Neural Pathways to Attention Enhancement: EEG Spectral Ratio Analysis of CM-II Meditation's Effect on Student Attention

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***Abstract*—This research-to-practice paper describes the development of an innovative practice aimed at addressing the global surge in student stress and related mental health challenges, particularly in engineering education. Student well-being is foundational to academic success, with studies indicating that dropout rates for students with stress are more than 50% and mental health problems can range as high as 83% in engineering education. Stress and elevated levels of inattention are associated with decreased academic interest, decision-making, self-efficacy, study skills, and GPA. Research has shown that stress levels can be reduced by meditation techniques and they induce attention. In this research, a three-stage guided meditation called ChakraMarmaKosha Meditation II (CM-II) was developed to improve the attention level of students. It involves past emotional cleansing, reviewing the day, visualizing the future components, and is accompanied by flute music that is composed based on a chosen Raga. In this study, a data analysis pipeline was developed for detailed spectral analysis to measure variations in attention due to meditation.**

In an in-person EEG experiment, a study group of 15 college students underwent this CM-II meditation process in a lab setting. The EEG spectral analysis underscored an enhancement in attentional focus post-meditation, as evidenced by key shifts in spectral ratios such as the notable decrease in Theta to Beta Ratio (TBR) and the surge in Theta to Gamma Ratio (TGR). The observed results were validated using attention scores from tests on the TestMyBrain tool. This study underscores the potential benefits of the CM-II meditation technique in fostering enhanced attention, reduced stress, and consequently improved academic performance in engineering education. While the current study provides promising results with CM-II meditation in enhancing attention, cognition, and relaxation, it's essential to acknowledge the limitations, such as the confinement to a single lab setting and a small sample size. Future research could explore larger, more diverse cohorts and investigate the long-term benefits of CM-II, potentially incorporating it into regular academic curricula.

***Index Terms*—Attention deficit, Mental health, Spectral ratio analysis, EEG.**

I. Introduction

Attention is a crucial cognitive skill, that profoundly impacts academic and professional performance. Given the economic implications of ADHD and the complexities of today's 'attention economy', the value of methods such as mindfulness and meditation comes to the forefront. This research endeavors to develop and evaluate the effectiveness of the ChakraMarmaKosha-II meditation (CM-II) technique, a guided meditation with background music, in enhancing attention, reducing stress, and thus improving mental health.

Attention, a crucial cognitive skill encompassing concentration, problem-solving, judgment, and language capabilities [1], plays a vital role in academic and occupational performance. Attention-Deficit Hyperactivity Disorder (ADHD), a neurodevelopmental disorder characterized by hyperactivity, inattention, and abrupt actions [2], poses significant challenges to individuals, education systems, and the broader economy. The economic costs of stress and ADHD on student performance and the larger economy are substantial. For instance, between 2018 and 2019, the total social and economic cost of ADHD was estimated to range from US$8.40 billion to US$17.44 billion, with costs of US$15,664 [3] per person. Particularly in the education system, with a conservative ADHD prevalence rate of 5% among children and adolescents, the associated annual costs were approximated at $13.4 billion [4]. Additionally, stress is estimated to cost the U.S. industry over $300 billion a year, covering absenteeism, turnover, diminished productivity, and additional healthcare expenditures among other factors [5].

The modern world's 'attention economy', driven by technology and social media, exacerbates these challenges, making practicing mindfulness challenging yet beneficial. Mindfulness and meditation practices have shown promise in countering these issues to some extent. The U.S. meditation market, valued at $1.21 billion in 2017, was projected to grow to $2.08 billion by 2022, indicating substantial economic activity around meditation practices [6]. Mindfulness-based cognitive therapy has been suggested to help in the treatment of adults with ADHD [7]. Moreover, mindfulness can lead to numerous positive outcomes by dialing down the body's response to stress, which could potentially reduce healthcare and other stress-related costs [8].

