My Title

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***Abstract*—**
***Index Terms*—**

I. Introduction

Insomnia and insomnia-related sleep disturbances remain among the most prevalent behavioral health concerns, with growing evidence indicating that contemporary digital lifestyles play an important role in shaping sleep health. Recent consensus reports and large-scale reviews consistently show that screen-based media use is associated with shorter sleep duration, longer sleep onset latency, and poorer subjective sleep quality, particularly when device use occurs close to bedtime [1], [2]. These associations are explained through a combination of biological and behavioral mechanisms. Exposure to short-wavelength blue light emitted by digital devices suppresses melatonin and delays circadian rhythms [3], [4], while interactive and highly engaging online content increases cognitive and emotional arousal that interferes with the natural de-arousal process required for sleep initiation [5], [6]. In addition, prolonged digital engagement displaces time that would otherwise be allocated for rest and recovery [7]. Recent studies further suggest that the timing of screen exposure, especially during the evening period, may be more strongly related to sleep disruption than total daily screen time alone [8], [9].

Despite the growing body of literature, most existing studies rely on cross-sectional or between-person designs and self-reported behavioral measures, limiting the ability to capture short-term and within-person dynamics of screen use and sleep [2], [10]. Laboratory studies have provided strong mechanistic evidence on the effects of blue light and cognitive stimulation on circadian and neurophysiological processes [3], [11], but their findings are seldom examined under real-world conditions using intensive daily behavioral data. Moreover, although physical activity is well established as a protective factor for sleep and insomnia symptoms [12], [13], its potential role in moderating the sleep-disrupting effects of evening screen exposure remains insufficiently investigated.

Motivated by these gaps, this study examines whether personal screen time behaviors, with particular emphasis on evening exposure, are statistically associated with insomnia-related sleep disturbances using daily self-logged data from a single participant. By applying correlation analysis, comparative hypothesis testing, and regression-based approaches to intensive longitudinal records of screen use, sleep indicators, and physical activity, the study aims to provide data-driven insights into short-term behavioral patterns that may inform individualized and practical strategies for improving sleep quality.

II. Literature Review

A. Screen Time and Digital Media Use as a Risk Factor for Insomnia

The rapid integration of digital technology into daily life has established electronic media use as a primary behavioral risk factor for sleep disturbances. A 2024 consensus statement by the National Sleep Foundation confirmed that screen use, particularly within the hour before bedtime, is universally associated with degraded sleep health across the lifespan [6]. A large-scale systematic review of adolescents and young adults supports this consensus, which consistently linked mobile phone and social media use to shorter sleep duration and increased sleep onset latency [1].

The literature identifies a tripartite mechanism through which digital media disrupts sleep: time displacement, psychological stimulation, and circadian disruption [2]. Time displacement occurs when media use directly replaces time intended for rest, a phenomenon observed to be particularly severe during the COVID-19 lockdowns, where increased evening screen exposure was directly correlated with a worsening time course of insomnia symptoms [9].

Psychological and cognitive arousal also play a critical role, especially regarding interactive media. Unlike passive media such as television, interactive platforms like TikTok and Instagram induce high levels of cognitive arousal that are incompatible with the ”de-arousal” phase required for sleep onset [11]. Neurobiological evidence suggests that digital addiction stimulates dopamine and cortisol production, keeping the brain in a state of high alertness and suppressing the natural sleep drive [10]. This addictive behavior often leads to ”after-midnight” use, which serves as a significant mediator between compulsive internet habits and clinical insomnia [7].

Furthermore, the physiological impact of blue light exposure remains a dominant theme. Devices emitting short-wavelength light (450 nm) suppress melatonin secretion, thereby delaying circadian rhythms [2]. Research indicates that ”morning” chronotypes may be even more sensitive to this light-induced delay than ”evening” chronotypes [5].

Crucially, recent evidence suggests that the timing of screen exposure is a more potent predictor of insomnia than total daily duration [8]. While general daily screen time is associated with poorer outcomes, use within the 2-hour pre-bedtime window shows the strongest correlation with insomnia severity and daytime fatigue [4], [9].

B. Evening Screen Exposure, Blue Light, and Cognitive Arousal Mechanisms

The disruption of the human sleep-wake cycle by electronic devices is primarily a biophotonic and neurophysiological process. Research establishes that the human circadian system is most sensitive to short-wavelength light in the 460–480 nm ”blue” region [12], [13]. This specific spectral power distribution targets intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) containing the photopigment melanopsin, which sends direct signals to the suprachiasmatic nucleus (SCN) [12], [19]. Exposure to blue-enriched light from modern LED screens in the evening acts as a potent ”alertness signal,” biologically triggering a state of wakefulness that opposes the natural sleep drive [18].

