in microvolts squared per hertz (µV^2/Hz) and are sometimes converted to decibels (dB) for easier comparison.

Statistical Analysis
ANOVA Testing: The ANOVA test was used to compare the mean band powers for each brainwave band across the times of day. The F-value indicated the overall differences between the means, while the P-value showed the likelihood of observing these differences by chance.

Tukey HSD Post-hoc Analysis: This test identified specific pairs of times that had significantly different mean band powers. For example, if the morning mean alpha power was significantly lower than the midday and night, it indicated lower alpha activity in the morning. Individual bands Af3 Af4 F3 F4 Fig 03 Alpha across all bands fig 04.





Preliminary Results
These findings are used to explore the relationship between brainwave activity and time of day, potentially contributing to studies on circadian rhythms and their impact on brain function. Preliminary findings suggest significant variations in certain EEG bands at different times of day. The data indicates that brain activity, as reflected through EEG band powers, varies significantly throughout the day. The differences can be attributed to various physiological and psychological factors like alertness, cognitive load, and sleep quality that fluctuate across the day. Morning: Generally characterized by lower Alpha, Beta, and Gamma powers, which might suggest lower alertness or waking state. Delta power is highest, which could be an indicator of the residual effects of sleep. Midday: Shows elevated levels of Beta and Gamma, typically associated with higher cognitive activity and alertness. Alpha also increases, suggesting a relaxed yet alert state. Night: Maintains higher Alpha similar to midday, indicating relaxation. Beta and Gamma decrease but are still higher than morning levels, reflecting a reduction in cognitive intensity as the day progresses.

Limitations
This study's primary limitations stem from its small sample size, limited to EEG data collected at morning, midday, and night, potentially restricting the representation of daily brain activity variations. The temporal resolution and participant variability were not extensively addressed, and while efforts were made to ensure measurement consistency, slight variations in electrode placement and environmental factors could have influenced the results. The study's statistical power may be limited due to the dataset size and the number of comparisons conducted, raising concerns about inflated error rates or missed meaningful differences. Generalizing the findings beyond the specific population, device, and experimental conditions should be approached cautiously, considering potential biases and variations that could affect broader applicability.

Summary of Observations
The exploration into EEG data analysis over different times of the day has yielded important insights into how brainwave activities shift in relation to our circadian rhythms. The preliminary results demonstrate significant differences in brain activity that correspond with morning, midday, and night. These variations are not merely statistical artifacts but appear to reflect real physiological and psychological changes that occur throughout the day. Given the variances observed in the study, it is evident that timing plays a crucial role in interpreting EEG data. These temporal influences should be carefully considered in future research to ensure accurate assessments of brain function.

References

Abhang, P. A., Gawali, B. W., & Mehrotra, S. C. (2016). Technological basics of EEG recording and operation of apparatus. In Elsevier eBooks (pp. 19–50). https://doi.org/10.1016/b978-0-12-804490-2.00002-6

Almeida, D. (2024, March 25). Basics of neural oscillations. EMOTIV. https://www.emotiv.com/blogs/tutorials/basics-of-neural-oscillations

Christian Cajochen, Daniel P. Brunner, Kurt Krauchi, Peter Graw, Anna Wirz-Justice, Power Density in Theta/Alpha Frequencies of the Waking EEG Progressively Increases During Sustained Wakefulness, Sleep, Volume 18, Issue 10, December 1995, Pages 890–894, https://doi.org/10.1093/sleep/18.10.890

Kenneth P. Wright, Pietro Badia, Albert Wauquier, Topographical and Temporal Patterns of Brain Activity During the Transition From Wakefulness to Sleep, Sleep, Volume 18, Issue 10, December 1995, Pages 880–889, https://doi.org/10.1093/sleep/18.10.880

Plass-Oude Bos, Danny. (2006). EEG-based Emotion Recognition. The Influence of Visual and Auditory Stimuli.