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Visualizing Sleep Efficiency Patterns: Data to Insights

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This study aims to investigate the impact of various factors, including age, gender, and lifestyle behaviors such as smoking, alcohol consumption, and exercise, on sleep efficiency and patterns using a dataset collected from a study conducted in Morocco. The dataset comprises 386 participants, from 4 different age groups consisting of 2.9% adolescents, 22.9 % Young adults, 42.3% middle Adults, and 31.9% Late adults. Various statistical visualization tools of R programming language, like boxplots, scatterplots, grouping, correlation plots, pie charts, and mosaic plots, were used to analyze important patterns between these observed metrics. It was observed that sleep efficiency varies tremendously between age groups, ranging from 0.6 to 0.95, while sleep duration is constant throughout, ranging from 7 to 9 hours. Furthermore, on average, women struggle more with sleeping due to inconsistent sleep patterns shown through larger variations and outliers. Additionally, sleep efficiency had a significant relationship with age, Rapid Eye Movement (REM) sleep percentage, deep sleep percentage, alcohol consumption, smoking, and regular exercise. A very strong positive correlation was seen between sleep efficiency and deep sleep percentage (0.79) and a negative correlation between sleep efficiency and light sleep percentage (-0.82), awakenings (-0.57), and alcohol consumption (-0.45), respectively. Inactive lifestyles significantly impact sleep efficiency as indicated by greater Pearson residuals in the inactive groups, especially among females with low activity levels. These findings emphasize the significance of lifestyle factors on sleep quality and offer insights for enhancing sleep efficiency in various demographic groups.

1. Introduction

Sleep efficiency is a measure simplified to 'the ratio of time spent asleep to the time spent in bed' according to the American Psychological Association in 2018. However, in order to contextualize the measurement of sleep which is subjective in nature and to calculate the parameters to reach the ratio described by APA, it is important to have a systematic understanding of the sleep assessment tools developed to measure sleep quality. Thus, multiple methods have been created to measure the variable, such as Pittsburgh Sleep Quality Index (PSQI) first developed originally by Buysse et. al, (1989) as the most conventional scale to measure sleep but still remains the most widely used scale (Kinman, 2025). Moreover, Fabbri et al. (2021) provides a comprehensive understanding of all the scales and their psychometric properties including reliability, validity and highlights that sleep encompasses multiple measures including total sleep time (TST), total wake time (TWT) and sleep efficiency (SE), all used in our research to measure sleep quality. Thus, they all provide reliable measures of sleep, which then contributes to quantify the Sleep Efficiency Index (SEI) formula used in our research (Blackwell et. al, 2011):

SEI = (Total Sleep Time/Time in Bed) ×100

While sleep-efficiency is well-defined, we have limited literature investigating the cumulative effect of multiple factors on it. Correlations have been found in independent papers, such as effects of alcohol, age, gender, or exercise on SE. However, they exist in disparate, exclusive studies that overlook a multivariate analysis on participants. Previous literature identifies alcohol use disorder scores (AUDIT-KR) to be a major predictor of poorer sleep quality (Lau-Barraco et al., 2016; Sirtoli et al., 2023). Likewise, frequent or periodic physical activity significantly affects sleep efficiency, particularly in young adults (Chang et al., 2016; Gupta et al., 2018; Sejbuk, et al., 2022). Gender and age have also been identified as notable predictors, with women and younger people consistently exhibiting lower SEI indices compared to men (Mong & Cusmano, 2016; Madrid-Valero et al., 2019; Harrington et al., 2022). While these variables tend to show consistent results, other variables provide a mixed outlook: some population-based studies, for instance, claim the effect of caffeine to be non-existent in older adults (Sakal et al., 2024), while Gardiner et. al (2023) contend that caffeine reduces SE by 7% after a systematic review.

Nevertheless, all these results indicate that sleep efficiency, although being a subject of research, has minimal literature that takes a cumulative look of multiple predictors to understand their combined effect and determine the extent to which each variable affects it. This study aims to investigate this deficit by analyzing a Moroccan dataset of 386 participants whose age, gender, physical activity, smoking, and alcohol intakes are measured, alongside sleep awakenings, deep and light sleep percentages.

To proceed with this, we will first visualize our data using a variety of plots as exploratory data analysis; this will help us identify variables of significant effect. A Multiple Linear Regression Model—using the R language—will then provide insight into the variance explained by each on SE. The purpose of giving precedence to data visualization is that it may highlight certain results that quantification via regression fails to account for. We will then collectively interpret the results of our graphs and regression equation to understand the extent to which each factor affects sleep efficiency and provide a well-rounded outlook on our variable under discussion. This will allow us to comment on the urgency of addressing each factor to improve one's quality of life while also suggesting priorities for future research, as well as practical solutions for people struggling with inefficient sleep.

2. Literature Review

In order to understand the effect, the variables in our dataset can have on sleep efficiency, we procured various studies. Literature on age, gender, exercise frequency and alcohol, was selected and while some factors were more significant than others, some general consistent trends were seen.

The article, "Factors involved in sleep efficiency: a population-based study of community-dwelling elderly persons" (Desjardins et al., 2019) provided us with some general findings about two variables, age and gender. A geographic sampling method, in which random phone numbers were generated, was used, and the corresponding participants were interviewed by health professionals. Subsequent results were analyzed using descriptive statistics and logistic regression to discover that age and gender both have a notable effect on SE. While multiple other factors were involved in this study, age and gender were relevant to our data. The findings of this research indicated that the elderly and women struggled the most with SE.

