CS 535 PROJECT REPORT
Studying the Impact of Meditation Apps on Sleep Quality

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Introduction

The proliferation of mobile applications aimed at improving health and well-being has extended into the domain of sleep science. Meditation apps, in particular, claim to enhance sleep quality by promoting relaxation and reducing pre-sleep cognitive arousal. While popular, the empirical evidence regarding the real-world impact of these apps on objectively measured sleep patterns remains an area requiring further investigation. Tools like smartwatches offer new possibilities for collecting objective sleep data (e.g., sleep onset latency, sleep efficiency) outside of traditional laboratory settings, allowing for ecological validity. This study undertakes an empirical evaluation of the effect of using meditation app sessions before bed on key sleep metrics in a small group of adult users, integrating objective data with user experiences.

Purpose of the Study

The primary purpose of this research project is to evaluate the effect of using a meditation application on objectively measured sleep quality. Specifically, this study aims to:

- Assess whether using meditation sessions (Guided Voice or Music-based) before bed leads to measurable improvements in sleep onset latency (time taken to fall asleep) compared to a baseline period without meditation.
- Determine if using meditation sessions before bed leads to measurable improvements in sleep efficiency (percentage of time in bed spent asleep) compared to a baseline period.
- Explore potential differences in effectiveness between Guided Voice meditation and Music-based relaxation techniques provided by the app on sleep onset latency.
- Investigate the alignment between objective sleep metrics (latency, efficiency) and users' subjective self-reported sleep quality.

By examining these aspects through a mixed-methods approach, we aim to understand both the quantitative impact and the qualitative user experience associated with using such apps for sleep improvement.

Background Research

Meditation practices have long been associated with relaxation and stress reduction, states conducive to initiating and maintaining sleep. Mobile meditation apps leverage technology to deliver guided sessions, calming soundscapes, and mindfulness exercises aimed at reducing pre-sleep rumination and physiological arousal. Previous research on mindfulness and meditation

interventions has shown promise for improving sleep quality, often focusing on clinical populations or subjective self-reports.

However, the specific impact of app-based meditation on objectively measured sleep parameters like sleep onset latency and efficiency in non-clinical populations requires more focused study. Furthermore, user experience research suggests that factors like the type of guidance (e.g., voice vs. music), session length, and perceived ease of use can significantly influence adherence and effectiveness. While tools like smartwatches provide accessible means for objective sleep tracking, understanding how users interact with meditation apps and how this interaction translates into measurable sleep changes is crucial for optimizing app design and recommendations. This study aims to contribute empirical data to this area by directly measuring sleep parameters and exploring user experiences within a structured comparison framework.

Research Questions:

1. How does using meditation sessions before bed influence sleep onset and sleep efficiency over a short-term period?
2. How do participants perceive their sleep quality on nights with and without app usage, and how does this align with objective sleep metrics?
3. How do user preferences for different meditation techniques (e.g., guided voice meditation vs. music-based relaxation) change over the study period and align with their sleep goals?

Research Type:

Category	**Description**
Research Type	Empirical
Concepts Studied	Sleep Quality, Sleep Duration and Efficiency, Sleep Onset Latency, User Preference of Meditation Techniques
Type of Experiment	Quasi-Experiment (Within-Subjects Design with Baseline and Intervention phases)
Unit of Analysis	Individuals
Type of Study	Longitudinal (Data collected over a 10-day period per participant)

Concepts:

1. Sleep Quality
2. Sleep Duration and Efficiency
3. Sleep Onset Latency
4. User Preference of Meditation Techniques

Operationalization:

Concept	Research Questions	Operationalised through	Measures	Instrument
Sleep Quality	RQ2	How well a person perceives their sleep experience.	Self-reported sleep rating (1-10), well-rested (Yes/No), qualitative responses	Daily Survey Questionnaire & Post-Study Interview Script
Sleep Duration & Efficiency	RQ1, RQ2	The total time a participant spends asleep and how effectively they sleep.	Total sleep time (minutes), Sleep efficiency (%)	Smartwatch Data logs
Sleep Onset Latency	RQ1, RQ2	The time it takes for a person to fall asleep after getting into bed.	Time to fall asleep (minutes)	Smartwatch data logs & Daily Survey Questionnaire
User Preferences for Meditation	RQ3	Participants' choices and evolving preferences between guided voice meditation and music-based relaxation.	Meditation choice tracking, effectiveness rating (1-10), reasons for switching, final preference, other qualitative feedback	Daily Survey Questionnaire & Post-Study Interview Script

Methods & Instruments:

This study employed a multi-faceted data collection strategy to capture a comprehensive understanding of participants' sleep patterns and experiences with the meditation application. The methods included a pre-study questionnaire, daily tracking surveys linked with objective sleep data, and post-study semi-structured interviews, allowing for the integration of baseline information, daily fluctuations, and in-depth qualitative insights.

Link for all the questionnaires : CS 535 Project Questionnaires

1. Pre-Study Survey
Instrument: **Pre-Study Survey Questionnaire**

Prior to commencing the 10-day study period, each participant completed a pre-study questionnaire designed to establish essential baseline information. This survey gathered demographic details (age, gender) and key aspects of their typical sleep patterns, including usual sleep duration, frequency of nighttime awakenings, and a self-rating of their general sleep quality. Crucially, it screened for pre-existing diagnosed sleep disorders. Furthermore, the questionnaire assessed participants' prior experience with meditation, particularly its use for sleep improvement, and gauged their initial expectations regarding the potential effectiveness and their anticipated preference between guided voice and music-based meditation techniques offered by the application. This initial data provided context for interpreting subsequent changes observed during the study.

