

# Multiple Linear Regression on Sleep Data

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## Introduction

### Motivation

Sleep is an important contributor to our well-being and is deeply connected to our physical health, and cognitive function. However we often find that many individuals struggle with getting long hours sleep, often finding themselves tossing and turning throughout the night. Consequently, there is now a growing interest in understanding the lifestyle and bio metric factors that influence sleep patterns and duration. General knowledge and intuition suggest factors such as physical activity and occupational stress may influence sleep duration. Therefore, our goal is to use linear regression techniques to quantify exactly how much these factors reduce or extend sleep time.

Before, analyzing the data set, we expect a number of our indicators to contribute significantly to sleep duration. In general, we would assume that occupation will play an important role in analyzing our data as a more stressful work environment may hinder sleep patterns and disturb the body's natural sleep cycle. Additionally, we may expect that higher levels of physical activity will work in tandem with deeper and longer duration of sleep.

Also, we seek to filter through and find the most important variables in our analysis. We expect that variables like Daily Steps and Physical Activity Level will be a contribute to sleep duration in a similar manner. In our data set, we have numerous combinations of variables that are alike in this way and therefore we want to reduce our factors to give the most precise and simple model possible.

### About the Data

Table 1: Variables From Our Data

Gender	Age	Occupation
Sleep Duration (hours)	Quality of Sleep (scale: 1–10)	Physical Activity Level (minutes/day)
Stress Level (scale: 1–10)	BMI Category	PP (Pulse Pressure)
Heart Rate (bpm)	Daily Steps	Sleep Disorder

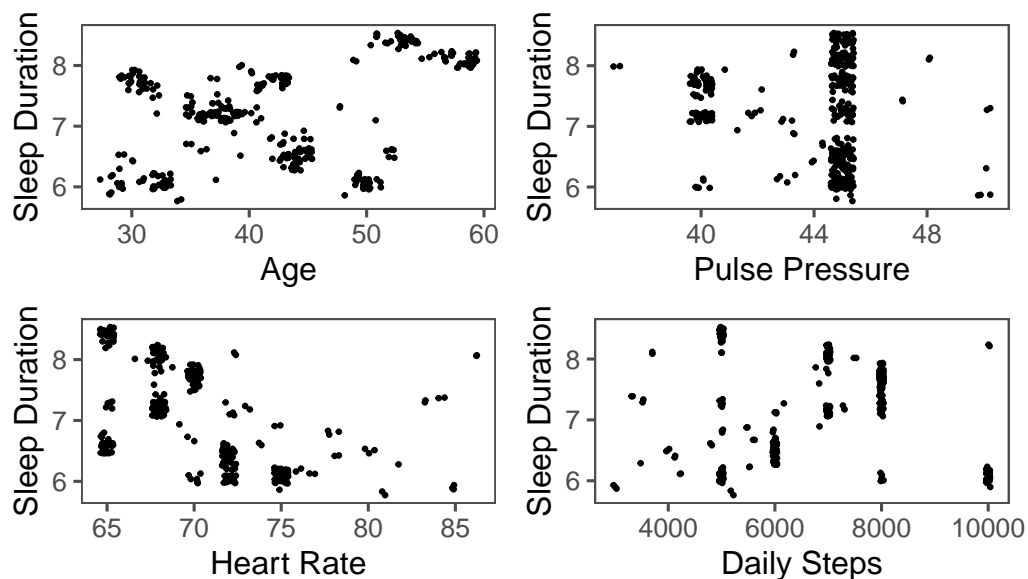
Sleep Duration is a continuous variable and will be our response variable. The rest will be our covariates. Gender, Occupation, Quality of Sleep, Stress Level, BMI Category and Sleep Disorder are categorical variables. Physical Activity, PP, agem and Daily steps are continuous variables. We have a total of 374 observations.

We had no missing data in the data set but we did have to make a mutation using `dplyr`. In the original data set there was a blood pressure variable that was encoded as a character but was a ratio, e.g. “ $\frac{120}{80}$ ”. We separated the blood pressure variable into two: Systolic and Diastolic. These two we suspected to be highly correlated but did not want to just drop one or the other. We had options of combining the two into something meaningful. One was Pulse Pressure (PP), which is calculated as  $PP = \text{systolic} - \text{diastolic}$ . PP is the force of the hearts contraction on the arteries. The other is called Mean Arterial Pressure (MAP), which is calculated as  $MAP = \frac{\text{systolic} \cdot \text{diastolic}^2}{3}$ . MAP is the average blood pressure throughout a cardiac cycle. We decided on PP because it was simpler to calculate and understand.