Thus, we proceeded to include an article that only examined age and gender and found Madrid-Valero et al. (2016) to echo these findings in "Age and gender effects on the prevalence of poor sleep quality in the adult population." According to the logistic regression model employed on the self-reported data in this study, adults over 50 were more likely to suffer from insomnia. Furthermore, women exhibited a 3 times higher propensity for requiring sleep medication compared to men (1.41 times more likely to develop insomnia, according to additional literature included in this article). This gives us a general expectation to find age to be inversely correlated with SE in our analysis, with women struggling more with sleep than men.

Then, to observe how gender individually correlates with SE, we included a third article, "Sex differences in sleep: impact of biological sex and sex steroids" (Mong et al., 2016). One prominent claim of this article was that subjectively, women reported lower SE than men; however, clinical results suggested otherwise. However, further investigation of this paper revealed that the consensus, released by the 2005 State of Science Conference, was that women were at a 40% greater risk of insomnia, with age and gender being the top risk factors for insomnia. The contradictory claim about clinical results was explained by the fact that this study was a secondary review of previous research, including animal models, and was commenting on the validity of varying perspectives. The final conclusion here, too, was that the differences in sleep between genders were very prominent, even to the extent that drugs showed an opposite effect in deep sleep for each gender.

The next variable, which turned out to be a significant predictor of SE, was alcohol consumption. For this, we studied multiple articles, each positing the same finding: alcohol seriously disrupts SE. The first article, “The Effects of Alcohol on Quality of Sleep” (Park et al., 2015) combined both the Alcohol Use Disorder Identification Test- Korean revised version (AUDIT-KR) and the Pittsburgh Sleep Quality Index-Korean version (PSQI-K) and administered it on 393 people. Chi-square tests, independent sample t-tests, Mann- Whitney test, and a multiple regression model were then run on the results. It revealed that men who reported higher AUDIT-KR scores were positively correlated with PSQI-K scores, indicating the prevalence of poor SE in alcohol users. Although the proportion of women included in this study consumed lesser alcohol than men overall, poor SE was reported among higher alcohol usage women too. Another cross-sectional study, “Effects of Tobacco and Alcohol Consumption on Sleep Quality of University Students” (Mesquita et al., 2011) revealed further, that while sleep patterns were unaffected by alcohol, alcohol consumers were at greater risk for having poor sleep quality and developing sleep disorders. This study also utilized the PSQI scale. Further analysis was done using chi-square, Fisher’s exact, Mann-Whitney, and Kruskal-Wallis tests, showing significance below 5%.

Physical activity was another variable measured in our dataset, and the paper “Association Between Exercise Participation and Quality of Sleep and Life Among University Students in Taiwan” (Chang et al., 2016) offered detailed insights into it. It employed t-tests, chi-square tests, Pearson correlation coefficients, and multiple regression analysis on PSQI scores to conclude for a sample of 1,230 students that physical activity was a significant predictor of good sleep and was positively correlated with high sleep efficiency.

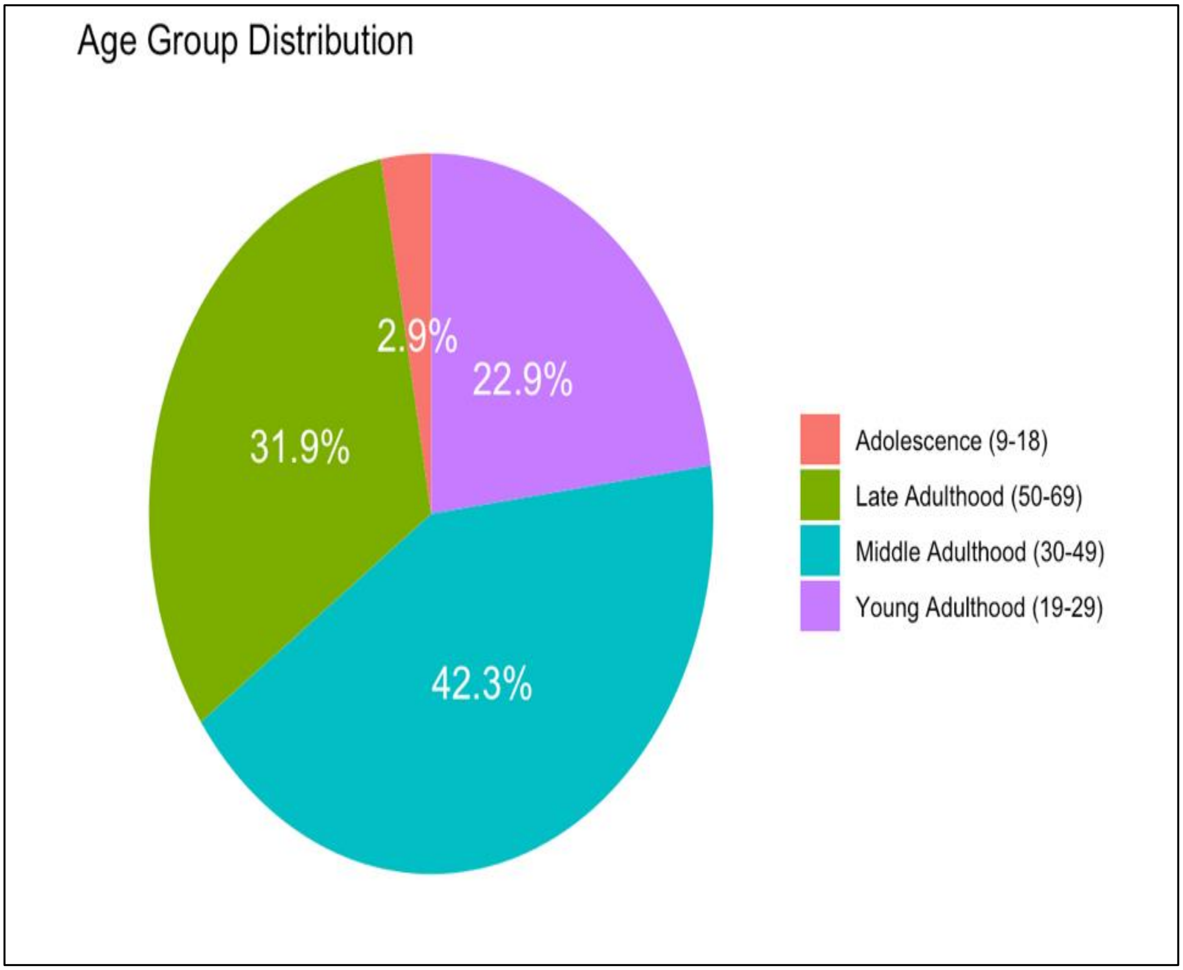
The included articles are within ten years of this research, making their findings appropriate for inclusion. Their findings imply the expectation that sleep efficiency will be inversely related to age, gender, and alcohol consumption, and directly related to physical activity within our dataset.

