Effect of caffeine and energy drinks on sleep quality and brain activity in college students

Oviedo, N., Tito, K., Cigarán, A., Tello, B.
Facultad de Ciencias e Ingeniería
Universidad Peruana Cayetano Heredia

ABSTRACT This study investigates the impact of caffeine and energy drink consumption on sleep quality and brain activity among college students. Using EEG technology, the research identifies specific brain activity patterns associated with prolonged energy drink use and poor sleep quality. Participants were divided into groups based on their sleep habits and caffeine consumption levels. Results indicate a significant correlation between high caffeine intake and disrupted sleep patterns, evidenced by increased variability and energy metrics in EEG readings. Conversely, participants with low caffeine consumption demonstrated better sleep quality. The study highlights the challenges in EEG signal interpretation due to external factors and underscores the need for rigorous control in future research to enhance data reliability. These findings provide valuable insights for further studies on caffeine's effects on sleep and cognitive performance, aiming to develop comprehensive recommendations for managing caffeine intake among university students.

KEYWORDS: Sleep, energy drinks, EEG, Ultracortex, cognitive performance

INTRODUCTION

Sleep is essential for physical and mental well-being, particularly in college students who frequently face academic and social challenges that can affect their sleep quality. Insufficient sleep can lead to decreased academic performance, attention and memory problems, and an increased risk of developing mental health issues such as anxiety and depression. Among the factors influencing sleep, the consumption of energy drinks has garnered attention due to their popularity and potential adverse effects [2] [3] [5].

Energy drinks contain ingredients such as caffeine and taurine, which act on the central nervous system. Caffeine targets multiple biochemical pathways, including GABA and adenosine A1 and A2A receptors. Blocking these receptors, especially adenosine A2A, is associated with psychoactive effects like increased intellectual capacity, alertness, and reduced mental fatigue. However, excessive consumption of caffeine can interfere with sleep, causing insomnia, anxiety, and long-term cognitive impairment. Additionally, high doses of caffeine may increase the risk of hallucinations and lower the seizure threshold [4] [6] [7]

Taurine, while potentially neuroprotective, can also negatively impact cognitive function and behavior, particularly in young adults. Taurine interacts with neurotransmitters and brain regions, suggesting a possible neuroprotective role. However, its supplementation may adversely affect cognitive function and behavior, especially in adolescents and young adults. Chronic insomnia has severe consequences for quality of life and health, negatively impacting physical, emotional, and social functioning; increasing the risk of accidents, including occupational accidents; reducing productivity and concentration at work; and being associated with a higher likelihood of developing depression and anxiety [8].

This study investigates how prolonged use of energy drinks and poor sleep quality affect brain activity and cognitive performance, using EEG to detect specific patterns.

PROBLEM STATEMENT

The consumption of energy drinks is prevalent among college students seeking to enhance their academic performance. However, these beverages can adversely affect sleep quality and cognitive function. Key ingredients in energy drinks, such as caffeine and taurine, have been shown to cause insomnia, anxiety, and cognitive impairment. There is a research gap regarding how prolonged use of energy drinks and poor sleep quality specifically impact brain activity and cognitive performance in students.

PROPOSED SOLUTION

This study aims to utilize EEG to identify specific brain activity patterns and evaluate the correlation

between energy drink consumption, altered sleep patterns, and cognitive performance.
A group of participants was sought and divided into groups according to their sleep habits and caffeine consumption. Using the Ultracortex, we recorded the brain activity of each participant performing different cognitive tasks. The captured signals were processed for further analysis.

METHODS

1. Selection of participants

Target Participants: We selected university students aged 19-25 with varying levels of energy drink consumption and sleep quality. Participants were non-smokers and did not use any psychoactive or psychotropic substances.

Questionnaires: Questionnaires were administered to evaluate participants' energy drink consumption and sleep quality.

Based on the questionnaire responses, we selected four participants:

- Participant 1: Poor sleep quality in the last 3 days, no regular caffeine consumption.
- Participant 2: Regular sleep quality in the last 7 days, regular coffee consumer.
- Participant 3: Poor sleep quality in the last 3 days, frequent consumer of caffeinated beverages.
- Participant 4: Good sleep quality in the last 7 days, no regular caffeine consumption.