For transparency it should be noted that the data is synthetic. Even though it is synthetic we still treat the analysis and report as if it was real data.

### Exploratory Data Analysis

#### Sleep Duration vs Continuous Variables



Visual relationship can be seen for Sleep Duration with Age and sleep\_duration. Not so much for PP and daily\_steps. The correlation between our numeric covariates is most notable between sleep\_duration and heart\_rate. age and hearts\_pressure

Table 2: Correlation Matrix of Continuous Variables

	sleep_duration	age	PP	heart_rate	daily_steps
sleep_duration	1.00	0.34	-0.16	-0.52	-0.04
age	0.34	1.00	0.46	-0.23	0.06
PP	-0.16	0.46	1.00	0.27	-0.31
heart_rate	-0.52	-0.23	0.27	1.00	-0.03
daily_steps	-0.04	0.06	-0.31	-0.03	1.00

### Finding Our Model

#### Full Model

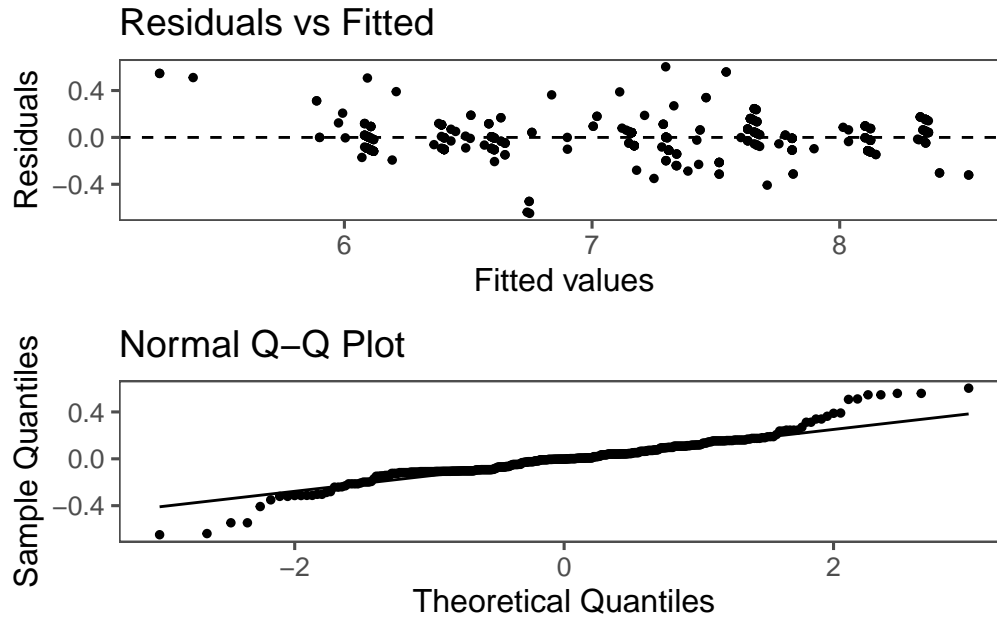
Running the full model we can see that our omnibus hypothesis test has an F-stat of 426.6 which is greater than the 99th percentile for our F-distribution,  $F_{31,342,.99} = 1.74$ . So we reject the null that all

coefficients are 0. We also see a high Adjusted  $R^2$  and very low Residual Sum of Squares compared to the Total Sum of Squares.

Table 3: Full Linear Model Outcome

F-statistic	Adjusted $R^2$	Residual Sum of Squares	Total Sum of Squares
313.34	0.958	9.28	236.13

We also saw all coefficients have standard error less than one.



As far as assumptions go homoscedasticity seems to be true and normality might be slightly violated with heavy tails but there is no excessive deviation from normality. We will explore multicollinearity and outliers next.