3. Materials and Methods

This research uses multiple statistical data visualization techniques, including pie charts, boxplots, correlation and mosaic plots, grouping, and multiple regression analysis in the end to prove visualization patterns. A detailed insight is made into sleep patterns to see how different factors impact sleep efficiency. The dataset used in the research was taken from Kaggle, which consists of a study conducted in Morocco, containing 386 subjects whose sleep patterns were recorded with 14 variables in total. The dataset uses the Sleep Efficiency Index to measure sleep quality. Each subject is given a unique identity number or ID, along with their age and gender recorded. While "Sleep duration" records the subjects' overall amount of sleep time in hours, "Bedtime" and "Wake-up time" indicate when the subject goes to sleep. The proportion of time spent in bed sleeping is known as "sleep efficiency." The percentages of sleep stages that correspond to the amount of time spent in each phase are also included in the dataset: "REM sleep percentage," "Deep sleep percentage," and "Light sleep percentage." In addition, data on smoking status, frequency of exercise, and alcohol consumption within 24 hours before bedtime are also recorded.

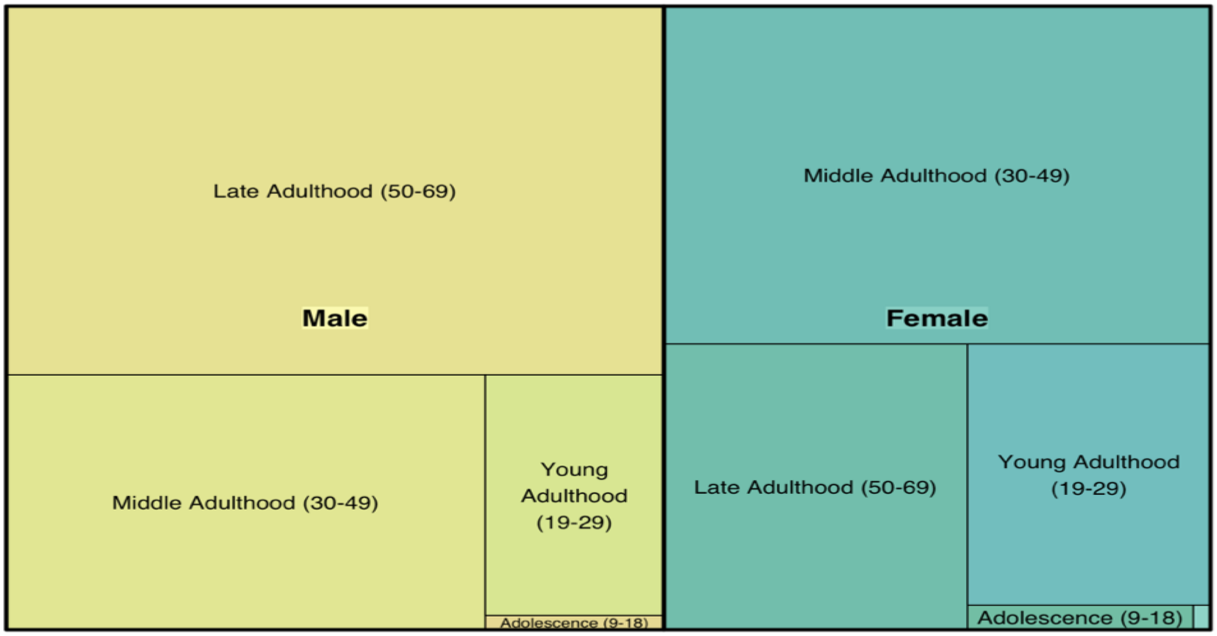