2. Signal acquisition

2.1. Ultracortex positioning

We used Ultracortex and its Open BCI interface to perform the tests.[9]

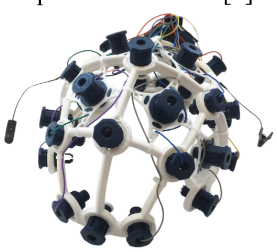

Fig 1. Ultracortex

The international 10-20 system is widely recognized for describing electrode positions on the scalp. It is based on proportional distances between key points, such as the nasion and inion. Each position is identified by a letter and a number describing the location in the brain lobes and hemisphere.

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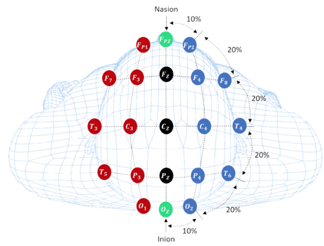

Fig 2. Electrode Positioning 10-20 [10]

2.2. Cognitive Tasks

Stroop Test: The Stroop test assesses focused attention and examines the ability to make decisions based on information from two different modalities. In the first part of the test, subjects are asked to read the names of different colors. Then, they must name the print color of a word that denotes a different color; for example, reading the word "blue" printed in green, which creates a word-color interference. Subjects are instructed to perform the task as quickly and accurately as possible [11].

Digit Span: The Digit Span test is used to measure short-term and working memory. The test consists of repeating a sequence of numbers in reverse order [11].

Selective Attention Test: This test involves evaluating the participant's ability to focus attention by watching a 30-second video designed to test selective attention. Participants are instructed to follow specific directions, such as counting the number of passes between players. Immediately after the video, they are asked a question related to the content to verify if they followed the instructions correctly, with the correct answer then displayed [12].

3. Data analysis

3.1. Filtering and Preprocessing

For filtering and preprocessing, the Python MNE library was used to speed up signal processing.

Creation of raw:
We started from the txt file obtained from OpenBCI from which the correct format was given to convert the data to raw (format in which the MNE works).
A standard montake was made for the positioning of the electrodes that will obtain the EEG signal.
Filtering:
The first filtering through which the data pass is a high-pass filtering recommended for later using independent components analysis (ICA), the library itself recommends it.
After obtaining the total spectrogram data and the spectrogram for each channel of the ultracortex, the ICA's are performed.
The processing with ICA in our data did not obtain unnecessary channels, therefore, all of them were considered for the following steps.
In this work we focused on analyzing the behavior of the Beta waves of the brain in different tests, therefore, a filtering was performed to extract only the Beta waves (16-30 Hz). The filter used is from the MNE library which works with the previously modified raw.
The power spectral density was visualized with the modified Welch function to observe the frequency characteristics of the data in each channel of the raw.
Finally, the signal was normalized (channel by channel) with a standard normalization (mean = 0).
The data from each individual channel was worked on, because the data obtained is not sufficiently correct to perform certain processing with MNE, such as obtaining events, epochs, etc.

3.2. Feature extraction

The discrete Wavelet transform was used for feature extraction, since it is an efficient and reliable method, regardless of the Wavelet family used or the number of coefficients. [13].
Based on this, a repository was found in which different features of EEG signals were extracted channel by channel.
The pre-processed information was decomposed and the features ed for each channel, for each user for each test were found. Subsequently, a table was made with the summarized information with which the corresponding comparisons were made.

From the extracted features, we selected the most relevant ones for each test.

For the digit span and selective attention tests, which rely on rapid reactions and responses, we used:

- **cD_Energy (Detail Coefficients Energy):** Reflects high-frequency brain activity crucial for attention. Sleep deprivation typically reduces this activity, impairing attention and concentration [14][15].
- **D_Entropy (Detail Coefficients Entropy):** Measures signal disorder, with higher entropy indicating attention difficulties. Sleep deprivation increases entropy, leading to more chaotic brain activity and reduced attention [14].
- **D_std (Detail Coefficients Standard Deviation):** Indicates variability in high-frequency activity. High variability suggests attention instability, which is exacerbated by sleep deprivation, resulting in less consistent brain activity [15].