Neurophysiological studies using Electroencephalography (EEG) have demonstrated that evening exposure to blue light shifts brainwave activity, increasing high-frequency Beta waves associated with active thinking and focus while decreasing Alpha waves required for relaxation [14]. This state of high cognitive arousal is characterized by faster reaction times and enhanced processing speeds, as evidenced by improved performance on Psychomotor Vigilance Tasks (PVT) and Digit Symbol Substitution Tests (DSST) following blue light exposure [20]. While these effects may enhance productivity during the day, their occurrence in the evening creates a ”circadian phase delay,” pushing the internal clock later and extending sleep onset latency [13], [15].

The consequences of this light-induced arousal are not limited to the night but extend into the following day. Structural Equation Modeling (SEM) has confirmed that pre-sleep gadget use is a significant predictor of ”next-day” memory impairments and concentration difficulties [15]. The suppression of slow-wave (deep) sleep and the disruption of the ipRGC-SCN-sympathetic neural pathway regulate the expression of master circadian genes like *Bmal1* and the repair of neural stem cells [16], [21]. Furthermore, experimental data on adolescent athletes reveal that even physically active individuals suffer from a ”motor performance hangover,” exhibiting reduced handgrip strength and explosive power following evening screen use [17].

Current research emphasizes that this disruption is a multidimensional threat to well-being, involving both circadian misalignment and physical digital eye strain [18]. Despite the everyday use of blue-light filters and ”Night Mode” settings, these countermeasures often fail to mitigate cognitive arousal, especially when the content is interactive or addictive [17], [18].

C. Physical Activity and Its Role in Sleep Quality and Insomnia

Physical activity (PA) remains proven as a robust, non-pharmacological intervention for improving sleep quality and mitigating insomnia symptoms. Systematic reviews and meta-analyses of randomized controlled trials (RCTs) confirm that regular exercise significantly reduces scores on the Insomnia Severity Index (ISI) and the Pittsburgh Sleep Quality Index (PSQI) [22], [26]. Physiological mechanisms, including adenosine accumulation, increase homeostatic sleep pressure throughout the day, and thermoregulation, where the subsequent drop in core body temperature after activity facilitates sleep onset [26], [28].

In the context of general population health, the total number of daily steps is a critical indicator of physical activity levels. Clinical reviews suggest that even light-to-moderate intensity aerobic activities, such as walking, are sufficient to improve sleep efficiency (SE) and increase total sleep time (TST) [26], [28]. Longitudinal evidence from decadal studies supports this, showing that individuals who maintain persistent physical activity habits—comparable to achieving consistent daily step targets—are significantly less likely to develop chronic difficulty falling asleep or excessive daytime sleepiness [24].

Furthermore, diverse demographics, including those with comorbid psychological stressors, show the protective role of physical activity[25]. By promoting parasympathetic dominance and reducing cortisol levels, physical movement acts as a physiological buffer against the ”arousal” states that characterize primary insomnia [27], [28]. While high-intensity interval training (HIIT) offers specific benefits for mood, moderate aerobic movement (walking) remains the most accessible and consistently beneficial form of activity for improving sleep architecture across the lifespan [26]. Despite the well-documented benefits of daily movement for sleep health, a significant research gap exists regarding the capacity of total daily steps to moderate the specific neurophysiological disturbances caused by evening digital media exposure. The research aims to address this by evaluating whether a high daily step count can neutralize the sleep-disrupting effects of high-energy visible (HEV) blue light.

III. METHODOLOGY

The following section details the research design and procedural framework employed to investigate the longitudinal relationship between digital behaviors, physical activity, and sleep outcomes. This methodology is structured to provide a replicable account of data acquisition, variable operationalization, and the statistical techniques used to evaluate the participant’s behavioral ecosystem.

A. Participants

This study utilizes a single-subject longitudinal research design ($n = 1$), focusing on a Gen Z college student. The participant represents a ”digital native” profile, characterized by high daily engagement with smartphones and tablets for academic communication, social networking, and entertainment. Given the academic and social demands of university life, the participant maintains an inconsistent sleep schedule with onset times ranging from 21:00 to 05:00. Despite this irregularity, the participant actively attempts to meet a physical activity target of at least 5,000 steps per day through campus-related commuting and gym attendance. This "Night Owl" profile provides a relevant baseline for examining how high-arousal digital habits interact with biological recovery.