2. Daily Sleep & Meditation Tracking Survey
Instrument: **Daily Survey Questionnaire**
Instrument: **Smartwatch Logs**

Throughout the 10-day study duration (covering both baseline and intervention phases), participants completed a brief survey each morning upon waking. This daily instrument served to capture immediate subjective perceptions of the previous night's sleep, including a rating of sleep quality on a 1-10 scale and a binary assessment of feeling well-rested (Yes/No). During the intervention phase (Days 5-10), the survey additionally prompted participants to report which type of meditation (Guided Voice, Music-based, or if skipped) they had used the preceding night and to rate its perceived helpfulness for their sleep. It also captured dynamic preferences by asking if they wished to switch techniques for the upcoming night and the reasons why. While these subjective reports were collected daily via the survey, objective sleep metrics such as sleep onset latency and sleep efficiency were automatically recorded by the participants' smartwatches and subsequently associated with the corresponding date for analysis.

3. Post-Study Semi-Structured Interview
Instrument: **Semi-Structured Interview Script**

Upon completion of the 10-day data collection period, individual semi-structured interviews were conducted with each participant. These interviews aimed to elicit rich qualitative data, providing depth and context to the quantitative findings. Using a flexible interview guide, the sessions explored participants' overall perceptions of how the meditation app impacted their sleep, comparing their experience to their pre-study baseline. Discussions delved into specific perceived effects on falling asleep, sleep depth, and restfulness. Participants elaborated on their preferences between guided voice and music-based meditations, the reasoning behind their choices, and whether these preferences evolved over the study period. The interviews also uncovered practical aspects of the user experience, including the most valued benefits, challenges faced (such as technical issues, time constraints, or usability hurdles), and how easily the app integrated into their nightly routine. Finally, participants shared their intentions regarding future use of the app and offered suggestions for improvement. Interviews were audio-recorded with consent and transcribed verbatim to facilitate subsequent thematic analysis.

Research Design:

This study employed a **Convergent Parallel Mixed-Methods Design** to investigate the impact of a meditation application on sleep quality and the user experience among a small group of participants (N=4). This approach was selected for its robustness in combining and corroborating both quantitative data (objective sleep metrics, survey ratings) and qualitative data (participant interviews) concurrently, allowing for a more comprehensive and nuanced analysis of the research questions.

The core quantitative component utilized a **within-subjects quasi-experimental design** implemented over a 10-day period for each participant. This design leverages participants as their own controls, comparing outcomes during the intervention phase against their own baseline period. This inherently minimizes variability due to stable individual differences in typical sleep patterns. While the study featured controlled conditions (e.g., mandated use of specific meditation types on certain days), it is classified as quasi-experimental primarily because the baseline phase systematically preceded the intervention phase for all participants, lacking randomization of the major condition order over time.

Updated Research Design:

During the refinement of our study design, an important modification was made to the intervention phase. Initially, our plan focused on a simple comparison between a baseline period (no meditation) and an intervention period where participants could freely choose their preferred meditation type. However, after further review of mixed-methods best practices for comparing intervention sub-types within a small sample, we recognized the need to ensure sufficient data for both guided voice and music-based meditations. To achieve this, while still allowing for natural preference to emerge, we adjusted the intervention protocol to gently encourage participants to experience each modality at least twice, ensuring we had adequate data points for

a more meaningful, albeit still exploratory, comparison between the two meditation types. This iterative adjustment aimed to strengthen our ability to address the research question regarding differential effectiveness, even within the constraints of our N=4 study.

The study was structured into distinct phases:

1. **Baseline Phase (Days 1-4):** Participants followed their normal pre-sleep routines without using the specified meditation application. Data collected during this phase served as the control condition for comparison.
2. **Intervention Phase (Days 5-10):** Participants were instructed to use the meditation application before sleep each night. This phase included sub-conditions to explore different aspects of the app's use:
    - Forced Modality Days: Specific days were allocated for mandatory use of either Music-based meditation or Guided Voice meditation (e.g., Days 6 & 8) to allow for direct comparison of these types.
    - User Preference Days: The final days (e.g., Days 9 & 10) allowed participants to choose their preferred meditation type, providing insight into user choice and its potential impact.

Quantitative data (objective sleep metrics, daily survey responses) were collected throughout both phases. Qualitative data were collected via semi-structured interviews conducted after the completion of the 10-day period. This concurrent collection allows for separate initial analysis of the quantitative and qualitative data strands, followed by **integration** during the interpretation phase. This integration aims to achieve triangulation, where quantitative trends (e.g., changes in sleep latency or efficiency) can be compared with, contextualized, and potentially explained by qualitative insights derived from participant interviews (e.g., reasons for preferences, perceived mechanisms of effect, usability feedback). While powerful for controlling individual variability, the design's reliance on a small sample size (N=4) inherently limits statistical power and the generalizability of findings, making the integration of qualitative data particularly crucial for a meaningful interpretation.

Independent & Dependent Variables:

Due to updated research design, these are the IVs and DVs of our experimental:
Independent Variables (IVs):

1. **Meditation Condition (Primary IV):**
   Levels: Baseline (No meditation) and Intervention (Meditation app use before sleep)
2. **Meditation Type (Secondary IV, within the Intervention Condition):**
   Levels: Guided Voice Meditation and Music-based Meditation

Dependent Variables (IVs):

1. Sleep onset latency.
2. Sleep duration
3. Sleep efficiency
4. Self-reported sleep quality
5. Final User preference for meditation techniques
6. Other Subjective Measures

Participant Demographics:

A total of four participants were recruited for this study, comprising two males and two females, with ages ranging from 22 to 24 years. All participants confirmed they had no pre-existing diagnosed sleep disorders, meeting a key inclusion criterion. Based on the pre-study survey, participants reported typically sleeping 6 hours per night. Most indicated they occasionally woke up during the night. Regarding prior experience with using meditation specifically for sleep, the sample was evenly divided: one participant had previously used meditation for sleep, while three had not. Despite this mixed prior experience, participants generally held positive expectations about the potential effectiveness of meditation for sleep improvement. Notably, three out of the four participants initially expected to prefer music-based meditation techniques, while one expected to prefer guided voice.