Meanwhile, for the Stroop test, which requires slower and more precise reasoning, we used:

- **cA_Energy (Approximation Coefficients Energy):** Reflects general energy in EEG signals, related to alertness and cognitive processing. Sleep deprivation reduces this energy, affecting cognitive efficiency [16] [17].
- **A_Entropy (Approximation Coefficients Entropy):** Measures disorder in EEG signals. Higher entropy can indicate difficulties in attention

and conflict processing, critical in the Stroop test. Sleep deprivation increases entropy, reducing the ability to handle interference [16] [18].

- **A_std (Approximation Coefficients Standard Deviation):** Indicates variability in brain activity. High variability suggests attention instability and difficulty maintaining focus. Sleep deprivation increases this variability, impacting performance in prolonged tasks [17] [18].

The results then will be graphed and compared with the other participants. Finally, to quantify the results, a methodology to assign points based on each participant's performance in the respective tests, where higher variability and high energy indicated poorer sleep quality. Points will be assigned on a scale where the highest variability and energy received 4 points, and the lowest received 1 point, indicating better sleep quality.

RESULTS

Selective Attention:

As shown in Fig 3., the graphs show that Participant 2 has generally higher values in D_Entropy, with peaks in Fp1 and C4, while Participant 4 shows less variability. In D_std, Participants 1 and 2 maintain more stable values. In cD_Energy, Participants 1 and 3 have moderate variability and Participant 2 maintains more stable values with some peaks.

Stroop test:

As shown in Fig 4, it is observed that participants 1 and 4 show greater variations in the selected characteristics. Participant 1 shows a decrease in entropy (D_Entropy) and a high standard deviation (D_std) in the frontal channels Fp1 and Fp2, indicating significant variability in the signal. On the other hand, participant 4 evidence marked changes in D_std and a significant increase in cD_Energy in channels P3 and P4. In contrast, participants 2 and 3 show less pronounced changes.

Digit span:

As shown in Fig 5, it can be observed that in the case of A_Entropy, participant 4 has considerable variability with high peaks in Fp1 and P3. In A_std, participant 1 has high variability in Fp1 and F4, while participant 2 shows a more stable trend. In cA_Energy, participant 4 has significant variability, while participants 1 and 3 have moderate variability**.**