Elevated levels of inattention are associated with decreased academic interest, decision-making, self-efficacy, study skills, and GPA [9]. Engineering students who experience attention

deficits may face difficulties in adapting to various aspects of academic life, such as setting goals, managing time effectively, and adjusting socially and emotionally [9]. A study compared 20 college students with ADHD with a control group of non-ADHD students and found that the ADHD group had lower scores on measures of academic adjustment, social adjustment, personal-emotional adjustment, attachment to college, and goal commitment, as well as lower scores on measures of self-esteem and overall social skills [10]. Poor-performing students may view continuing their education as not valuable even if they don't fail out or realize a higher likelihood of future failure. Poor academic performance can reduce the enjoyment of school and affect perceptions of future earnings [11]. Consequently, this has resulted in high drop-out rates, with as many as 39 million students dropping out in the United States [12]. In engineering education, 50% of students switch their majors during their studies, and over 83% experience mental health issues such as depression, anxiety, PTSD, eating disorders, or significant psychological distress[13]. More than 16% of engineering students reported having received a formal diagnosis of a mental health condition in the USA [14].

Meditation, especially in communities of individuals with ADHD, has been recognized as a viable method for improving attention [15]. In the context of academic environments, early detection and intervention, through meditation could enhance attention and potentially reduce the substantial economic burden associated with adult ADHD. In a previous experiment of 11 people conducted by the author, it was proved that ChakraMarmaKosha-I (CM-I) [1] was effective in reducing stress [Blinded]. CM-II is a sequel of CM-I in which the script focuses on emotional cleansing thereby improving attention and self-efficacy. It guides the user through their emotional memories and releases past painful emotions associated with trauma. For instance, individuals with acute stress disorder may have significant psychological issues and distress that could have arisen from past stored emotions. In addition, they may also have distorted cognition formed from convictions during trauma that keep them under stress. CM-II addresses these issues by guiding the listener through past emotional release and cognitive restructuring.

The hypothesis in this research is that CM-II reduces stress and improves cognition and attention. In this research, our contributions are enlisted as follows:

1) Conducted literature review to identify the gap in stress management in engineering education.
2) Developed a novel meditation practice.
3) Composed background music for enhanced attention.
4) Developed a methodology to measure meditation's effect on attention using EEG waves.
5) Conducted an in-person experiment with 15 college students.
6) Conducted spectral ratio analysis on the EEG measurements to measure the shifts in stress and attention.

[1]https://youtu.be/5e9qwQbXFcI

In short, the implications of attention and ADHD on both individuals and the economy underscore the urgency of finding effective solutions. This research explores the potential of the CM-II meditation technique as an intervention to improve attention and mental health in engineering education, offering a promising avenue to address the multifaceted challenges posed by attention deficits. Research-based attention tests and band wave ratio analysis are performed on EEG data collected from selected participants to assess the influence of CM-II on cognition and attention.

II. Related works

A. Stress reduces attention

Symptoms of inattention and hyperactivity/impulsivity were significantly correlated with generalized anxiety and panic attacks, in engineering education [16]. High stress, anxiety, and depression can lead to symptoms of inattention and they reduce the effectiveness of the inhibitory function and hinder concentration in engineering education [17, 18, 19]. Students with ADHD reported higher anxiety ratings concerning academics than life in general, with significant differences [20]. Students with high levels of anxiety performed worse on cognitive tasks when their symptoms of inattention were high [20]. This creates a vicious circle where students with low attention face specific challenges related to college life and academics, such as social skills, adapting to college, relationships, and academic pressure. As academic pressure and stress increase in engineering, symptoms of inattention also rise, perpetuating the cycle. Early identification and treatment of attention-related issues can lead to timely intervention, better academic performance, course completion, and overall quality of life for students [21, 22].