4. Results and Discussion

Figure No 1: Pie chart for Age Group Distribution



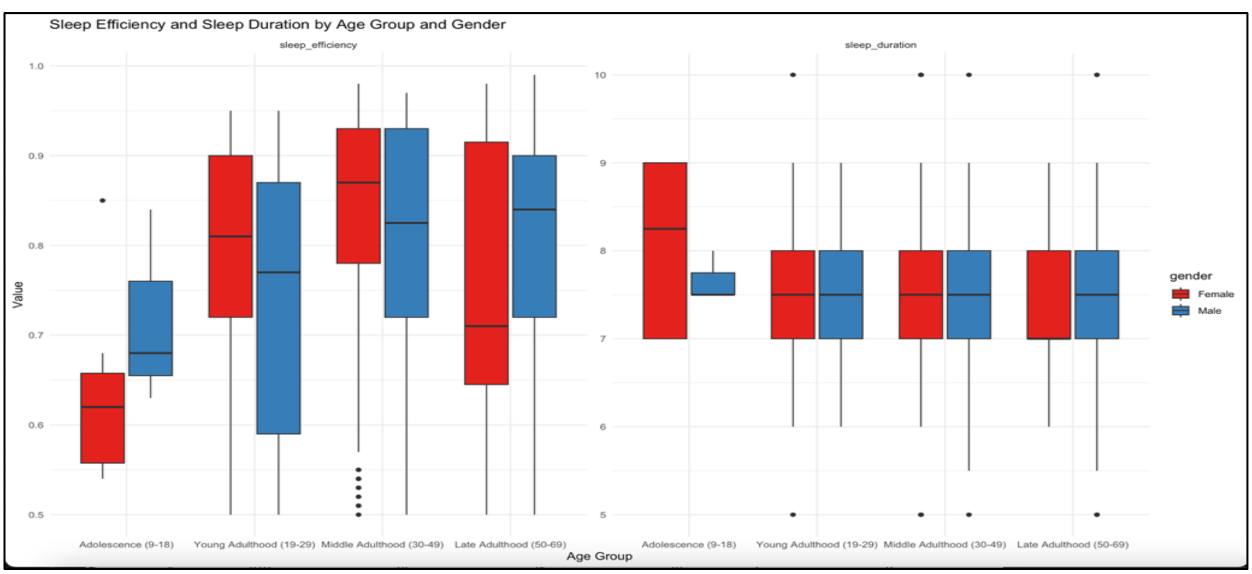
The figure above illustrates age groups into four distinct categories. Middle Adulthood (30-49 years) with 166 subjects, making up the largest portion of the pie chart, at approximately 42.9%. Late Adulthood (50-69 years) with 123 subjects follows as the second largest portion, with 31.9%. Young Adulthood (19-29 years) accounts for 22.9% or 88 subjects in this category, while Adolescence (9-18 years) comprises only 2.9%, which is equal to 11 subjects only. The dataset suggests that it primarily consists of Late and middle-aged people with fewer young adults or adolescents, with middle-aged people dominating the most.

Figure No 2: Tree Map for Gender by Age Group Distribution



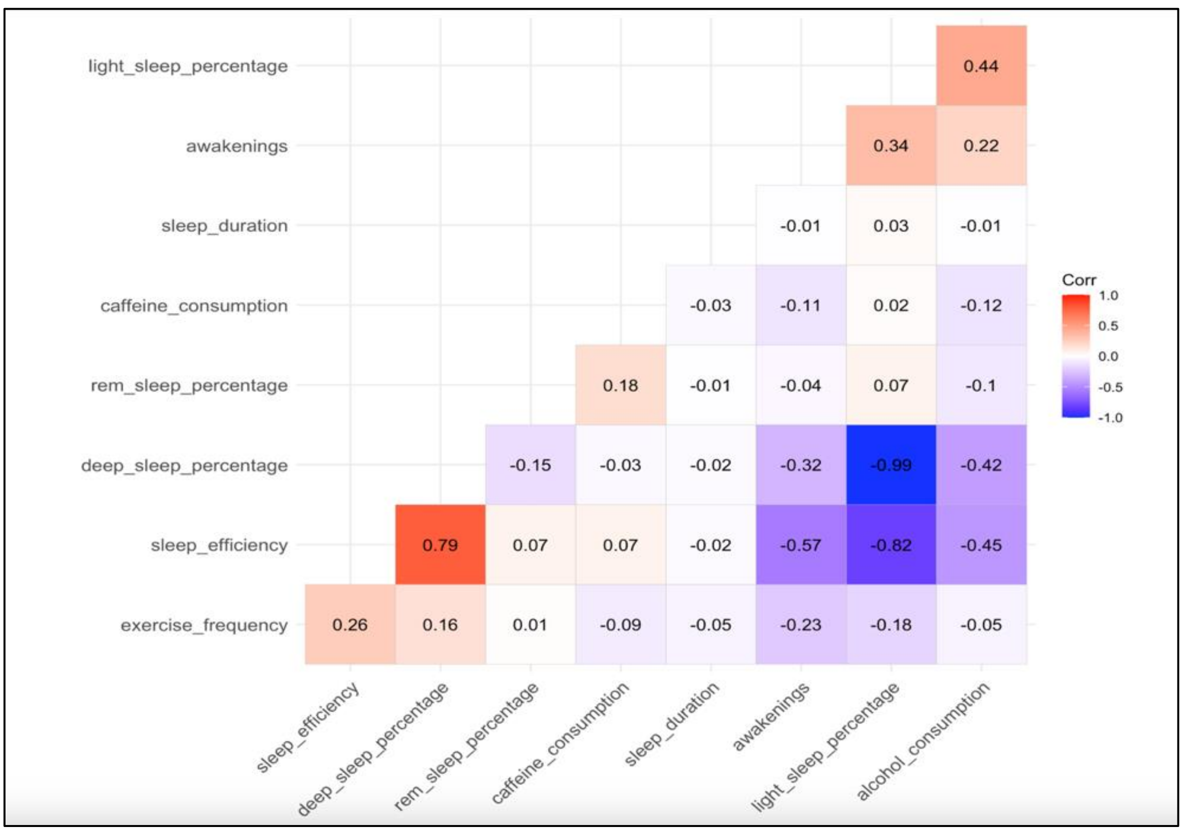
The Tree Map above illustrates Gender: Male and Female by Age Group Distribution into 4 distinct groups: Adolescence (9-18), Young Adulthood (19-29), Middle Adulthood (30-49), and Late Adulthood (50-69). It shows that the highest proportion in males is Adults in Later adulthood (above 50 years), and the highest proportion in females is adults in middle adulthood (above 30 years). The least proportion of age group in both genders is adolescents (below 18 years).