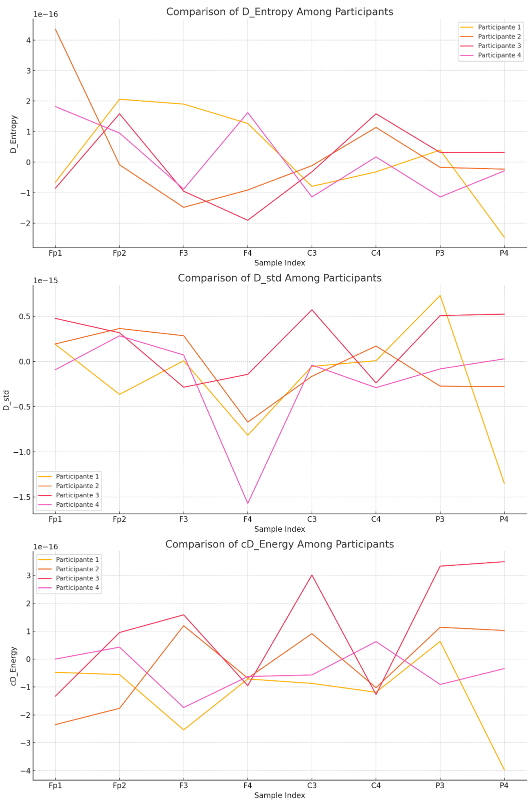

Fig 3. Selective Attention

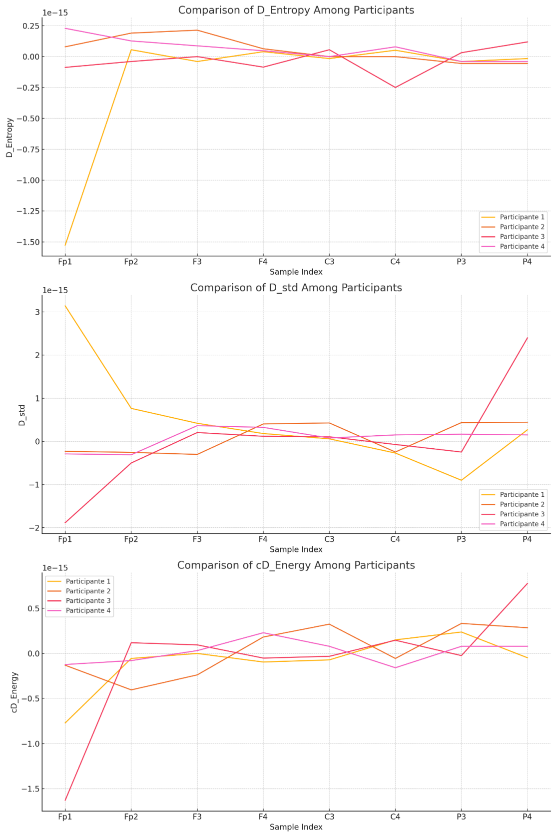

Fig 4. Stroop test

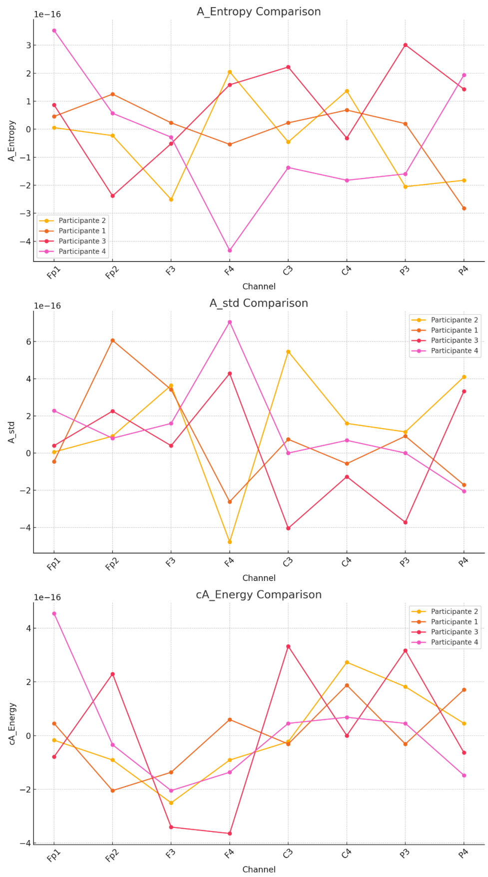

Fig 5. Digit Span

Finally, we use the previous method to assign points for the results of each test to its target participant. The results were graphed in Table 1.

Participant	Selective Attentiont Test	Digit Span Test	Stroop Test	Combined Score
Participant 1	12	12	11	35
Participant 2	9	9	9	27
Participant 3	6	6	7	19
Participant 4	3	3	3	9

Table 1. Score assigned to each participant

In Table 1 it can be seen that participant 1 got the highest score, which means that he has the worst sleep quality. In contrast to participant 4, who has the lowest score and therefore the best sleep quality.

DISCUSSION

The results of this study provide a clear comparison of sleep quality among the participants based on their scores from various tests. (Participant 1) consistently scored the highest in terms of variability and energy, indicating the poorest sleep quality. This aligns with her high caffeine consumption. (Participant 2) followed with a combined score indicating moderate sleep quality, while (Participant 3) had better sleep quality, and (Participant 4) showed the best sleep quality with the lowest combined score.

The final rankings derived from our methodology were consistent with the participants' reported states, validating the effectiveness of our approach. (Participant 1) highest combined score of 35 points underscores significant sleep disruption, likely due to her caffeine intake. (Participant 2) moderate score of 27 points suggests that while her sleep was affected, the impact was not as severe. (Participant 3), with 19 points, exhibited some negative effects but to a lesser degree, and (Participant 4) with a score of 9 points indicates minimal impact on sleep quality, which concurs with his description of good sleep quality and low caffeine consumption.