Participants were selected based on their willingness to participate, informed consent, and access to the necessary technology (meditation app and compatible sleep tracking device). This purposive sampling approach aimed to ensure engagement, although the small sample size (N=4) limits the generalizability of the findings.

Link for Pre - Study Survey Responses: Pre Study Survey Responses
Link for Daily Survey Responses i.e Participant Data.csv : CS 535 : Daily Survey Responses
Link for Post Study Interview Responses: CS 535 : Transcribed Interviews

Quantitative Data Analysis:

This report details the quantitative findings from a study evaluating the impact of a meditation mobile application on sleep quality among a small group of 4 participants. The primary objective was to assess whether using the app influenced objective sleep metrics, specifically Sleep Onset Latency (SOL) and Sleep Efficiency (SE). Sleep Efficiency was calculated using the following formula: **(Actual sleep time / Total time in bed) × 100%.**

Given the small sample size (N=4), the analysis relied on non-parametric statistical tests, with careful consideration given to descriptive statistics, visualizations, and effect sizes to interpret the findings.

Link for Quantitative Data Analysis i.e GitHub Repository Link: CS 535 Project GitHub Link

Objective:

The objective of the quantitative data analysis was to numerically measure and statistically evaluate the effect of the meditation app on specific sleep metrics. This involved quantifying changes in objective measures like sleep onset latency and sleep efficiency between baseline and intervention periods, comparing guided voice versus music meditation types, and testing the significance and strength of these changes and observed correlations using statistical tests appropriate for the small sample size.

- **Data Preparation:** Objective sleep data (Sleep Latency (m), Sleep Efficiency (%)) from Participant Data were processed. Participant averages for these metrics were calculated for distinct conditions: Baseline (Days 1-4), Intervention (all meditation nights, Days 5-10), Guided Voice nights (within Intervention), and Music-based nights (within Intervention).
- **Statistical Testing:** The Wilcoxon Signed-Rank test was employed for comparing paired conditions (e.g., Baseline vs. Intervention averages per participant). This non-parametric test is appropriate for paired data from small sample sizes where normality assumptions cannot be reliably verified.
- **Hypothesis Testing:** Directional (one-tailed) hypotheses were tested based on the expected effects of meditation (e.g., decreased latency, increased efficiency). The alpha level for statistical significance was set at $\alpha = 0.05$.
- **Effect Size:** The effect size r (calculated as $r = Z / \sqrt{N}$, where N=4 pairs) was calculated for Wilcoxon tests to estimate the magnitude of observed differences, which is crucial given the low statistical power of tests with N=4.
- **Correlation:** Spearman Rank Correlation was used to assess the monotonic relationship between per-night objective sleep metrics and self-reported sleep quality ratings, leveraging the larger number of data points available when pooling nights (N=40).

Hypothesis Testing Results:

<u>Hypothesis 1: Impact of Meditation on Sleep Onset Latency</u>

- **Null Hypothesis (H_0):** Median sleep onset latency is the same between Baseline and Intervention nights.
- **Alternative Hypothesis (H_1):** Median sleep onset latency is lower during Intervention nights compared to Baseline nights.
- Test Used: Wilcoxon Signed-Rank Test.
- Justification: Appropriate for comparing two related (paired) conditions (Baseline vs. Intervention averages per participant) with N=4, without assuming data normality.
- **Descriptive Statistics:** The median average sleep latency decreased from 58.62 minutes (Baseline) to 23.92 minutes (Intervention). Fig 1 shows a consistent decrease for all 4 participants.

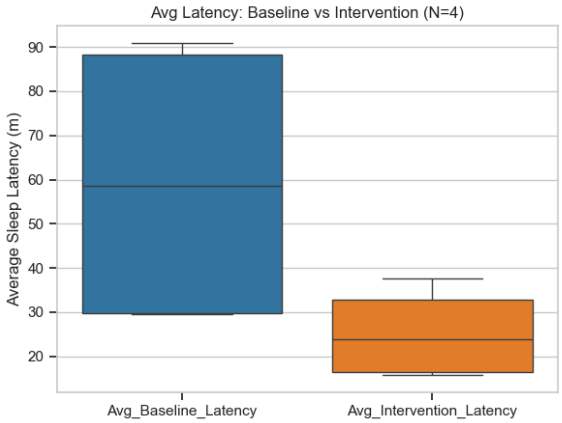

Fig 1: Box plot of average participant sleep latency for baseline vs intervention phases.

- **Results and Findings:** The Wilcoxon Signed-Rank test yielded W=10.00, with a one-tailed p-value of p = 0.0625. The calculated effect size was r = 0.913 (Very Large Effect).

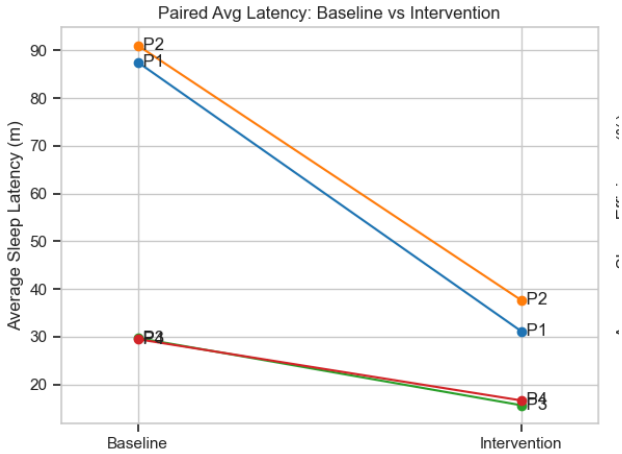

Fig 2: Paired plot of average participant sleep latency for baseline vs intervention phases.