	GVIF	Df	GVIF <sup>1/(2*Df)</sup>
gender	15.879968	1	3.984968
age	26.029394	1	5.101901
occupation	9618.696656	10	1.581815
quality_of_sleep	30.593110	1	5.531104
physical_activity_level	10.667470	1	3.266109
stress_level	8788.039407	5	2.479643
bmi_category	125.886061	3	2.238702
heart_rate	14.888503	1	3.858562
daily_steps	10.043217	1	3.169103

	GVIF	Df	GVIF <sup>1/(2*Df)</sup>
sleep_disorder	12.533533	2	1.881561
PP	8.672479	1	2.944907

age and quality\_of\_sleep have  $GVIF^{2 \cdot DF} > 5$ . We may want to explore Lasso to deal with this.

Looking now towards outliers we selected observations that had one of following: leverage  $> 2 \cdot \frac{p+1}{n}$ , studentized residual  $> 2$ , and a cooks threshold  $> 1$ . We saw a total of 57 observations that exceeded at least one of these thresholds. Since we can't say that any of these observation are errors we will only remove row 264 because it has a leverage of 1 and NaN for the rest. This is clearly a problem observation.

Table 5: Row with Highest Leverage

	Leverage	Studentized	DFFITS	Cooks_Distance
264	1	NaN	NaN	NaN

### Updating Model: VIF and Lasso Considerations

We removed variables age and quality\_of\_sleep and ran a MLR model. Our results showed that the reduced VIF model was very similar to the full model. Adjusted  $R^2$  was essentially unchanged. Therefore, we concluded that age and quality\_of\_sleep did not contribute much to the regression analysis because they were linear combinations of other independent variables.

Table 6: MLR Outcome for age and quality of sleep removed

F-statistic	Adjusted $R^2$	Residual Sum of Squares	Total Sum of Squares
308.43	0.952	10.6	236.08

In order to avoid overfitting issues, we utilized a greedy algorithm process to select variables that provided the lowest AIC value. We ran 3 model selection process as discussed in class and recorded the variables selected for each method. We found that all 3 methods took all of our variables in our data set. We knew that AIC penalizes the fitted model for each additional variables taken. Despite this, we saw that all variables were significant. Note that the variable selection process was done after our high VIF variables were removed.

Table 7: Variable Selection

Variable	Backward	Forward	Stepwise
bmi_category	Yes	Yes	Yes
daily_steps	Yes	Yes	Yes
gender	Yes	Yes	Yes

Variable	Backward	Forward	Stepwise
heart_rate	Yes	Yes	Yes
occupation	Yes	Yes	Yes
physical_activity_level	Yes	Yes	Yes
PP	Yes	Yes	Yes
sleep_disorder	Yes	Yes	Yes
stress_level	Yes	Yes	Yes

For our suggested regression, we used LASSO regression. We hoped to extract the most important input features to achieve a simple yet powerful model. To find the optimal  $\lambda$  or the regularization parameter, we used a cross-validation process by splitting our data set: train = 80%. We saw that gender, occupation, bmi\_category, and sleep\_disorder converged to zero. Optimal lambda value was 0.0009622.

Table 8: Non-Zero Coefficients from LASSO (Selected by Cross-Validation)

Variable	Coefficient
(Intercept)	10.8659
gender	0.0000
occupation	0.0000
physical_activity_level	0.0133
stress_level	-0.3173
bmi_category	0.0000
heart_rate	-0.0141
daily_steps	-0.0001
sleep_disorder	0.0000
PP	-0.0260

Table 9: Optimal Lambda from Cross-Validation

Description	Value
Optimal lambda (lambda.min)	0.0009622

Table 10: Final Model Statistics

F-statistic	Adjusted R <sup>2</sup>	Residual Sum of Squares	Total Sum of Squares
343.56	0.88	27.61	236.08

Table 11: Coefficients and P-values from Linear Model

term	estimate	p.value
(Intercept)	10.500	0.00
physical_activity_level	0.004	0.00
stress_level4	-1.307	0.00
stress_level5	-0.780	0.00
stress_level6	-0.972	0.00
stress_level7	-1.657	0.00
stress_level8	-2.139	0.00
heart_rate	-0.007	0.19
PP	-0.046	0.00

## Discussion

Upon comparing the final model to the original full model, we observe a reduction in the Adjusted  $R^2$  from 0.958 to 0.880, and an increase in the Residual Sum of Squares (RSS) from 9.28 to 27.61. The F-statistic increased slightly from 313.34 to 343.56, while the Total Sum of Squares remained nearly unchanged at approximately 236. This suggests that, although the simplified model explains slightly less of the variation in sleep duration, it still performs quite well in terms of overall fit and statistical significance.