B. RAGA flute music reduces stress and improves attention

"Raga is that form of music composition comprised of melodic motions that have the effect of clearing the hearts of men," writes Matanga, Indian musicologist and theorist (9-10th century AD). The term 'Raga' finds its roots in Sanskrit and holds the essence of 'coloring or dyeing'—in the case of applying the term to music, it metaphorically colors the mind and evokes emotions in the performer and listener [23]. A recent research paper explored the relaxation effects of Raga in an immersive virtual reality environment and found that after six days of VR-based Raga intervention, participants showed a significant reduction in stress, anxiety, and depression scores [24]. Another research focuses on the anxiety levels of pregnant women in their third trimester and how music therapy using a flute instrument can alleviate this anxiety [25]. Ragas music could improve the state of despair and make one feel happy [26] and specifically Raga Hindol, used to compose music in this research, aids in memory sharpening and attention [26]. Moreover, the soothing tones of flute instruments have been shown to be particularly effective in reducing anxiety levels in specific populations, such as pregnant women in their third trimester [25]. In this study,

the author composed flute music in the Indian Raga "Hindol" which is used as the background music for CM-II.

C. Meditation reduces stress and improves attention

In recent years, the scientific community has increasingly recognized the potential of meditation practices in enhancing attention and cognitive functions. A study indicated that even a short 10-minute VR session significantly improved participants' attention span, as evidenced by both game scores and EEG signals [27]. Another research by Jain and Markan (2022) explored the impact of brief meditation interventions on executive control of the attention system. Their results, based on both behavioral responses and neuro-physiological findings, suggested a positive effect on attention even after short meditation sessions in non-meditating populations [28]. Even more, it was found that as the novice participants meditated more, their effects deepened [29]. Another study suggests that engaging in a single session of mindfulness meditation can lead to immediate motor benefits, and there might be a connection between these motor benefits and cognitive improvements [30]. These studies underscore the potential of meditation as a viable tool for attention and cognitive enhancement, highlighting its relevance in today's attention-driven economy.

D. Principles and Potential of CM-II Meditation

CM-II meditation is intended to provide a venue for regular practice to improve and sustain attention. It was developed based on three principles such as emotional processing, past reviewing, and future visualization. Psychotherapy-based emotional processing addresses the root psychological adverse childhood experiences (ACE) for healing attention among ADHD patients [31]. Reviewing the past leads to 'effortless attention' by "letting go", which is an integral part of attention – to pay attention means letting go of everything other than what is in the focus [32]. Future visualization can reduce confusion, give purpose, and improve focus [32]. Meditation can potentially improve mental processes such as attention, memory, learning ability, and conscious perception [32]. CM-II is developed based on these principles and its architecture as shown in fig 1 is described in the methodology section that follows.

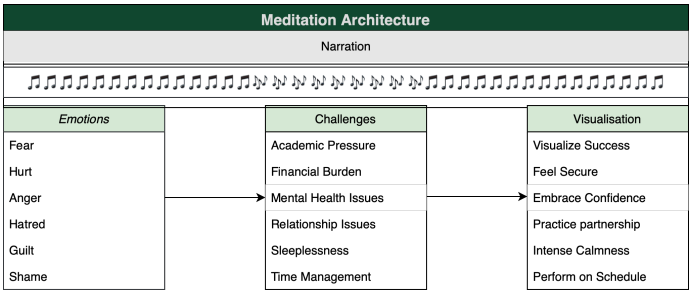

Fig. 1: CM-II architecture

E. EEG Spectral Ratios indicate slides of attention

Electroencephalography (EEG) has emerged as a pivotal tool in the realm of neuroscience to gauge the intricate dynamics of brain activity during meditation. EEG is a test that examines irregularities in brain waves or electrical activity of the brain. EEG traditionally describes raw brain waves in frequency bands such as Gamma(>30 Hz), Beta(13-30 Hz), Alpha(8-12 Hz), Theta(4-8 Hz), and Delta (<4 Hz). The spectral ratio analysis of EEG signals offers granular insight into the oscillatory patterns associated with various cognitive states, including attention [33]. For example, a decrease in the Theta/Beta Ratio (TBR) in the frontal channels over time is indicative of increased attention and focus, and TBR can be a reliable marker for attentional shifts [34]. Even more, the Delta/Theta ratio (DTR) in the frontal channels has been associated with transitions from relaxation or drowsiness to alertness. Significant changes in the DTR during cognitive tasks were found in a study that indicates a shift from a relaxed state to heightened alertness [35]. Besides, the Theta/Gamma ratio (TGR) has been linked to cognitive processing as well [36]. Furthermore, the latest studies emphasized the significance of Theta/Alpha ratio (TAR) in modulating and improving attentional capacities, suggesting its potential as a neurofeedback metric for attention enhancement [37, 38]. The effect of ratios on attention as summarized in table I