- **Conclusion (H1) (Latency: Baseline > Intervention):** We fail to reject H_0 ($p \geq 0.05$). There is insufficient statistical evidence at the α=0.05 level to conclude that sleep onset latency was significantly lower during the intervention phase compared to baseline. However, the descriptive data, consistent trend across all participants, and the very large effect size (r=0.913) strongly suggest a potentially meaningful decrease in latency associated with the intervention, which failed to reach statistical significance likely due to the study's low statistical power (N=4).

Hypothesis 2: Impact of Meditation on Sleep Efficiency

- **Null Hypothesis (H_0):** Median sleep efficiency is the same between Baseline and Intervention nights.
- **Alternative Hypothesis (H_1):** Median sleep efficiency is higher during Intervention nights compared to Baseline nights.
- Test Used: Wilcoxon Signed-Rank Test.
- Justification: Appropriate for comparing two related (paired) conditions (Baseline vs. Intervention averages per participant) with N=4, without assuming data normality.
- **Descriptive Statistics:** The median average sleep efficiency increased from 81.35% (Baseline) to 90.97% (Intervention). Fig 3 shows a consistent increase for all 4 participants.

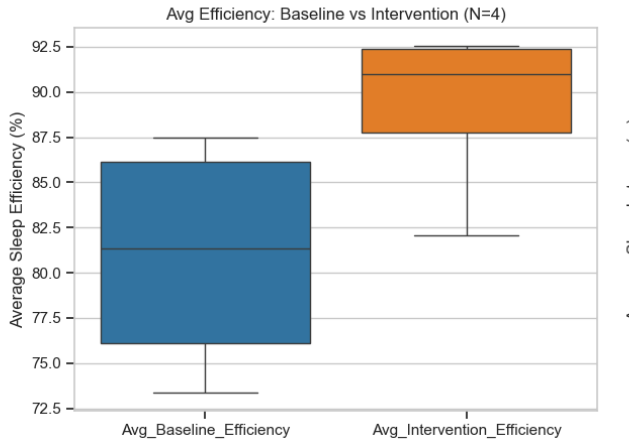

Fig 3: Box plot of average participant sleep efficiency for baseline vs intervention phases.

- **Results and Findings:** The Wilcoxon Signed-Rank test yielded W=10.00, with a one-tailed p-value of p = 0.0625. The calculated effect size was r = 0.913 (Very Large Effect).
- **Conclusion (H2) (Efficiency: Intervention > Baseline):** We fail to reject H_0 ($p \geq 0.05$). There is insufficient statistical evidence at the α=0.05 level to conclude that sleep efficiency was significantly higher during the intervention phase compared to baseline. Similar to H1, despite the non-significant p-value, the descriptive increase, consistency

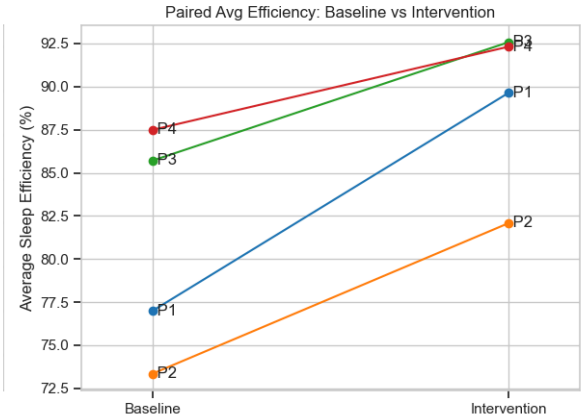

Fig 4: Paired plot of average participant sleep efficiency for baseline vs intervention phases.

across participants, and the very large effect size (r=0.913) provide suggestive evidence of a meaningful improvement in efficiency associated with the intervention, likely limited by statistical power.

Hypothesis 3: Comparing Guided Voice vs. Music-Based Meditation on Sleep Onset Latency

- **Null Hypothesis (H_0):** Median sleep onset latency is the same between Guided Voice nights and Music-based nights (within the Intervention phase).
- **Alternative Hypothesis (H_1):** Median sleep onset latency is lower on Guided Voice nights compared to Music-based nights (within the Intervention phase).
- Test Used: Wilcoxon Signed-Rank Test.
- Justification: Appropriate for comparing two related (paired) conditions (average Guided vs. average Music latency per participant) within the intervention phase for N=4, without assuming data normality.
- **Descriptive Statistics:** The median average sleep latency was lower for Guided Voice nights (17.50 minutes) compared to Music-based nights (35.08 minutes). The Fig 5 shows this trend consistently for all 4 participants.

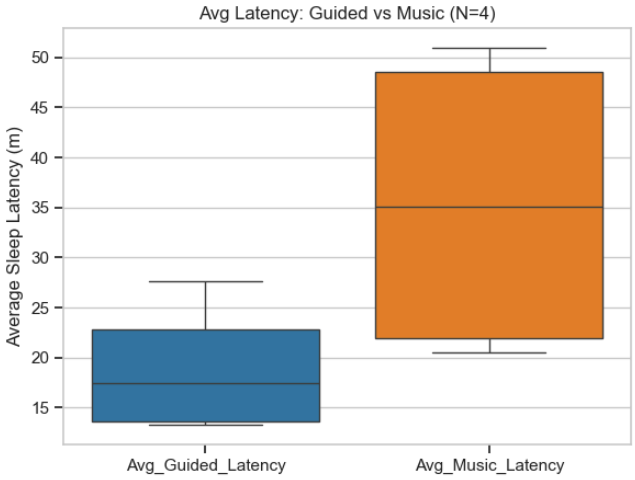

Fig 5: Box plot of average participant sleep latency for guided vs music based meditation days.

- **Results and Findings:** The Wilcoxon Signed-Rank test yielded W=0.00, with a one-tailed p-value of p = 0.0625. The calculated effect size was |r| = 0.913 (Very Large Effect).