Despite the modest drop in Adjusted  $R^2$ , we are confident in selecting the final model. This model is much simpler, yet retains highly significant explanatory power, making it more interpretable and potentially more useful in real-world applications. The use of Lasso regularization, which penalizes more complex models, likely contributed to the decrease in Adjusted  $R^2$ . This trade-off was intentional. We prioritized a simpler model with a more strict variable selection. This has important practical benefits: a simpler model enables more efficient and cost-effective data collection for future studies. For example, if a healthcare provider wanted to screen individuals for sleep issues, collecting a smaller set of variables would be faster and less resource-demanding. In the final model, several predictors emerged as statistically significant at the 5% level, including: Physical Activity Level, Stress Levels 4 through 8, and Pulse Pressure (PP).

These results align well with our expectations—individuals experiencing higher stress levels or reduced physical activity tend to sleep less. Interestingly, heart rate, while retained in the model, was not statistically significant at the 5% level, suggesting its role may be less direct in predicting sleep duration. Based on the final model, individuals expected to have the longest sleep duration are those with high physical activity levels, low stress (level 1), lower heart rate, fewer daily steps, and lower pulse pressure (PP). In particular, physical activity shows a small but positive effect on sleep duration. Alternatively, the worst sleep duration is expected among individuals with very high stress levels (especially level 8), elevated heart rates, high PP, and excessive daily steps. These findings emphasize the importance of stress management and cardiovascular health in promoting better sleep. Lastly, 10-fold cross-validation showed that both the full and final models performed well, with the final model achieving only a slight

decrease in  $R^2$  but with a meaningful gain in simplicity. This further supports our choice to recommend the final model as a strong, interpretable, and efficient tool for predicting sleep duration.

Table 12: 10-Fold Cross-Validation Results for Initial and Final Models

Model	RMSE	Rsquared
Initial Model	0.1921801	0.9435390
Final Model	0.2761879	0.8782622

Table 13: Final Model Coefficients and Significance

Term	Estimate	Standard Error	Significance
(Intercept)	14.8555	0.6299	***
physical_activity_level	0.0158	0.0015	***
stress_level4	-1.3565	0.0458	***
stress_level5	-0.6208	0.0491	***
stress_level6	-0.9042	0.0600	***
stress_level7	-1.3989	0.0627	***
stress_level8	-1.6704	0.0740	***
heart_rate	-0.0401	0.0059	***
daily_steps	-0.0002	0.0000	***
PP	-0.0821	0.0089	***



Table 14: Interpretation of Final Model Coefficients

Term	Estimate	Interpretation
Intercept	14.86	Baseline predicted sleep duration (in hours) when all predictors are at reference or zero levels.
Physical Activity Level	0.0158	Each unit increase in physical activity is associated with an increase of approximately 0.016 hours (about 1 minute) of sleep.
Stress Level 4	-1.36	Individuals with stress level 4 sleep 1.36 fewer hours than those at the reference level (e.g., stress level 1).
Stress Level 5	-0.62	Stress level 5 corresponds to 0.62 fewer hours of sleep compared to the reference level.
Stress Level 6	-0.90	Stress level 6 is associated with a reduction of 0.90 hours of sleep.
Stress Level 7	-1.40	Individuals at stress level 7 sleep about 1.40 hours less than those at the reference level.
Stress Level 8	-1.67	The highest stress level is linked to a reduction of 1.67 hours of sleep — the strongest negative effect.
Heart Rate	-0.0401	Each 1 bpm increase in heart rate is associated with 0.0401 fewer hours ( 2.4 minutes) of sleep.
Daily Steps	-0.0002	Each additional step slightly reduces sleep. For example, 5,000 more steps corresponds to about 1 hour less sleep.
Pulse Pressure (PP)	-0.0821	Each 1 mmHg increase in pulse pressure corresponds to 5 minutes less sleep.