B. Data Collection Methods

Data collection spanned 89 consecutive days from October 27, 2025, to January 25, 2026. The temporal window allowed for the capture of a variety of behavioral contexts, including standard academic weeks and holiday breaks. Digital engagement metrics were collected using the embedded Android Digital Wellbeing feature on both the participant's smartphone and tablet. This tool provides granular, sub-daily usage logs that eliminate the recall bias often associated with self-reported screen time.

A digital pedometer integrated into the smartphone recorded cumulative daily step counts. Sleep data were collected using a dual-method approach: objective duration, Sleep Start, and Sleep End times were used to determine sleep duration. In contrast, each morning, the participant records their subjective Sleep Quality in a manual diary in Google Sheets. This diary served as the central repository for merging objective device logs with subjective assessments.

C. Operational Definitions

To ensure analytical precision, the following variables were operationalized:

- Total Screen Time: The cumulative daily duration, in minutes, of active screen use across all mobile devices, calculated as the sum of usage in four six-hour diurnal blocks.
- Effective Evening Screen Time (TEST): The primary independent variable, defined as the sum of screen usage occurring between 18:00 and 06:00. This window represents the nocturnal period most critical to melatonin suppression and circadian alignment.
- Interactive vs. Non-Interactive Screen Time: Interactive screen time comprises cognitively demanding activities, specifically Social Media (e.g., Instagram, X) and Game Use. Non-Interactive usage refers to passive consumption, primarily through video app usage (e.g., Netflix, YouTube).
- Physical Activity (Steps): The total number of steps recorded in 24 hours.
- Sleep Metrics: Sleep Duration serves as the total minutes elapsed between Sleep Start and Sleep End. Sleep Quality is a subjective rating captured on a 4-point Likert scale (1 = Very Bad, 2 = Fairly Bad, 3 = Fairly Good, 4 = Very Good), adapted from the Pittsburgh Sleep Quality Index (PSQI).

D. Data Cleaning

Data preparation involved several stages to ensure compatibility between disparate metrics. Converting all sleep duration values from hours to minutes aligns with screen time units. A temporal shifting procedure was applied to the dataset to align behavioral "causes" with their subsequent "effects." Specifically, screen time and step counts from Day N were mapped to the Sleep Quality and Duration values reported on the morning of Day $N+1$. For the "digital hangover" analysis, features were further shifted to Day $N + 2$.

While no outliers were removed, as extreme values represent authentic behavioral fluctuations in a single-subject study, all continuous features were standardized into z-scores. This transformation was essential for the regression models, allowing for a direct comparison of predictors measured in different units (minutes vs. steps). Categorical features were also derived, such as "Steps Intensity" (Sedentary: ¡5,000; Active: 5,000–10,000; Very Active: ¿10,000) and "Evening Usage Category" (High vs. Low), based on the established 120-minute threshold.

E. Statistical Analysis

The analytical strategy utilized Python (v3.10) to execute a multi-tiered statistical evaluation. To address the relationship between screen volume and the ordinal sleep quality scale, Spearman's Rank Correlation (ρ) was employed, as it does not assume a normal distribution. To address the primary objective of comparing timing versus volume, a Standardized Ordered Logistic Regression (OLR) was used. This model enabled the estimation of Odds Ratios, quantifying the likelihood of shifting between sleep quality ranks with standardized increases in evening exposure.

To analyze objective sleep duration, a Multiple Linear Regression (MLR) was conducted. This model yielded coefficients that quantified the number of minutes of sleep lost per standard deviation of screen time. The Mann-Whitney U Test was used to validate the 120-minute threshold by comparing the distribution of sleep quality between high- and low-usage groups. Finally, a moderation analysis was performed by including an Interaction Term (Evening Screen Time $\times$ Steps) within the OLR framework to determine if physical activity levels altered the strength of the relationship between digital use and sleep quality. Visualizations, including standardized coefficient forest plots, regression slope plots, and time-series "mirror" plots, were generated to provide behavioral context and ensure the transparency of the longitudinal trends.

IV. Results

This chapter presents findings from exploratory data analysis to statistical hypothesis testing, ranging from associations between screen time and daily step count to insomnia-related sleep disturbances, particularly next-day sleep duration and sleep quality over the next two days.

A. Overview of the Dataset

The section provides a general characterization of the 89-day longitudinal dataset, presenting the central tendency and dispersion across the observation period. The data includes daily observations of screen time (24-hour and evening windows), physical activity (daily steps), and sleep metrics (quality and duration).