Figure No 3: Grouped and faceted box plot for sleep efficiency and sleep duration distribution across different age groups and gender



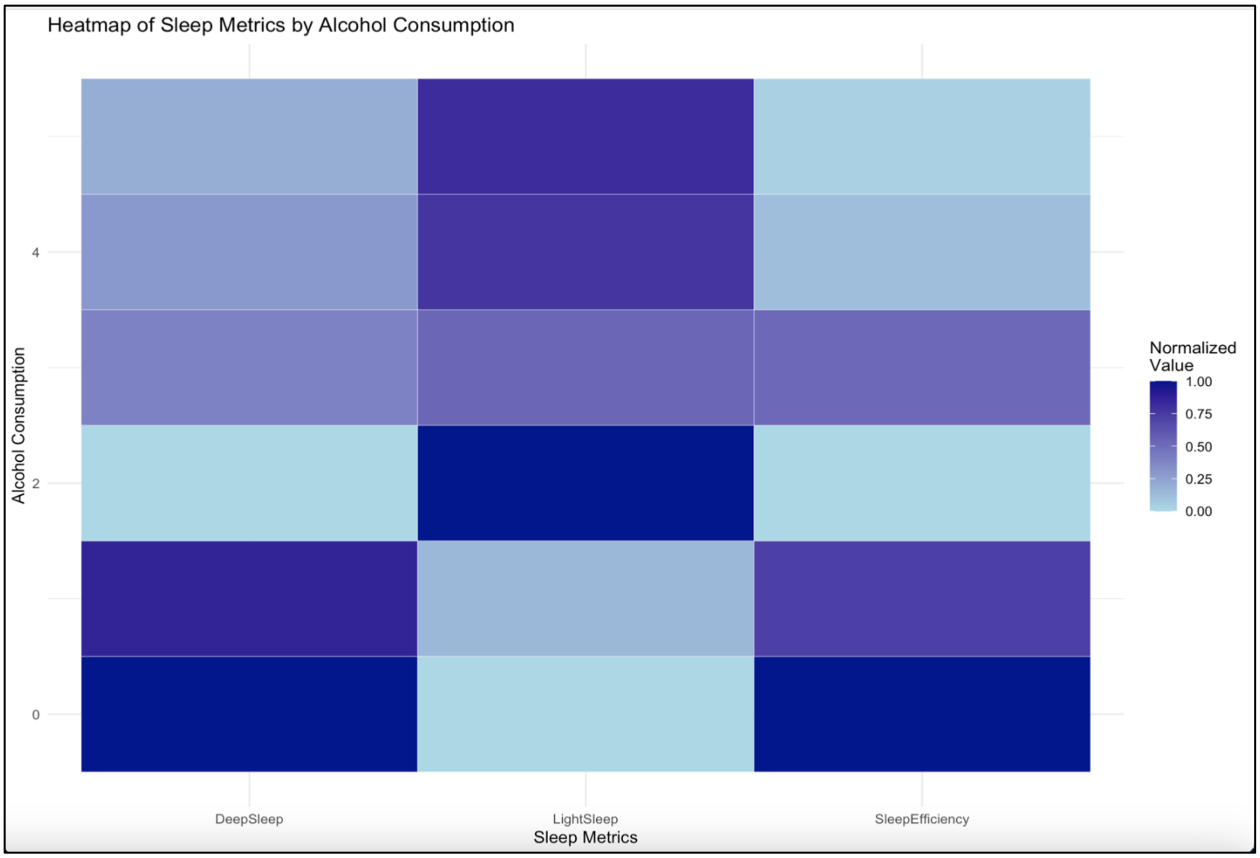
The figure above shows the sleep efficiency and sleep duration distribution on the y-axis ranging between 0.5 to 1 for different age groups on the x-axis and gender, color-coded with rust representing the females and teal-blue representing the males. The adolescent group shows overall lower sleep efficiency, around 0.66 for males and 0.63 for females, with males having slightly higher median sleep efficiency than females despite females having the highest sleep duration ranging from 7 to 9 hours. Young adults have comparatively higher sleep efficiency than adolescents, with females having higher sleep efficiency of around 0.81, as compared to males with around 0.76. The young adult age group also has more variability and, thus, less precision. Middle-aged adults show the highest median sleep efficiency with less variability, having sleep efficiency around 0.87 for females and 0.82 for males. The late adulthood age group indicates a drastic decrease in female sleep efficiency, with a value of 0.71, while it remained almost the same for males, with a value of 0.84. Sleep duration stays the same for young, middle, and late adulthood, indicating no impact on sleep efficiency, ranging from 7-8 hours for both genders. There are also a few outliers for females in the adolescent and middle-aged groups, probably due to individual differences. The inconsistent sleeping pattern of females as compared to males, with high variability and outliers, suggests poor sleep quality for females.