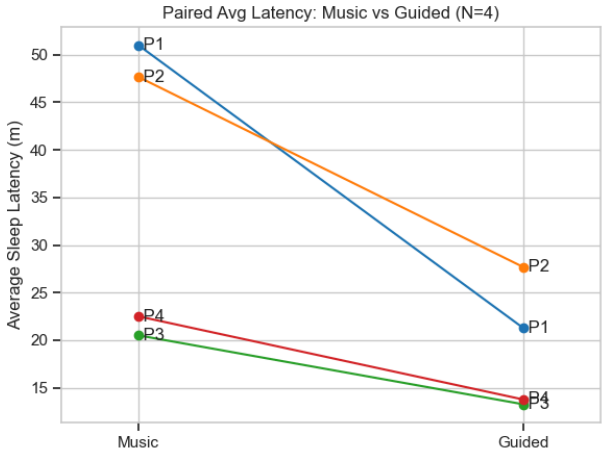

Fig 6: Paired plot of average participant sleep latency for guided vs music based meditation days.

- **Conclusion (H3) (Latency: Guided < Music):** We fail to reject H_0 ($p \geq 0.05$). There is insufficient statistical evidence at the $\alpha=0.05$ level to conclude that Guided Voice meditation leads to significantly lower sleep latency compared to Music-based meditation. Again, despite the non-significant result due to low power, the consistent descriptive difference favoring Guided Voice, observed across all participants and accompanied by a very large effect size ($|r|=0.913$), suggests a potentially meaningful difference between the meditation types that warrants further investigation.

<u>Hypothesis (H4): Testing the relationship between objective metrics and subjective quality ratings.</u>

- **Null Hypothesis (H_0):** No significant correlation exists.
- **Alternative Hypothesis (H_1):** A significant correlation exists.
- Test Used: Spearman Rank Correlation.
- Justification: Suitable for assessing monotonic relationships between potentially non-normally distributed variables, using pooled per-night data (N=40).
- **Descriptive Statistics:** Per-night data descriptives are available in GitHub repository. Distributions are visualized in Fig 7.
- **Results and Findings:**
    - Latency vs. Quality: Spearman's rho = -0.583, p = 0.0001.
    - Efficiency vs. Quality: Spearman's rho = 0.747, p = 0.0000.

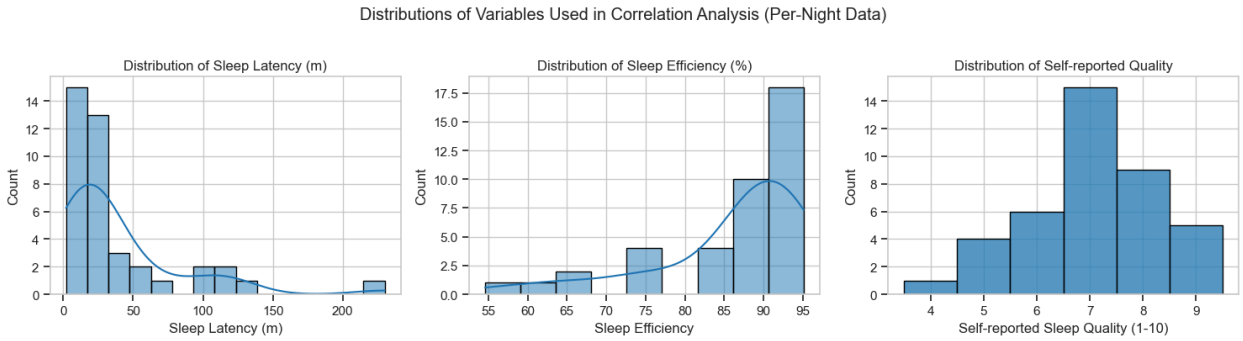

Fig 7:Correlation analysis between objective and subjective sleep data.

- **Conclusion (H4):** We reject H_0 for both correlations ($p < 0.05$). There is a statistically significant, moderate-to-strong negative correlation between sleep latency and self-reported quality, and a statistically significant, strong positive correlation between sleep efficiency and self-reported quality. This indicates that participants' subjective assessments of their sleep quality align significantly with these objective measures – faster sleep onset and higher efficiency correspond to feeling sleep was better.

Overall Conclusion of Quantitative Analysis

The quantitative analysis of this N=4 study indicates clear and consistent trends suggesting potential benefits of the meditation app intervention. Descriptively, sleep onset latency decreased, and sleep efficiency increased during the intervention phase compared to baseline for all participants. Guided voice meditation showed a descriptive advantage over music-based meditation for reducing sleep latency, again consistently across participants. These observed differences were associated with very large effect sizes ($r \approx 0.91$).

However, due to the extremely limited statistical power inherent in a study with only four participants, none of the primary hypotheses comparing conditions (H1, H2, H3) achieved statistical significance at the conventional $\alpha=0.05$ level (all $p=0.0625$). Therefore, we cannot formally conclude statistically significant effects based solely on these tests.

Significant correlations were found between objective sleep metrics and self-reported sleep quality when analyzing pooled per-night data, suggesting that subjective perceptions align well with objective latency and efficiency measures.

In summary, while statistical significance was lacking for the primary comparisons due to low power, the combination of consistent directional trends across all participants, very large effect sizes, and significant correlations provides suggestive quantitative evidence supporting the potential positive impact of the meditation app (particularly Guided Voice) on sleep latency and efficiency. These findings strongly underscore the need for integration with qualitative data to provide context, explanation, and a more complete understanding of the observed phenomena.