However, the signals from (Participant 2) and (Participant 3) were difficult to analyze, even though they should have been easy to differentiate because of the differences in both participants. Several factors could have influenced these results, starting from the condition of the Ultracortex and its current configuration, which could have been unappropriate for these tests.

There are also variations in EEG signals that can arise from numerous factors, including social pressure, individual intelligence coefficients, and environmental conditions. Additionally, the tests themselves could yield more reliable results with a stricter protocol [18]. Ensuring that participants are in a controlled environment and minimizing external stressors could reduce variability in the data.

Despite these potential influences, the variation in the final rankings compared to the initial state of participants was not substantial. This suggests a great correlation between caffeine consumption and sleep quality, as observed in our results.

For future studies, it will be important to control these external factors more rigorously to enhance the accuracy and reliability of the results. Improved device calibration, consideration of psychological and environmental factors, and a larger sample size could provide more robust data. By addressing these variables and implementing a stricter testing protocol, future research can better elucidate the impact of caffeine on sleep quality and potentially offer more precise recommendations for managing caffeine intake among university students.

CONCLUSIONS

In conclusion, this study has demonstrated a significant correlation between caffeine and energy drink consumption and sleep quality among college students. Participants who reported higher caffeine intake, such as (Participant 1), exhibited greater sleep disruption, as evidenced by their higher scores in variability and energy metrics. Conversely, participants with lower caffeine consumption, such as (Participant 4), showed better sleep quality with minimal variability and energy, aligning with their self-reported good sleep habits.

The analysis also highlighted potential challenges in EEG signal interpretation, influenced by factors such as device condition, social pressures, and environmental conditions. These findings underscore the importance of rigorous control over external variables and the implementation of a stricter testing protocol to improve data reliability in future studies.

The insights gained from this research can guide further investigations into the effects of caffeine on sleep and cognitive performance. By refining methodologies, future studies can build upon these findings to provide more comprehensive recommendations for managing caffeine intake and enhancing sleep quality among university students.

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BIOGRAPHY

1. **Nadira Oviedo**, from Lima, is currently in her eighth semester at the Pontifical Catholic University of Perú - Peruvian University Cayetano Heredia. She has experience working in her areas of interest, which include instrumentation and electronics in medical equipment and research in biomedical signals and images (at the Medical Imaging Laboratory of PUCP). Typically works with Matlab or python for signal or image processing. Also had an internship in a cellular signaling laboratory and has experience working with nano antibodies. In addition to her academic experience, she has an interest in neuroscience. Therefore, one of her future goals is to work in a biomedical field, focusing on physiological signals and incorporating her curiosity in neuroscience. She also completed courses in Signal Processing and Machine Learning using Matlab software.

2. **Kimberly Tito,** from Huancayo, is currently in her seventh semester at the Pontifical Catholic University of Perú - Peruvian University Cayetano Heredia. She has experience working in her areas of interest such as biomaterials and 3D bioprinting (at the Medical Engineering Laboratory of PUCP). In addition to her academic experience, she has an interest in tissue engineering. Therefore, one of her future goals is to work in a biomedical field, focusing on cell-based bioprinting.

3. **Bruno Tello**, from Lima, is currently in his eighth semester at the Pontifical Catholic University of Perú - Peruvian University Cayetano Heredia. He has experience in courses related to tissues, biomaterials, and biomedical signals and has shown a strong interest in the field of clinical engineering. Bruno is dedicated to improving the current healthcare system in the country, with the goal of making healthcare accessible to all Peruvians. His passion for clinical engineering drives him to seek innovative solutions that can significantly impact the quality of life for the population. In the future, he aspires to work in the biomedical field, contributing to the development of technologies and processes that optimize healthcare in Perú.

4. **Alvaro Cigarán,** from Lima, is currently in his eighth semester at the Pontifical Catholic University of Perú - Peruvian University Cayetano Heredia. He has experience working in the Medical Engineering Laboratory. In addition, one of his areas of interest is clinical engineering, as he is motivated to contribute to the improvement of the Peruvian health system.