TABLE I: Rise in spectral ratios and effect on attention [39, 40, 41]

Spectral Ratio	Effect on Attention as it Increases
Theta/Alpha Ratio (TAR)	Decreases
Delta/Theta Ratio (DTR)	Decreases
Theta/Gamma Ratio (TGR)	Increases
Theta/Beta Ratio (TBR)	Decreases

In brief, the relationship between stress, music, meditation, and attention offers insights into enhancing cognitive performance. With stress affecting attention, Raga music and CM-II meditation practices might provide therapeutic solutions.

III. Methodology

In this section, we detail the methodology employed for our study. We go through CM-II architecture, the in-person experiment we conducted, and the online tests to assess participants' cognitive abilities before and after the guided meditation and monitor their EEG readings.

A. CM-II Architecture

The script for CM-II was developed based on M. Linehan's cognitive-behavioral treatment ideas for borderline personality disorder [42, 43]. Emotions such as Anger, Fear, Joy, Love, Sadness, and Shame could affect the attention span of a person [43]. A regular focused practice would lessen the extra thinking caused by analyzing or understanding a chosen object, resulting in reduced inner noise and enhanced attention [44]. The CM-II has three main components as follows:

1) Emotional Processing: Emotions, both primary and secondary, play a pivotal role in human behavior and decision-making. Emotions, while powerful, are transient and not factual. They can influence actions, potentially leading to urges or addictions. It's essential not to judge emotions but to recognize and fully experience the past baggage. As we stay with them within, over time, they dissipate, and this gives inner space for focusing on the present moment [43].

2) Reviewing the past: According to one study, whatever you read, see, hear, talk about, or experience in the last 45 minutes of the day has a significant impact on your sleep and the next day [45]. Reviewing the past lets one address the immediate concerns in life and plan actions as necessary. This will also process any minor emotions, unclutter the mind, and regulate thought flow, giving space to concentrate [43].

3) Future Visualization: Taking a few moments to visualize the upcoming day's events can significantly enhance focus and manifest the desired outcomes [45]. The law of attraction suggests that our thoughts shape our reality, attracting either positive or negative outcomes [46, 47]. Visualization meditation has been shown to reduce stress, anxiety, and depression while increasing achievement-oriented motivation [48]. An 8-week program demonstrated that this form of meditation enhanced self-awareness and reduced anxiety among stressed female university students [49]. Clearly defining one's goals can further boost creativity and focus [50]. Thus, visualization can be a powerful tool for optimizing attention and daily performance.

B. Experiment

We recruited 15 students in engineering and computing education and conducted an in-person experiment to measure EEG brain waves during the meditation. The research method involves three main steps that took place one time for each participant in our research lab. Based on the above literature review, we structured the experiment as shown in the figure 2.

1) **Visual reasoning attention pre-test:** The participants were asked to wear the EEG headset/cap and the heart coherence earphone clip and take the 8-minute visual reasoning attention test online.
2) **Listening to CM-II:** After the participants take the pre-test the EEG headset/cap and the heart coherence earphone clip are kept connected and they are asked to sit in silence in the lab and listen to CM-II for 45 minutes with headphones.
3) **Visual reasoning attention post-test:** After the participants finish the guided meditation, they are asked to re-take the same visual reasoning attention test online. This will take 8 minutes and after that, the devices are disconnected, and the participants can leave the lab [2].