Qualitative Data Analysis:

Objective:

The objective of the qualitative data analysis was to deeply explore and understand participants' subjective experiences, perceptions, and the context surrounding their use of the meditation app. Through analyzing interview transcripts, the goal was to identify key themes related to perceived benefits (like relaxation), reasons for preferences (e.g., for guided voice), challenges faced during use, and the overall lived experience, capturing the "why" and "how" behind the quantitative observations.
Link for the Qualitative Data Analysis i.e codebook: CS 535: Codebook

Methodology:

A reflexive thematic analysis approach using Atlas.ti, guided by the principles outlined by Braun & Clarke (2006), was employed to analyze the transcripts from semi-structured post-study interviews conducted with all four participants (N=4). The analysis aimed to identify recurring patterns and themes related to participants' subjective experiences with the meditation app, perceived changes in sleep, preferences, benefits, challenges, and overall feedback. The process involved familiarization with the data, systematic line-by-line coding, searching for themes by collating codes, reviewing potential themes against the data, defining and naming the final themes

Codebook Development:

The objective of developing the codebook was to establish a systematic and reliable framework for the qualitative analysis of interview transcripts. It defined a set of codes : labels representing specific concepts or ideas (e.g., 'Quieted Mind', 'Time Constraint') ensuring consistent application across all interviews. This structured approach facilitated the organization of complex narrative data and enabled the rigorous identification of recurring patterns and themes relevant to the research questions.

Theme	Codes
PT 1: Enhanced Perceived Sleep Quality & Efficiency with Meditation	Improved SQ Rating
	Meditation Better than Baseline
	Faster Sleep Onset (Perceived)
	Increased Morning Refreshment/Well-Rested
	More Solid/Less Interrupted Sleep
PT 2: Guided Voice Meditation as the Preferred & More Effective Modality	Preference: Guided Voice
	Guided Voice Felt Best/Better

	Guided Voice: Helps Focus
	Music: Mind Wandering
	Music: Less Effective/Boredom
	Music: Lower Perceived Efficiency/Quality
	Preference Changed (Music to Guided)
	Stable Preference (Guided)
	Guided Voice: Soothing/Engaging
PT 3: Key Benefit - Pre-Sleep Relaxation & Mental Quieting	Benefit: Pre-Sleep Calmness/Relaxation
	Benefit: Wind Down
	Benefit: Reduced Restlessness
	Benefit: Reduced Anxiety
	Benefit: Quieted Mind / Settle Down
NT 1: Practical Barriers to Consistent Use	Challenge: Time Constraint
	Challenge: Forgetting/Tiredness
	Challenge: Technical (Watch Charge)
	Challenge: Drifting Off During Session
	Challenge: Session Length (Too Long)
	Challenge: Environmental Noise
NT 2: Future Intentions & Specific App Feedback	Future Intentions
	Suggestion: Auto-Stop App
	Suggestion: Shorter Options
	Suggestion: More Personalization (Anxiety)
	Liked App Personalization (Existing)
	Reminder for Charging
	Interest in Data

Findings: Identified Themes

Five main themes emerged from the analysis:

PT 1: Enhanced Perceived Sleep Quality & Efficiency with Meditation

Participants consistently reported subjective improvements in their sleep during the meditation intervention phase compared to the baseline phase. This encompassed perceptions of falling

asleep faster, feeling more refreshed upon waking, experiencing more solid/less interrupted sleep, and rating their overall sleep quality higher on meditation nights.

PT 2: Guided Voice Meditation as the Preferred & More Effective Modality

A strong and consistent preference emerged across all participants for guided voice meditations over music-based options. This preference was primarily attributed to the guided voice's ability to provide structure, enhance focus, prevent mind-wandering, and consequently be perceived as more effective in facilitating relaxation and improving sleep outcomes compared to music.

PT 3: Key Benefit - Pre-Sleep Relaxation & Mental Quieting

The most significant perceived benefit derived from the meditation practice was its ability to induce a state of calm and relaxation before bed. Participants highlighted feeling less restless, less anxious, and experiencing a quieting of racing thoughts, which they perceived as crucial for facilitating the transition to sleep.

NT 1: Practical Barriers to Consistent Use

Despite the perceived benefits, participants encountered several practical challenges that could potentially hinder consistent, long-term adherence to the meditation routine. These included difficulties finding time, general tiredness making it hard to initiate a session, forgetting to perform the meditation or related study tasks (like charging the watch), and environmental factors like noise. The length of sessions was also mentioned as a potential barrier on busy days.

NT 2: Positive Future Intentions & Specific App Feedback

Participants generally expressed a positive outlook towards continuing meditation, particularly the preferred guided voice sessions, as part of their routine, especially on difficult nights. They also provided specific, actionable feedback for the app developers, suggesting features like automatic session stopping, options for shorter sessions, and potentially more personalized content (e.g., focused on anxiety).

Conclusion of Qualitative Data Analysis:

The qualitative data strongly supports the conclusion that participants perceived a positive impact of using the meditation app on their sleep quality compared to baseline (Theme 1). They consistently reported improvements in several subjective sleep parameters, including sleep onset latency and feeling more rested.

Furthermore, the analysis reveals a clear preference for guided voice meditation over music-based options (PT 2). This preference was not arbitrary; participants articulated specific reasons related to focus, structure, and reduced mind-wandering, linking the guided voice

modality to greater perceived effectiveness in achieving the desired pre-sleep state of relaxation and mental quietude (PT 3). The experience of P3, who initially tried music, found it lacking, and then experienced significant improvement after switching to guided voice, provides compelling evidence for the differential effect.

Mixed Method Integration:

Objective:

The objective of the mixed-methods approach was to synthesize findings from both the quantitative and qualitative analyses to gain a more comprehensive, holistic, and validated understanding of the meditation app's impact. By integrating numerical trends with participant narratives, the aim was to triangulate results, use qualitative insights to explain quantitative patterns (especially non-significant findings or preferences), enrich the data with contextual detail, and ultimately produce more robust and nuanced conclusions than either method could achieve alone.