Figure No 4: Correlation matrix of different sleep-related variables



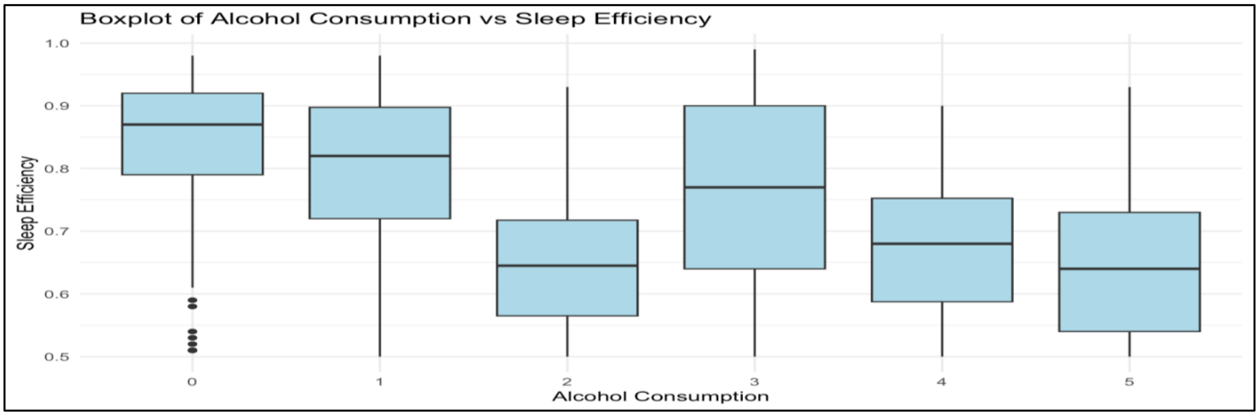
The above figure shows a correlation matrix visualizing the relationship between different sleep-related variables present in the dataset, ranging from -1 to 1, where -1 indicates a strong negative correlation, colored blue in the matrix, 0 means no correlation, and +1 indicates a strong positive correlation with red shaded boxes in the matrix. Deep sleep has a strong positive correlation (0.79), and light sleep has a strong negative correlation (-0.82) with sleep efficiency. They also have an inverse correlation with each other (-0.99), indicating that the more a person spends time in light sleep, the lower the sleep efficiency, while more time in deep sleep increases SE. Alcohol consumption has a positive correlation with light sleep (0.44) and a negative correlation with deep sleep (-0.42) and sleep efficiency (-0.45), indicating its negative impact on our overall sleep quality. Awakenings also strongly impact sleep efficiency negatively (-0.57) as it is directly linked with light sleep, while exercise has a low positive correlation with sleep efficiency (0.27), implying that regular exercise can positively impact our sleep quality.

Figure No 5: Heatmap for Alcohol Consumption on different sleep stages and overall sleep efficiency



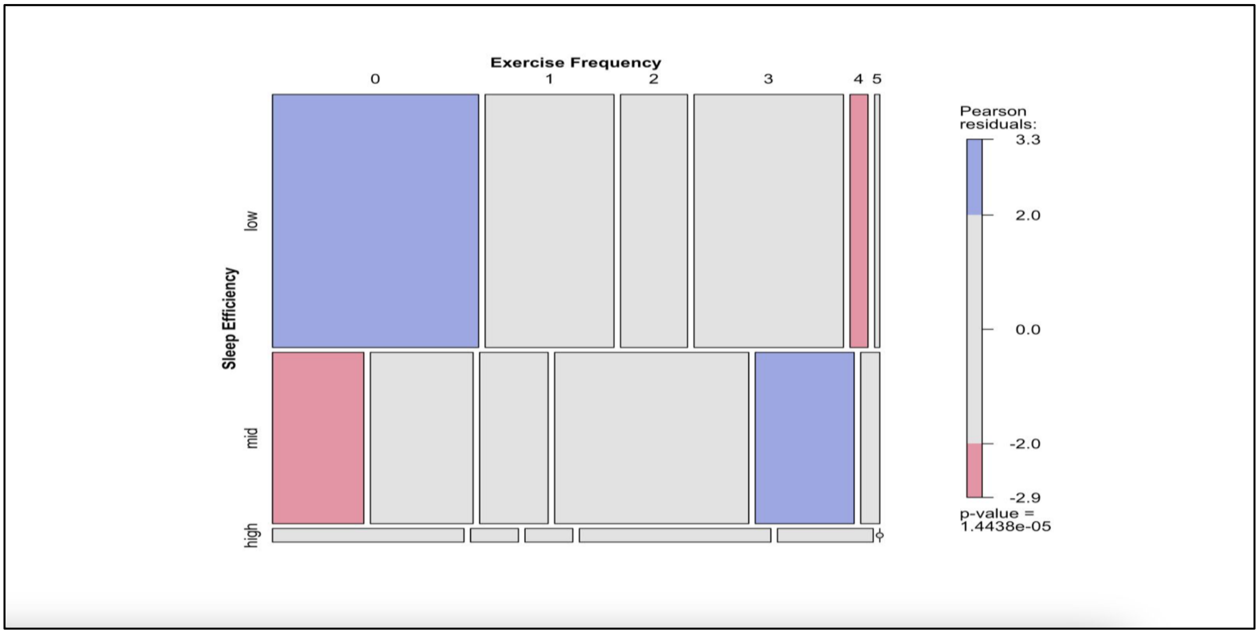
The heatmap above visualizes the exact impact of alcohol on sleep. It confirms the relationship shown in the correlation plot, indicating that alcohol consumption negatively affects deep sleep, as evidenced by the color intensity highest at 0 and decreasing upwards as the alcohol consumption level increases. The same color trend is shown by sleep efficiency, as it is strongly correlated with deep sleep. In contrast, light sleep shows light color intensity at lower alcohol consumption levels and intensifies at 2 or above. Thus, as the amount of alcohol consumption increases, our sleep quality decreases drastically, as less time is spent in restorative sleep due to more frequent awakenings and fragmentation.