Table X. Descriptive Statistics of Daily Screen Time, Physical Activity, and Sleep Outcomes

The participant exhibited high levels of digital engagement, with an average Total Screen Time of 551.13 minutes ($SD = 168.59$), ranging from 123 to 912 minutes. Within this cumulative exposure, Social Media Usage ($\mu = 144.49$) and Games Usage ($\mu = 58.79$) accounted for significant portions of daily activity, with gaming showing the highest relative variance ($SD = 73.72$), indicating inconsistent play patterns over the study period.

Diurnal analysis of screen time distribution reveals that digital usage remained relatively consistent from midday through midnight, with the 12:00 to 18:00 ($\mu = 184.40$) and 18:00 to 24:00 ($\mu = 175.13$) windows showing the highest activity levels. Notably, the Effective Evening Screen Time, defined as usage within the high-arousal pre-sleep window (18:00 to 6:00 Next Day), averaged 243.99 minutes, which is nearly equivalent to the Daytime Screen Time average of 307.15 minutes. Descriptive statistics prove that nearly half of the participants' digital consumption occurs during circadian-sensitive periods. Furthermore, the participant favored Non-Interactive Screen Time ($\mu = 319.06$) over Interactive Screen Time ($\mu = 203.28$), although both metrics indicate substantial daily screen time.

Physical activity, measured by Steps, averaged 6,195.63 steps per day, reflecting a wide range of activity levels from sedentary (36 steps) to highly active (16,342 steps). Regarding sleep outcomes, the participant's self-reported Sleep Quality remained stable across both $t{+}1$ and $t{+}2$ measurements, with means of 2.67 and 2.69, respectively. These values, combined with a median of 2.0, indicate that the participant typically experienced "Fairly Bad" to "Fairly Good" sleep quality based on the adapted 1-4 Likert scale. Sleep Duration averaged 392.36 minutes (approximately 6.5 hours), with significant fluctuations evidenced by a standard deviation of 134.18 minutes and a minimum recorded sleep of 60 minutes.

B. Exploratory Data Analysis

To assess the longitudinal stability of the data, boxplots, histograms, and time-series visualizations were generated to identify descriptive distributions, temporal fluctuations, and behavioral cycles.

Figure X. Count Plot of Sleep Start Frequencies

The data reveals a distinct "Night Owl" chronotype, with the highest frequency of sleep events occurring between 01:00 and 02:00. Specifically, a peak of 25 instances was recorded at 02:00, followed by significant frequencies at 01:00 ($n = 16$) and midnight ($n = 15$). The distribution is notably right-skewed, with sleep onset occurring as late as 07:00. The vast majority of participants' pre-sleep arousal occurs during the biological night.

Figure X. Count Plot of Sleep End Frequencies

Peak frequency for waking was 08:00 ($n = 23$), with the majority of wake events concentrated between 06:00 and 09:00. This pattern suggests that despite late sleep onset, the participant maintains a relatively consistent morning wake window, likely due to external social or academic constraints. The narrow window between late onset and early wake times directly impacts the total sleep duration recorded throughout the study.

Figure X. Distribution of Total Screen Time

The distribution of total screen time was approximately normal, with a slight right skew toward 900 minutes. This distribution confirms that high-volume digital engagement was a consistent behavioral baseline throughout the study period.

Figure X. Distribution of Screen Time Across Different Times of Day

Screen time across different diurnal windows reveals significant variations in digital engagement throughout the 24-hour cycle. The nocturnal window of midnight to 06:00 exhibits the lowest median usage but contains outliers exceeding 300 minutes, indicating occasional nights of extreme nocturnal digital arousal. Usage remains relatively low in the morning window (06:00 to 12:00), with a median duration of approximately 125 minutes, suggesting a slower start to digital engagement. The afternoon and evening periods, with medians of approximately 175 minutes, were the highest sustained periods of digital activity. A narrow interquartile range in the evening window indicates high, sustained usage, consistent with the participant's habitual digital behavior before sleep onset.

Figure X. Distribution of Total Daytime Screen Time (Hours 6 to 18)

The distribution of Total Daytime Screen Time, defined as usage occurring between 06:00 and 18:00, follows a roughly normal curve with a moderate right skew, peaking between 225 and 275 minutes. While most daytime usage remains clustered around 400 minutes, observations extending to 600 minutes indicate days of intensive daylight digital activity.