In the initial step, we employed online TMB Matrix Reasoning and TMB Flanker Attention tests from TestMyBrain to evaluate the participants' reasoning capabilities and attention

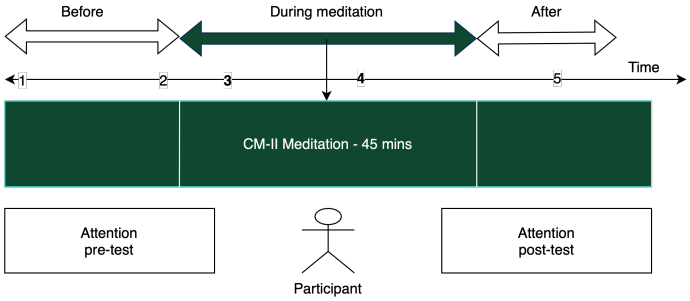

Fig. 2: Experimental Setup

control, respectively [51]. The Matrix Reasoning test challenges individuals to discern patterns and finalize matrices, whereas the Flanker Attention test gauges the capacity to concentrate attention and filter out extraneous details during a visual activity, yielding corresponding scores.

C. EEG Device

We used Muse 2, a portable EEG headset that produces raw EEG data from the electrical brain signals that are captured by electrodes placed on the head fig. 3 [52]. From this user-friendly wireless device with four electrodes, EEG data was exported for further analysis.

Fig. 3: EEG experiment-Museheadset

D. Spectral Ratio Analysis

In this study, we further developed a spectral ratio analysis pipeline of EEG data pre-processing, spectral extraction, and ratio analysis to determine the shifts in attention states 4.

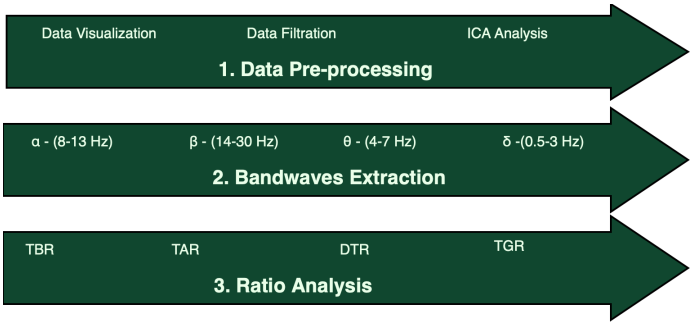

Fig. 4: Spectral Ratio Analysis Pipeline

Our algorithm[3] primarily involves processing and analyzing EEG data to explore attention states and stress levels. Initially,

[2]https://testmybrain.org

[3]https://github.com/datasci888/EEG-Spectral-Analysis

the data is pre-processed to handle missing values and filter necessary frequency components. Then, Independent Component Analysis (ICA) is applied to reduce noise and dimensionality, and the Fourier Transform is applied to transition the data to the frequency domain, enabling the calculation of power spectra for various EEG frequency bands. Attention metrics like the Theta/Beta Ratio are derived, aggregated, and analyzed to understand collective attention dynamics. These analyses are segregated into three equal time intervals to observe temporal variations across the measurement time. Using the same methodology, we analyzed the EEG readings taken before, during, and after the meditation.

IV. Results

The following section details the results of the analysis of various EEG ratios during and after meditation that offer insights into the influence of meditation on attention and cognitive states.

A. Ratios Percentage Shift

The table II shows how the ratios shifted during the meditation in both the frontal and temporal lobes of the brain.

	Stage	TBR	TAR	DTR	TGR
Attn Test I					
F	2/3	-0.155	-0.0554	-0.317	-0.2724
F	3/3	0.0697	0.0023	0.2297	-0.1139
T	2/3	0.2122	-0.0145	-0.0092	2.8107
T	3/3	-0.0238	0.0274	0.1905	0.0465
Meditation					
F	A	0.0421	0.0151	-0.1881	0.0247
F	R	-0.0437	-0.0383	0.0263	0.0784
T	A	0.0056	-0.0568	-0.2741	4.7195
T	R	-0.0511	-0.0363	0.2188	-0.6891
Attn Test II					
F	2/3	-0.0619	-0.0784	-0.7591	-0.2624
F	3/3	0.1204	0.0246	2.948	2.2057
T	2/3	-0.4879	-0.1523	0.3537	2.2788
T	3/3	0.85	0.0563	-0.0696	-0.3468

TABLE II: Overall Ratios Percentage Shift
Abbreviations: F-Frontal; T-Temporal; 1/3: First part; 2/3: Second part; 3/3: Third part; A: Analyzing challenges; R: Rehearsing solutions.