Approach:

A mixed-methods approach was employed to synthesize the quantitative findings and qualitative themes, aiming for a more comprehensive and nuanced understanding. This involved:

- **Triangulation:** Using qualitative data to corroborate and add depth to quantitative trends.
- **Explanation**: Leveraging qualitative insights to understand why certain quantitative results (or lack thereof) occurred.
- **Complementarity**: Incorporating rich qualitative details not captured by quantitative metrics.
- **Case Analysis**: Examining individual participant data to illustrate the interplay between objective and subjective experiences.
- **Addressing Non-Significance:** Employing a "weight of evidence" approach combining quantitative trends (direction, effect size) with qualitative convergence to interpret findings robustly despite the small sample size.

Integrated Findings:

Okay, here is the shortened "Integrated Findings" section with the quotes formatted in italics:

Integrated Findings:

1. **Convergence on Sleep Improvement (H1 & H2 + PT1):** Despite non-significant tests ($p=0.0625$), quantitative data showed strong trends (large effect sizes, $r \approx 0.91$) towards reduced sleep latency and improved efficiency during the intervention. This strongly aligns with qualitative findings (Theme PT1) where participants unanimously perceived these benefits, noting faster sleep onset (*"Yes, I think I was falling asleep quicker most*

nights during the intervention." - P4) and better quality nights (*"The meditation nights were definitely better than baseline."* - P3). Furthermore, perceptions of more solid sleep (*"And I wasn't waking up as much during the night, it felt like more solid sleep..."* - P3) and feeling more rested (*"I felt a bit more rested some mornings too..."* - P2) were common. This convergence provides compelling evidence suggesting a positive impact, likely limited in statistical detection by the small sample size.

2. **Explanation of Guided Voice Superiority (H3 + PT2):** The quantitative trend favoring guided voice for lower latency ($p=0.0625$, $r \approx -0.91$) is clearly explained by qualitative data (Theme PT2). Participants universally preferred guided voice, citing better focus (*"It was easier to focus when someone was talking and guiding you."* - P2) and finding it *"more engaging and they helped me focus my thoughts better"* (P4). Conversely, music allowed mind-wandering (*"With the music... my mind would still wander a lot,"* - P1). P3 found music less impactful (*"I initially tried the music-based meditation... and I didn't feel much. I felt a bit bored..."*), and their switch to guided voice because it *"felt much better, more effective"* further illustrates this difference.
3. **Alignment of Objective and Subjective Perceptions (H4 + PT1):** Significant quantitative correlations confirmed that lower latency (rho=-0.583) and higher efficiency (rho=0.747) strongly predict higher self-reported sleep quality. This validates subjective reports (Theme PT1), as participants explicitly linked better experiences to higher ratings (e.g., P1: *"Hmm, before I'd say maybe a 6 on average... Now, I think it's generally better, maybe closer to an 8... during the meditation phase"*).
4. **Mechanism of Action - Relaxation (PT3):** Qualitatively, the primary perceived benefit driving sleep improvement was pre-sleep relaxation and mental quieting (Theme PT3). Participants reported feeling *"more calm and relaxed before bed"* (P4) and that meditation *"really helped quiet my mind compared to before"* (P1). P3 specifically mentioned *"Feeling more relaxed and less anxious before bed."* This provides context for *how* the app likely works.
5. **Contextual Factors - Barriers and Feedback (NT1 & NT2):** Qualitative data revealed practical barriers like time constraints (*"Sometimes it was hard to find the time, especially if I had a late night."* - P1) and environmental noise (*"And my roommates were a bit noisy sometimes, which made it hard to really focus occasionally."* - P4) that add real-world context and may explain quantitative variability. Actionable feedback like P2's suggestion (*"It would be cool if the app could detect that and maybe stop the session..."*) was also provided.
6. **Individual Variability (Case Analysis):** Examining individual participant journeys (e.g., P1's significant latency drop alongside a clear preference: *"Definitely the guided voice... I liked having someone guide me"* ; P3's switch after finding music ineffective: *"...my mind still wandered... I felt a bit bored... [Guided Voice] felt much better, more effective"*) revealed nuances in responses, underscoring the value of integrating individual qualitative narratives.

Discussion of Results (with respect to the Research Questions) :

This study aimed to evaluate the impact of a meditation app on sleep quality using a mixed-methods approach. The integration of quantitative and qualitative findings provides a richer understanding than either method alone, particularly given the limitations of the small sample size.

RQ1: How does using meditation sessions before bed influence sleep onset and sleep efficiency over a short-term period?

The quantitative analysis revealed strong trends towards reduced sleep onset latency and increased sleep efficiency during the intervention phase ($r \approx 0.91$), though failing to reach statistical significance ($p=0.0625$). This numerical suggestion is powerfully corroborated by qualitative data (Theme PT1), where participants unanimously perceived these exact improvements. P4 explicitly linked the intervention to faster sleep onset, stating, *"Yes, I think I was falling asleep quicker most nights during the intervention – my latency times were lower then."* Similarly, P2 perceived increased restfulness: *"I felt a bit more rested some mornings too, like."* The convergence strongly suggests a positive impact, meriting larger-scale investigation.

RQ2: How do participants perceive their sleep quality on nights with and without app usage, and how does this align with objective sleep metrics?

Participants consistently perceived their sleep quality as better on meditation nights compared to baseline (Theme PT1). P3 stated unequivocally, *"The meditation nights were definitely better than baseline."* This subjective perception demonstrated strong alignment with objective metrics through significant correlations (H4): nights with lower objective latency and higher efficiency received higher self-reported quality ratings. P1 exemplified this connection: *"Hmm, before I'd say maybe a 6 on average... Now, I think it's generally better, maybe closer to an 9.."* This indicates participants' subjective assessments accurately reflected key objective sleep parameters.

RQ3: How do user preferences for different meditation techniques (guided voice vs. music-based relaxation) change over the study period and align with their sleep goals?