Figure X. Distribution of Total Evening Screen Time

Analyzing the period most likely to disrupt the participant's biological sleep drive further elucidates digital engagement. The distribution of Effective Evening Screen Time (TEST), which captures usage from 18:00 to 06:00, is approximately normal, with a peak between 200 and 270 minutes. While the majority of evening sessions conclude within 400 minutes, the distribution includes instances of prolonged use extending up to 600 minutes, representing nights of nearly continuous digital exposure during the pre-sleep and nocturnal hours.

Figure X. Frequency Distribution of Steps

The frequency distribution of daily Steps is multimodal, peaking between 4,000 and 6,000 steps. While the participant reached peak activity levels exceeding 16,000 steps, a significant portion of the observations fell within the 0 to 4,000 range, representing more sedentary days.

Figure X. Frequency Distribution of Interactive Screen Time

Interactive Screen Time encompasses cognitively demanding activities such as gaming and active social media communication. The distribution peaks between 150 and 250 minutes, showing a relatively balanced engagement with interactive platforms throughout the study. While lower than the cumulative daily volume, the consistent presence of interactive usage, particularly in the evening, provides a basis for examining how active cognitive arousal competes with the biological drive for sleep.

Figure X. Frequency Distribution of Non-Interactive Screen Time

Non-Interactive Screen Time includes passive activities such as video streaming or reading. The frequency distribution is right-skewed, with a primary peak between 200 and 300 minutes and several instances extending beyond 600 minutes. The higher mean volume of non-interactive usage ($\mu = 319.06$) compared to interactive usage ($\mu = 203.28$) suggests that passive digital consumption is the participant's primary mode of engagement.

Figure X. Frequency Distribution of Next Day Sleep Quality

Next Day Sleep Quality was recorded on an adapted 1-4 Likert scale, answering the question "How well did you sleep last night?". The distribution is predominantly centered at a score of 2.0 ("Fairly Bad"), with more than 40 observations during the 89 days. While scores of 3.0 and 4.0 (indicating better sleep) were frequent, the relative scarcity of the highest quality rating and the presence of "Very Bad" (1.0) ratings suggest a baseline of suboptimal rest.

Figure X. Frequency Distribution of Next Day Sleep Duration

The distribution of sleep duration in minutes on the next day is approximately normal, with a distinct primary peak between 350 and 425 minutes, corresponding to the study's average sleep duration of approximately 6.5 hours. While most observations cluster around the 6.5-hour mark, the distribution shows substantial variability, including instances of extreme sleep deprivation and periods of extended recovery sleep exceeding 700 minutes.

Figure X. Spearman's Rank Correlation Matrix for Sleep Quality

Effective Evening Screen Time (TEST) was the most significant digital disruptor of perceived restfulness, exhibiting a moderate negative correlation of -0.42 with Sleep Quality. In contrast, Daytime Screen Time showed a weak positive correlation ($\rho = 0.19$), suggesting that digital engagement during daylight hours does not carry the same perceived sleep penalty as evening usage. Total Screen Time demonstrated a weak negative association ($\rho = -0.17$).

Figure X. Distribution of Total Screen Time across different Next Day Sleep Quality Values

The median total screen time remains relatively stable across the "Very Bad" (1.0), "Fairly Bad" (2.0), and "Fairly Good" (3.0) categories, hovering near the 550 to 600-minute mark. On days when the participant reported "Very Good" (4.0) sleep quality, the median total screen time dropped notably below 500 minutes. However, this category also exhibits significant variance and several high-usage outliers, suggesting that total daily volume alone is not a consistent predictor of peak sleep quality.

Figure X. Distribution of Evening Screen Time across different Next Day Sleep Quality Values

There is a discernible downward trend in the median evening screen time as sleep quality improves. The median usage for "Very Bad" (1.0) and "Fairly Bad" (2.0) sleep quality is consistently above 250 minutes, whereas the median for "Very Good" (4.0) sleep drops sharply to approximately 150 minutes. Days resulting in "Very Good" sleep quality (4.0) show a much tighter interquartile range (IQR) and are notably absent from the extreme high-usage outliers seen in the lower-quality categories.

Figure X. Pearson's Correlation Matrix for Sleep Duration

The Pearson correlation matrix confirms a significant inverse relationship between evening digital activity and sleep duration. Total Evening Screen Time showed the most substantial negative correlation with sleep duration ($r = -0.38$). Similar to the quality findings, Total Screen Time exhibited a much weaker negative association ($r = -0.19$). Non-Interactive Screen Time demonstrated a stronger negative association with duration than Interactive Screen Time ($r = -0.28$ vs. $r = -0.21$), suggesting that "passive" consumption in the evening may be more likely to lead to sleep displacement.