Figure No 6: Boxplot for Alcohol Consumption and Sleep Efficiency



The figure above further elaborates on alcohol intake and its effect on sleep efficiency with respect to the quantity of consumption. Alcohol consumption is given on a scale of 0-5, with increasing values as the level of consumption increases. From 0-1 with no or little alcohol consumption, the sleep quality is maximum, ranging from 0.87 to 0.82, respectively. For moderate levels of consumption, the ratio of sleep efficiency decreases drastically at 2, with a median value of 0.65, and increases a little at 3 to a median value of 0.77. For scores 4-5, which represent a higher level of alcohol consumption, the sleep efficiency ratio is relatively low, with a median value of 0.68 and 0.64, respectively. This indicates that higher alcohol intake can lead to reduced restorative sleep and corresponds to overall low sleep quality. A few outliers are seen at 0 alcohol consumption level with unusually low sleep efficiency, maybe due to some other lifestyle factor, e.g., Smoking or no physical exercise, that can impact sleep quality.

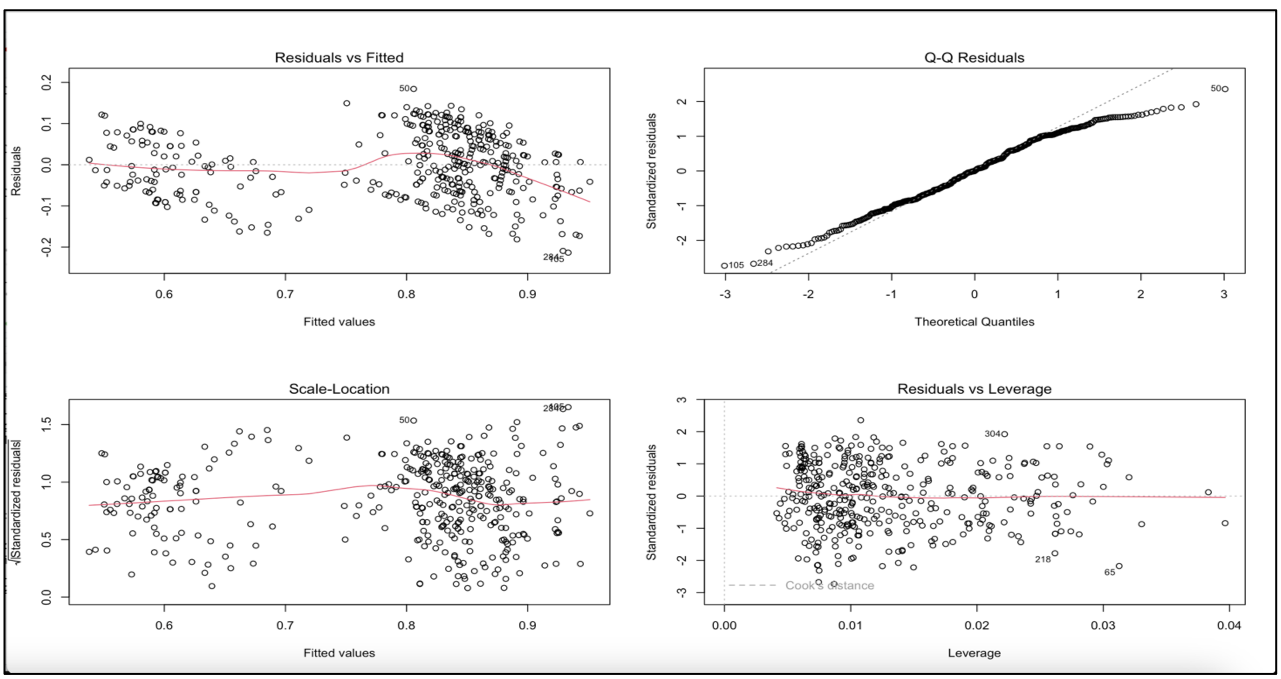
Figure No 7: Mosaic Plot Indicating the Effects of Exercise on Sleep Efficiency