In Figure 5 and 6, the plots illustrate the aggregated progression of EEG band powers across three distinct phases: before meditation, during meditation, and after meditation. Each curve in the plot represents one of the EEG frequency bands, namely Theta, Alpha, Delta, Beta, and Gamma. The x-axis delineates the time intervals, segmented for clarity, while the y-axis represents the average power of the EEG signal.

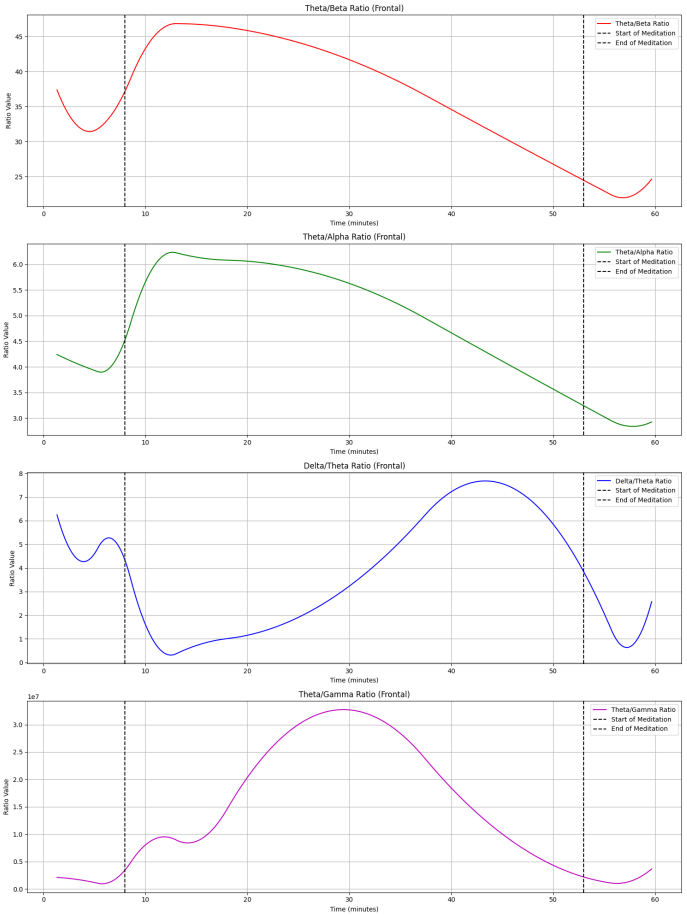

Fig. 5: Band Ratios - Frontal

As seen in the plots 5 and 6, the meditation session exerted a notable influence on participants' attention dynamics. In the frontal region, the TBR, represented in red (figure 5), shows a decline during the initial 8 minutes, consistent with the premise that as attention heightens, TBR decreases. This is supported by a decrease of 15.5% (table II in the TBR before the meditation. However, as the meditation process begins, post the 8-minute mark, there's a visible resurgence, peaking around the 30-minute mark, possibly indicating fluctuating attention levels during the introspective phase. This trend reverses again in the post-meditation period, with a notable decrease of 6.19%, suggesting a reversion to a more relaxed cognitive state.

The TAR in green, which initially reduces by 5.54% before meditation, then stabilizes during the meditation, indicating a consistent attention level. Post meditation, this ratio witnesses an uptick, further emphasizing the cognitive engagement induced by the meditation, supported by an increase of 2.46%.