Figure X. Time-Series Plot of Total Screen Time and Sleep Duration Next Day

The data show significant daily variation in total digital engagement, with values frequently fluctuating between 400 and 800 minutes. There is no consistent visual pattern suggesting that peaks in total daily volume correspond directly to troughs in sleep duration. In complement with the Pearson correlation results ($r = -0.19$), total daily volume is a poor predictor of sleep length on a day-to-day basis.

Figure X. Time Series Plot of Total Evening Screen Time and Sleep Duration Next Day

In contrast, Total Evening Screen time shows a more pronounced inverse relationship. Sharp drops frequently follow periods of sustained high evening usage in the sleep duration line. The "mirroring" effect, where an upward spike in evening digital use coincides with a downward spike in sleep, is visually evident across several clusters in the 89-day sequence.

Figure X. Distribution of Steps per Sleep Quality Category

Unlike the evening screen time distributions, the relationship between step counts and sleep quality is less distinct. The median step counts for "Very Bad" (1.0) and "Fairly Good" (3.0) sleep are similar, suggesting that physical activity levels do not have a straightforward, unidirectional effect on perceived sleep quality for this participant. The presence of high-activity outliers in the "Fairly Bad" (2.0) category suggests that even high levels of physical exertion (15,000+ steps) were occasionally insufficient to overcome other sleep disruptors.

C. Association Between Total Daily Screen Time and Sleep

The primary objective sought to examine the relationship between cumulative daily screen volume and insomnia-related disturbances.

Table X. Spearman's Rank Correlation Matrix of Total Daily Screen Time

Both sleep quality and sleep duration are negatively correlated with total daily screen time, as shown in Table 2. The correlation values, -0.1730 for quality and -0.1852 for duration, represent weak associations. At the standard alpha level of 0.05, neither association reached statistical significance ($p = 0.1050$ and $p = 0.0823$, respectively), suggesting that total daily volume is not a reliable standalone predictor of sleep disturbances for the participant.

D. Association of Evening Screen Time vs. Total Screen Time in Insomnia-related Sleep Disturbances

Table X. Standardized Ordered Logistic Regression for Sleep Quality

A standardized ordered logistic regression model was used to evaluate the relative influence of the timing of digital exposure versus cumulative volume on subjective sleep quality. Total Evening Screen Time emerged as the dominant and highly significant negative predictor, yielding a coefficient of -1.7088 ($p < 0.001$), corresponding to an Odds Ratio of 0.1811. In contrast, Total Screen Time exhibited a significant positive coefficient of 0.7853 ($p = 0.011$) and an Odds Ratio of 2.1932 when modeled alongside the evening window.

Table X. Multiple Linear Regression Results for Sleep Duration

The physical impact on objective sleep duration was quantified using a multiple linear regression model. Total Evening Screen Time was the sole significant driver of fluctuations in sleep duration, with a negative coefficient of -71.5219 ($p < 0.001$), indicating that for every one-standard-deviation increase in evening screen use, the participant's sleep duration decreased by over 71 minutes. Conversely, Total Screen Time showed a non-significant association ($p = 0.157$), indicating that cumulative daily screen time does not reliably predict the number of minutes the participant slept when nocturnal timing was controlled.

Figure X. Regression Slope Plot of Total Evening Screen Time and Total Screen Time

The regression line for Total Evening Screen Time exhibits a steep, negative trajectory, while the line for Total Screen Time displays a much flatter, slightly positive trajectory. This visual contrast confirms that evening digital arousal is the primary driver of sleep reduction.

E. Comparative Analysis of High and Low Screen Time

Figure X. Comparison of Sleep Quality Proportion based on Screen Time Usage Category

Categorizing into "High" (> 240 min) and "Low" (≤ 240 min) evening usage groups enabled statistical testing of significant differences in sleep outcomes. On days with low evening screen time, the distribution is concentrated in the higher-quality ranks. Conversely, the High Evening Screen Time category shows a distinct shift toward "Fairly Bad" and "Very Bad" ranks.

Table X. Statistical Results of Average Sleep Quality between Low and High Screen Usage

A Mann-Whitney U test confirmed a statistically significant difference ($p = 0.0003$). The Median Sleep Quality for the Low usage group was 3.0 ("Fairly Good"), whereas the median for the High usage group dropped to 2.0 ("Fairly Bad"). The Z-score of 3.2249 and an Effect Size (r) of 0.3418 reinforce that the 240-minute mark serves as a statistically reliable "tipping point" for predicting suboptimal sleep outcomes.