The mosaic plot indicates a close relationship between exercise frequency and sleep efficiency. The height of each cell shows the distribution across sleep efficiency levels (low, medium, and high). The width of each cell represents the number of individuals who participated in each exercise category. The colors in the columns reflect the Pearson residuals: blue and red shades indicate overrepresentation and underrepresentation, respectively, while darker shades signify stronger deviations. The statistically significant p-value (1.4438e-05) confirms a strong association among these variables, as it confirms that the association is unlikely to occur by chance. Individuals with no exercise are over-represented by dark blue color, showing that low sleep efficiency is most common in people with low levels of exercise, as the observed count is more than expected, with a Pearson residual value above 2.0. Moreover, people with a moderate level of exercise with 3 times a week, also show over-representation by the dark blue shade, hinting that moderate sleep efficiency is common in people who work out three times a week, as observed count is more than expected. For people who work out 4 times a week, low sleep efficiency is under-represented with dark red shade, with a Pearson residual value below -2.0, meaning that fewer people are observed with low sleep efficiency with high exercise frequency, demonstrating that exercise frequency helps in increasing sleep efficiency. Thus, the dominant trend remains that low exercise frequency, especially no exercise, is strongly linked to poor sleep efficiency.

To further quantify the above variables under observations with sleep efficiency, and their relationship to evaluate predictive power, a multivariate linear regression model is run with significant variables found in the visual analysis.

Figure No 8: MLRM for Significant predictors of SE



Predictor	B	SE	t	p
Intercept	0.4267097	0.0211222	20.202	< 2e-16 ***
Age	0.0007153	0.0003018	2.370	0.0183 *
Deep Sleep (%)	0.0061557	0.0002893	21.278	< 2e-16 ***
Alcohol Consumption	-0.0122273	0.0026972	-4.533	7.79e-06 ***
Exercise Frequency	0.0128915	0.0028074	4.592	5.98e-06 ***

Note. *R^2 = 0.6666, Adjusted R^2 = 0.6631, F (4, 381) = 190.5, p < 2.2e-16.* Significance levels: *p < .05, **p < .01, ****p < .001.*

The first plot of the residual vs fitted plot shows low linearity as the distribution lies on the horizontal axis with divergence at the end. The Q-Q residual plot shows low normality, as mostly mid values follow the line but go beyond the line at the end. The third plot shows homoscedasticity, as the red line is approximately at zero standard residual, mostly, and only deviates in the end. The last plot of residual vs leverage doesn't show any outliers that highly affect the regression line.

This Multiple Regression Analysis is run to predict sleep efficiency from various predictors that were significant through our visualization and regression, including demographics such as sleep stages, and lifestyle behaviors (alcohol and exercise). The model is significant overall, with a p-value smaller than *0.001*, and an adjusted R^2 value of 0.663, suggesting that the model explains 66% of the variance in sleep efficiency. Age and exercise frequency have a significant effect on sleep efficiency, as already visualized above, with a p-value of 0.0183 and 5.98e-06, respectively. Alcohol has a negative impact on sleep efficiency, shown as significant with a p-value of 7.79e-06.

5. Conclusion

We analysed sleep efficiency for 4 distinct age groups: Adolescents (9-18), Young Adulthood (19-29), Middle Adulthood (30-49), and Late Adulthood (50-69), with female subjects being higher in the young and middle age groups, and males dominating the adolescent and late adulthood age groups. The first notable finding was the difference in sleep efficiency between genders in the adolescent age group. While the sleep duration came out to be higher for women, SE was lower than for men. This pattern was only observed in the adolescent age group, however, for the remaining subjects, there appeared to be no contrast between SE and sleep duration for any subgroup. It was further observed that across age, females experienced higher sleep efficiency, peaking in middle adulthood, whereas males rated highest on sleep efficiency in late adulthood; the middle adulthood group of men scored second in SE. Further analysis via correlation coefficients revealed an inverse relationship between light sleep and deep sleep as well as SE. Higher deep sleep scores correlated with higher SE scores. Furthermore, alcohol consumption correlated negatively with deep sleep and SE and positively with light sleep, indicating that it diminishes SE. Alcohol came out to have a negative effect on sleep efficiency across each analysis, reflecting the findings in previous literature. Among other variables, physical activity made an observable difference; subjects who performed little to no exercise had reduced SE, but the opposite for males and females, as expected. Women tend to have lower SE than expected, and men tend to have higher SE than expected, at lower exercise frequency. This causes us to deduce that the most significant variables affecting SE were alcohol consumption, physical activity, gender, and age. The findings for each were in line with what previous literature also suggests.

5.1 Limitations

The current findings certainly have the potential for application. For example, women of specified age groups could be provided with better sleep plans to suit their biological needs. Employee guidelines can also be adjusted for age and gender to maximize productivity by allowing employees to prioritize their well-being. Physical activity can be introduced for people suffering from poor-quality sleep. Alcohol intake regulations should also be established to ensure that alcohol is not consumed to the point that SE is compromised.

Our research, however, is limited by the fact that it fails to account for exogenous factors such as genetics, environmental influencers, and sleep timings. Additionally, like many other studies, we used a cross-sectional sampling method, which could lead to discrepancies in results due to these exogenous factors. Furthermore, an entirely Moroccan sample means that these results may not be generalizable to other nationalities, as there was no assurance of ethnic inclusion in our sample. This study focuses on identifying correlations; however, we could also expand it to understand causation.

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