The DTR in blue, which declines by 31.7% before meditation, displays a trajectory similar to TBR. It peaks around the 50-minute mark, aligning with the idea that as attention heightens, DTR decreases. The subsequent decline post the 50-minute mark might suggest a return to a more relaxed or introspective state.

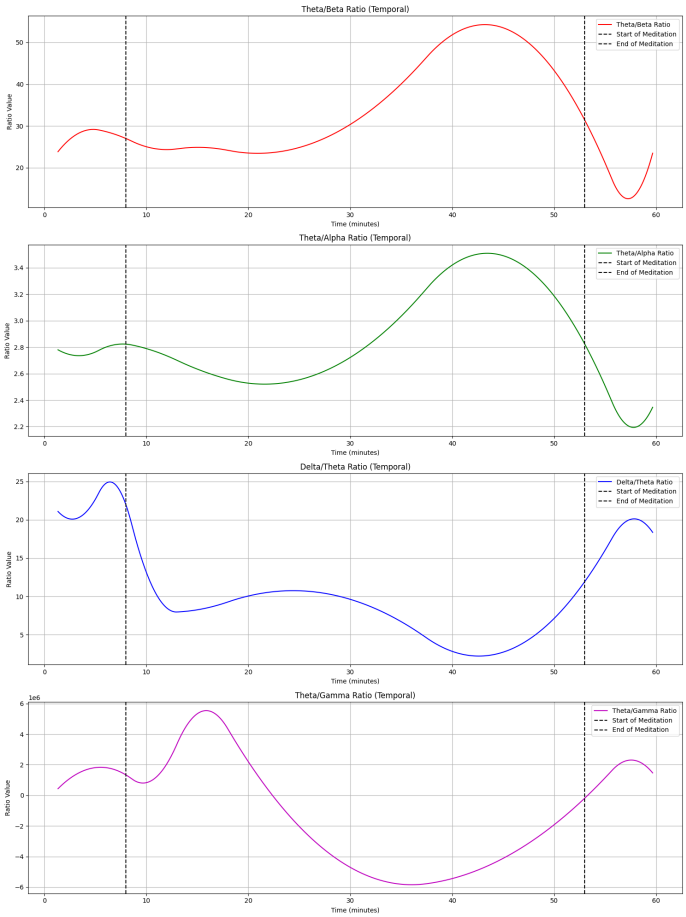

Fig. 6: Band Ratios - Temporal

The TGR in magenta, interestingly, remains relatively stable during the initial and meditation periods, with an initial increase of 281.07%, but shows variability post-meditation. Since an increase in TGR is associated with heightened attention, the spikes observed, particularly around the 53-minute mark, signify moments of heightened cognitive alertness or engagement.

In the temporal region, a similar pattern emerges, but with more pronounced peaks and troughs. The TGR spikes significantly, by a remarkable 471.95%, around the 20-minute mark, and then again post-meditation. Such pronounced shifts in the temporal region could indicate enhanced engagement with auditory stimuli or memories. The aggregated interpretation of all participants is shown in the table III

B. Visual Reasoning Attention Test

In our statistical analysis of how meditation influences attention test scores, the findings were interesting. The null hypothesis was that there is no significant difference in scores before and after meditation for both the Reasoning and Flanker tests. However, paired t-tests yielded p-values of 0.0077 and 0.0035 for the Reasoning and Flanker tests respectively, and thus we can reject the null hypothesis (as $p < 0.05$). Furthermore, the effect sizes (Cohen's d) of 0.8307 for Reasoning and 0.9369 for Flanker, both considered large, emphasize the substantial magnitude of this difference (as $d > 0.8$ (Table V). The box plots 7 further reinforce this trend, with the post-meditation medians residing notably higher than that of pre-meditation. Thus, there was a statistically significant improvement in scores post-meditation.