F. Short-Term Temporal Effects of Screen Time Behaviors

Table X. Lagged Correlation Analysis for Temporal Effects of Screen Behaviors

A lagged correlation analysis evaluated the relationship between screen behaviors on day t and subjective sleep quality on day $t + 2$. Most digital behaviors do not maintain a statistically significant association by the second night. Evening Screen Time showed a diminished and non-significant correlation of -0.183 ($p = 0.0855$) when lagged, suggesting that the disruptive influence is primarily acute. Interestingly, Non-Interactive Screen Time emerged as a statistically significant positive predictor for sleep quality at the $t + 2$ lag ($\rho = 0.269, p = 0.0109$), indicating a potential delayed relaxation response.

G. Moderating Role of Physical Activity

Table X. Standardized Ordered Logistic Regression for Moderation Effect of Steps in Sleep Quality

An interaction model was evaluated to determine whether physical exertion buffers the sleep-disruptive effects of nocturnal digital engagement. The results indicate that physical activity does not significantly moderate the negative impact of evening screen time. Total Evening Screen Time remained the most substantial predictor by magnitude, while the Interaction term produced a non-significant p-value of 0.308. Disruptive influence of digital arousal during the nocturnal window persists regardless of physical activity levels, indicating that biological sleep quality is more sensitive to immediate light-emitting digital exposure than to the benefits of daily physical activity.

V. Discussion

The findings of this longitudinal study provide a detailed examination of the behavioral ecosystem governing the relationship between digital engagement and sleep. By analyzing 89 days of personal data, the results delineate a clear hierarchy of influence where the timing of screen exposure outweighs the cumulative volume of usage in predicting insomnia-related disturbances. This section interprets these findings through the lens of circadian biology and behavioral psychology, situating the results within the broader context of existing sleep literature.

A. Interpretation of Results

The primary finding of this research is the dominant role of evening screen time in predicting both subjective sleep quality and objective sleep duration. The statistical models revealed that while total daily screen volume had a negligible or even paradoxically positive relationship with sleep quality, the minutes accumulated after 18:00 exerted a severe penalty. The participant's biological sleep-wake cycle is relatively resilient to high-volume digital engagement during daylight hours but highly vulnerable to nocturnal exposure.

Sleep displacement and melatonin suppression likely explain this pattern. Because the participant exhibits a "Night Owl" chronotype, with sleep onset frequently occurring between 01:00 and 02:00, the evening screen window constitutes an extended period of high-intensity blue-light exposure and cognitive arousal. The 71-minute reduction in sleep duration per standard deviation increase in evening usage indicates that screen time is not merely a pre-sleep ritual but a direct competitor for sleep time. The "mirroring" effect observed in the time-series plots suggests that, as digital engagement spikes, the sleep window is physically compressed, likely due to "revenge bedtime procrastination", a phenomenon in which individuals stay awake late into the night to regain a sense of personal freedom after a day of academic or social constraints.

Furthermore, the observation that non-interactive screen time showed a stronger negative correlation with duration than interactive screen time was unexpected. While gaming and social media are high-arousal activities, the passive nature of video streaming may lead to longer, less monitored sessions. This "passive binging" likely facilitates a state of flow that masks the biological cues for sleepiness, leading to greater sleep displacement than the discrete sessions typical of interactive gaming.

B. Comparison to Related Work

The results of this study align closely with findings from researchers who emphasize that the timing of screen use is more critical than total duration. The significant negative association between evening screen time and sleep quality supports findings from studies that argue that blue-light-emitting devices used in the hours preceding sleep suppress melatonin secretion and increase alertness. The 120-minute threshold identified in the Mann-Whitney U test as a "tipping point" for sleep quality corresponds with the clinical recommendation to cease screen use at least two hours before bed to allow the circadian system to transition into a sleep-ready state.

Conversely, this study contradicts research suggesting that total daily screen time is a primary driver of insomnia among adolescents and young adults. In this dataset, total volume was not a significant predictor, given controlled nocturnal timing, suggesting that the "dosage" of screen time is only toxic when administered during the biological night. Additionally, the failure of physical activity to moderate the effects of screen time challenges the common assumption that a highly active day can "offset" the negative effects of a late-night digital lifestyle. While exercise generally promotes sleep through homeostatic drive, these results suggest that, for this participant, the acute arousal caused by evening light and content is a stronger force than the cumulative physical fatigue of the day.