A clear and consistent preference for guided voice meditation emerged (Theme PT2). The quantitative trend favored guided voice for lower latency (H3, $r \approx -0.91$). Qualitatively, this preference was strong and explicitly linked to effectiveness for sleep. P2 explained the benefit for focus: *"It was easier to focus when someone was talking and guiding you," contrasting with music where "my thoughts would still race."* P1 also noted music's tendency to allow distraction: *"...my mind would still wander a lot."* Participants perceived guided voice as better aligned with their goal of using meditation to improve sleep, viewing music as less effective, as P4 summarized: *"[Music] I found I could get distracted more easily, and my sleep quality and experience weren't quite as nice on those nights."*

Core Perceived Benefit and Context:
Beyond specific metrics, the core benefit consistently highlighted was pre-sleep relaxation and mental quieting (Theme PT3). Participants felt the meditations helped them achieve a calmer pre-sleep state, as P1 described, *"It really helped quiet my mind compared to before."* P4 echoed this, valuing *"Just feeling more calm and relaxed before bed, instead of my mind racing."* This perceived mechanism likely underpins the observed effects on sleep onset. However, practical barriers identified in Theme NT1, such as P1 finding it *"hard to find the time, especially if I had a late night,"* represent real-world usage challenges that add important context to the findings.

Validity and Reliability of Findings:

Reliability:

Objective sleep data relied on consumer-grade smartwatches. While not as precise as polysomnography, they provide reasonable trend estimates for metrics like latency and efficiency in field studies. Standardized survey questions were used for daily subjective ratings, ensuring consistency in questioning. The reliability of the thematic analysis was supported by a systematic, inductive process with clear code definitions applied consistently across all interview transcripts.

Internal Validity:

The within-subjects design is a key strength, controlling for stable individual differences by comparing each participant's intervention results against their own baseline.Confidence in findings is enhanced by the convergence observed between quantitative trends (e.g., reduced latency) and qualitative reports (e.g., participants feeling they fell asleep faster).

Lack of a placebo control group prevents definitive causal claims attributing effects solely to the meditation content versus participant expectation or routine change.Potential order effects (baseline always preceding intervention) exist, although the short 10-day duration may limit their impact.

External Validity:

Sample Limitations: Findings have limited generalizability due to the very small sample size (N=4) and the specific demographic profile (age 22-24, likely students).Results are exploratory and indicative for this specific group, not statistically generalizable to wider populations (e.g., older adults, individuals with diagnosed sleep disorders) without further research.

Ecological Validity:

Setting & Task: The study possesses good ecological validity as it was conducted in participants' natural home environments, using a commercially available app and wearable technology as they

might in real life. Real-World Relevance: The identification of practical barriers (time constraints, tiredness, environmental noise) through qualitative interviews reflects authentic challenges faced during real-world use, further supporting the ecological relevance of the findings.

Generalizability of the Study:

The findings of this study have limited generalizability due to the very small sample size (N=4) and the specific participant characteristics (e.g., age range 22-24, likely students, recruited from a specific context). The results should be considered exploratory and indicative, rather than statistically generalizable to a broader population of meditation app users or individuals with sleep difficulties. However, the qualitative insights regarding user experience, preferences (Guided vs. Music), perceived benefits (relaxation), and barriers may possess greater transferability and relevance for understanding how similar individuals might interact with such apps.

Future Scope:

Based on these findings and limitations, future research should:

1. **Increase Sample Size:** Replicate the study with a significantly larger and more diverse sample (age, gender, sleep history) to achieve adequate statistical power, confirm quantitative trends, and allow for subgroup analyses.
2. **Extend Duration:** Conduct a longer-term study (e.g., 4-8 weeks) to assess the sustainability of effects beyond novelty and potential habit formation.
3. **Test Novel Features:** Incorporate and A/B test features suggested by participants (Theme NT2), such as variable session lengths, anxiety-specific content, and auto-stop functionality, evaluating their impact on usability and outcomes.
4. **Explore Mechanisms:** Investigate the physiological correlates of the perceived relaxation effect (e.g., heart rate variability during meditation) to better understand the underlying mechanisms.
5. **Compare Modalities:** Conduct comparative studies focusing specifically on different types of guided meditations (e.g., body scan vs. visualization) or comparing different apps.

Conclusion:

This mixed-methods study provides valuable exploratory insights into the impact of using a meditation app on sleep quality for a small group of young adults. While limited by the sample

size, the findings demonstrate a compelling convergence between quantitative trends and qualitative experiences. Participants consistently perceived improvements in falling asleep faster and experiencing better quality sleep during the intervention phase, strongly aligning with objective data trends showing reduced latency and increased efficiency (supported by large effect sizes, though p=0.0625). Guided voice meditation was clearly preferred and perceived as more effective than music-based options, primarily due to its ability to aid focus and reduce mind-wandering. The core perceived benefit was pre-sleep relaxation and mental quieting.

Despite practical barriers to consistent use, the overall positive experience suggests that meditation apps, particularly those featuring guided voice sessions, hold significant potential as accessible tools for improving subjective sleep quality. The mixed-methods approach proved crucial in painting a richer, more nuanced picture than quantitative data alone could provide, highlighting the importance of integrating user voices when evaluating such interventions. Further research with larger samples is warranted to confirm these promising initial findings.

References:

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Contributions:

Team Member	Key Contributions
Sanmitha Shetty	• Project Planning & Coordination • Literature Review • Lead Interviewer, • Qualitative Data Analysis (Thematic Analysis, Codebook Development) • Mixed-Methods Integration • Presented final results and discussions. • Report Writing • Presentation Preparation
Shreyash Kadam	• Research Proposal Development • Study Design & Methodology • Daily Reminders • Instrument Setup and Maintenance • Python Scripts for Smartwatch data • Quantitative Data Analysis (Statistical Testing, Visualization) • Mixed-Methods Integration • Report Final Review
Raksha Parag Pawar	• Data Management & Cleaning • Created Pre Study Form • Created daily survey form • Presentation Preparation • Participant Recruitment & Onboarding

Link for working document: CS 535 Project Working Doc

GitHub Repository Link: CS 535 Project GitHub Link