TABLE III: Overall Interpretation

Metric	Shift	Interpretation
TBR	Initial rise, later tapering	Deepened introspection, maintained external focus
TAR	Progressive rise	Enhanced relaxation/meditation depth
DTR	Significant end spike	Promoted deep relaxation or introspection
TGR	Very high start, vast end increase	Amplified introspection, reduced external processing
Attn Test	Consistent high scores	Sustained attention post-meditation

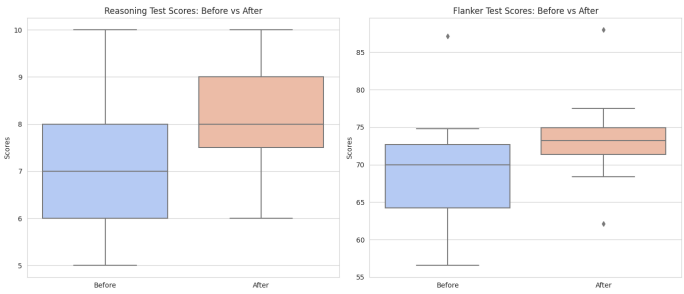

Fig. 7: Attention scores box plot

TABLE IV: Attention test statistical analysis

Test	p>value	Effect Size (Cohen's d)	Box Plot Interpretation
Reasoning	0.0077	0.8307	Median score post-meditation is higher, indicating improved reasoning.
Flanker	0.0035	0.9369	Median score post-meditation is higher, indicating enhanced attention control.

V. Discussion

Throughout the entire duration of the experiment, spanning from the pre-meditation attention test, the 45-minute meditation session, and the post-meditation attention test, a clear pattern emerges. In this journey of the mind transitioning through various stages of consciousness, the frontal region, as evidenced by spectral ratios like TBR and TAR, highlighted an oscillating attention span, with a notable rebound post-meditation. Especially significant is the 281.07% surge in TGR, pinpointing heightened cognitive engagement moments. The temporal region, with its remarkable 471.95% TGR spike,

underscores an intensified auditory engagement, perhaps resonating with deep-seated memories or reflections.

During the meditation phases, notably the "Emotional Review" and "Analyzing Challenges" stages, the observed TGR was exceptionally high. This elevated TGR can be attributed to potentially three scenarios. Firstly, the Theta power might be remarkably increased, indicating that participants are deeply immersed in a meditative or introspective state. Secondly, there's a possibility of notably reduced Gamma power. Given that Gamma waves correlate with cognitive tasks, information transfer, and learning, a dip in its power can imply participants are less engaged with external stimuli, reinforcing an inward-focused, meditative stance. Lastly, the heightened TGR could also result from a simultaneous surge in Theta power and a decline in Gamma power.

This aligns with the post-attention test results, where an overwhelming 93% of participants manifested heightened attention post-meditation and statistical analysis as in table . These findings highlight meditation's potential to enhance attention in engineering students.

A. Limitations

While this study presents valuable findings, it is essential to acknowledge its limitations. The EEG data was collected in a controlled setting, which might not mirror real-world scenarios. Furthermore, among the limited number of participants, most were novices to meditation and would not have peace of mind to focus. Due to busy class schedules and time constraints, the meditation was done only once. Besides, the lack of accounting for demographics could also have influenced the study.

VI. Conclusion

From the findings presented, it becomes clear that CM-II meditation, accompanied by Raga music, holds significant potential to enhance cognitive functions, particularly in the areas of attention and introspection. Through EEG spectral ratio analysis validated by online attention tests, the transformative capacity of CM-II meditation is evident. The integral components of emotional review, daily challenge analysis, and future visualization further enrich this method. Therefore, educators, researchers, and practitioners in the field of engineering education might consider this music-assisted meditation as a promising intervention for the early detection and management of attention challenges in both ADHD and non-ADHD individuals. This innovative practice offers a novel approach to addressing mental health issues and improving academic outcomes in engineering education.

A. Future Work

Building on the foundations of this study, future research could venture into several promising avenues. Firstly, we could have a larger sample size with varied backgrounds with a control group. Secondly, conducting the sessions in more naturalistic environments with and without music could offer deeper insights. Thirdly, repeated meditation sessions over extended periods could be conducted to discern the cumulative and long-term impacts of CM-II meditation.

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