C. Limitations

Several limitations must be acknowledged when interpreting these findings, the most prominent being the single-subject design ($n = 1$). While the 89-day observation period provides high internal validity for the participant, the generalizability of the results to the broader population or to different age groups remains in question. The study is also subject to self-report bias, particularly regarding the 1-4 Likert scale for sleep quality. Subjective assessments of "Fairly Good" or "Fairly Bad" rest may shift over time, depending on the participant's mood or daily stress levels, rather than on purely physical rest.

The reliance on mobile device tracking also presents a technical limitation, as it may not capture screen time from other devices, such as laptops or televisions, potentially underestimating total digital exposure. Furthermore, the 89-day window, while robust for an undergraduate study, may not account for long-term seasonal variations or the intense fluctuations of a full academic year.

D. Recommendations and Future Work

For future research, it is recommended that students adopt a multi-modal approach to data collection. Combining subjective Likert scales with objective physiological data, such as heart rate variability (HRV) or actigraphy from a wearable device, would provide a more nuanced understanding of sleep architecture beyond mere duration. Future studies should also consider the "content" of screen time more granularly; for example, distinguishing between academic work and entertainment, as the cognitive load of each may have different effects on sleep onset latency.

Researchers should also explore additional moderators, such as caffeine intake, room temperature, and light intensity, which were not accounted for in this study. Incorporating a larger sample size would enable cross-comparisons of different chronotypes to determine whether "Early Birds" exhibit the same 120-minute threshold as "Night Owls." Finally, intervention-based studies in which participants are required to implement a "digital detox" for a set period would be a valuable next step toward establishing a more definitive causal link between reduced evening screen time and improved longitudinal sleep health.

VI. Conclusion

The primary objective of this study was to evaluate the relationship between digital engagement and insomnia-related sleep disturbances by comparing the influence of cumulative daily screen volume against the specific timing of nocturnal exposure. By analyzing an 89-day longitudinal dataset, this research sought to determine whether the "dosage" of screen time or the "timing" of its use was the more potent driver of sleep quality and duration. The investigation was further extended to identify specific behavioral thresholds and to assess whether physical activity could moderate the physiological consequences of a high-intensity digital lifestyle.

The key findings of this research provide a definitive answer to the original research questions, indicating that the timing of digital exposure is a substantially more reliable predictor of sleep disturbances than total daily volume. While cumulative screen time showed a statistically nonsignificant association with sleep outcomes, effective evening screen time emerged as a dominant negative driver. Specifically, a 1-standard-deviation increase in evening usage was associated with a reduction of over 71 minutes in objective sleep duration and a nearly 82% reduction in the odds of achieving superior sleep quality. Furthermore, the study identified a 120-minute threshold as a critical "tipping point," beyond which the probability of suboptimal rest increases significantly. Perhaps most notably, the moderation analysis revealed that daily physical activity, although beneficial for overall health, did not protect participants from the sleep-disruptive effects of nocturnal digital arousal.

On a personal level, this analysis has provided profound insights into the mechanics of the "Night Owl" chronotype and the behavioral trap of sleep displacement. The data confirmed that my evening habits are not merely a means of unwinding but a primary source of physiological stress that reduces the body's recovery time. Learning that passive, non-interactive bingeing was more disruptive than interactive gaming was particularly illuminating, challenging my prior assumption that "relaxing" with a video stream was less harmful than the cognitive load of a video game. The evidence suggests that my digital behaviors are deeply integrated into a cycle of revenge bedtime procrastination, where the evening window becomes a contested space between digital autonomy and biological necessity.

These findings have direct applications for daily life and behavioral modification. The rejection of the "physical activity buffer" hypothesis suggests that a healthy lifestyle cannot be compartmentalized; one cannot simply "exercise away" the effects of poor digital hygiene. Instead, the results advocate for a strict temporal boundary on screen use, specifically the implementation of a digital "curfew" two hours before intended sleep onset. By maintaining evening screen time below the 120-minute threshold, the data suggests a statistically higher probability of achieving restorative rest. Applying these insights requires a shift in focus from reducing total screen time to strategically managing the nocturnal window, prioritizing circadian rhythm preservation over reducing cumulative screen time.

This study demonstrates that, for modern digital users, the clock is more important than the counter. Insomnia-related disturbances in this dataset were not a product of how much time was spent on a screen throughout the day, but rather a direct consequence of when that time occurred. The profound 71-minute sleep penalty associated with evening usage highlights a significant public health concern in an increasingly connected world. Ultimately, the preservation of sleep health in the digital age depends on recognizing the biological night as a protected space, requiring intentional behavioral constraints to prevent digital arousal from overriding the fundamental human need for rest.

References