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The Association Between Sleep Quality and Blood Pressure Using Linear Regression

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Abstract. Among Chinese adults, approximately 27.9% suffer from hypertension, and the group affected by hypertension is becoming younger. More and more studies are beginning to explore cardiovascular diseases from the perspective of sleep. However, current research on these issues is rather scattered and is limited to the elderly population. This study utilized the "Sleep Health and Lifestyle" dataset from Kaggle (with 1500 samples) and conducted an in-depth analysis of the relationship between sleep quality and blood pressure levels among different age groups (young group: 18-38.6 years old; middle-aged group: 38.6-59.3 years old; The research results indicate that poor sleep quality is an important predictor of future hypertension. Younger groups have a higher sensitivity to blood pressure due to sleep quality than middle-aged and elderly groups. Sleep quality may regulate blood pressure levels by influencing heart rate. Based on these findings, targeted intervention strategies were proposed to provide scientific support. Early hypertension prevention and theoretical references on sleep health were provided.

Keywords: hypertension, sleep quality, blood pressure regulation, incidence risk, sleep disorder

1. Introduction

Cardiovascular diseases are a significant factor contributing to death. Hypertension, as a common chronic cardiovascular disease among them, imposes a huge burden on public health. According to the World Health Organization, there are approximately 1.3 billion people with hypertension worldwide, and each year, a large number of people die due to indirect or direct complications related to hypertension [1, 2]. The situation of hypertension in China is also not optimistic. According to the "China Cardiovascular Health and Disease Report 2024", the prevalence of hypertension among Chinese adults has reached 27.9%, and the number of patients exceeds 330 million. In recent years, hypertension has shown a clear trend of becoming more common among young people. Due to the fact that young people are constantly living in a high-pressure and fast-paced environment and are constantly exposed to excessive use of electronic devices, it leads to insufficient sleep and subsequently damages their physical functions. Studies have shown that long-term lack of sleep significantly increases the burden on the cardiovascular system, and one of the key factors contributing to the younger age of patients with hypertension [2-5]. According to the

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"2023 China Sleep Research Report", although the average sleep duration of Chinese residents in 2022 was 7.37 hours, there was a two-level distribution. However, 16.7% of the population still slept for less than 7 hours. This lack of sleep is one of the reasons for the trend of younger-onset hypertension [4, 6]. The American Heart Association (AHA) has included sleep as one of the eight elements, and studies have proved the impact of sleep duration on cardiovascular health [3, 5].

Hypertension, as the most common subtype of cardiovascular diseases, the continuous damage of high blood pressure to the vascular system is a factor leading to heart failure and stroke, etc. It has become a risk factor for premature death and disease burden worldwide. Due to the asymptomatic onset of hypertension, it often occurs at night or during sleep, making it difficult to detect, and long-term poor-quality sleep leads to an increase in hypertension [1-3, 7]. The pathogenesis of hypertension is relatively complex. Changes in the renin-angiotensin-aldosterone system (RAAS) and disruption of the circadian rhythm have led to the onset of hypertension. Among them, the circadian rhythm is an important factor [1, 3, 5]. At the same time, modern life stress and the high incidence of sleep disorders have made insufficient sleep a common problem among contemporary young people. Sleep disorders caused by the fast-paced and high-pressure environment in which young people work in contemporary society are also one of the reasons for the younger onset of hypertension. Elderly men with insufficient deep sleep time will lead to a significant increase in the risk of hypertension [3, 7-9]. As a key stage for the body's repair, neural regulation, and maintenance of metabolic homeostasis, the interaction between deep sleep and the cardiovascular system has become a hot topic in current medical research. Existing studies have preliminarily confirmed that there is a certain influence between sleep quality and hypertension: insufficient deep sleep (such as less than 1.5 hours per day) will directly increase the risk of hypertension onset, and the physiological fluctuations caused by hypertension at night will further disrupt the sleep structure [2, 5, 7, 10]. Mechanically, this may be related to excessive activation of the sympathetic nervous system, disorder of the RAAS system, and systemic inflammatory response [11].

Nevertheless, previous studies have mostly relied on subjective questionnaires. The in-depth exploration of the objective "deep sleep quality" and blood pressure regulation is still in its infancy. To address these gaps, this study aims to explore the intrinsic relationship between sleep quality and blood pressure levels through quantitative analytical methods. Utilizing the "Sleep Health and Lifestyle Extended Dataset" consisting of 1,500 samples, employing descriptive statistics and linear regression analysis. Unlike previous studies that often focused on the elderly, this research conducts a stratified analysis across three age groups: young adults (20-40 years old), middle-aged (40-60 years old), and the elderly (60-80 years old), seeking to reveal the differential impact of sleep quality on blood pressure regulation across the lifespan. Furthermore, this study investigates the regulatory role of heart rate as a potential mediator, aiming to provide targeted scientific evidence and theoretical references for early hypertension prevention and sleep health interventions, particularly for the younger population.

2. Methods

2.1. Data

This data is sourced from the "Sleep Health and Lifestyle Extended Dataset" on Kaggle [12], containing 1500 samples with ages ranging from 20 to 80 years old. This dataset covers various population types, such as medical professionals, those who have been on shift work for a long time, and people who are often sedentary, among others. The dataset also includes multiple indicators, such as daily steps and stress levels. Different age groups in the citation have certain physiological

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differences. The samples are divided into three equally wide age groups: young people (20-40 years old), whose basal metabolic rate is vigorous and physiological indicators are relatively stable; middle-aged people (40-60 years old), marking the beginning of functional decline and an increase in the incidence of chronic diseases; and the elderly (60-80 years old), which is a stage of significant overall physiological decline. The analysis supposes systolic pressure for the dependent variable, after cleaning the data to ensure its quality. Then divide the sample into the case and normal groups. Age is an important factor, so minimize its influence and focus on sleep quality. The research aims to explore the impact of sleep quality on blood pressure. On this basis, it can use the linear regression model.

2.2. Statistical analysis

Let Y be the systolic pressure, and X be the Quality of Sleep, a subjective score assessed based on the participants' self-reported perceptions. The linear regression gives the expression:

$$Y = \beta_0 + \beta_1 X + \epsilon, \tag{1}$$

where ϵ denote the random error, which is usually assumed to be Gaussian distribution with zero mean and constant variance. Now, suppose the observed data with n samples $(y_i, x_i), i = 1, \ldots, n$. The two regression coefficients, β_0 and β_1, can be estimated using the ordinary least square estimation, given by the normal equations,

$$\sum_{i=1}^{n} y_i = n\hat{\beta}_0 + \hat{\beta}_1 \sum_{i=1}^{n} x_i, \quad \sum_{i=1}^{n} x_i y_i = \hat{\beta}_0 \sum_{i=1}^{n} x_i + \hat{\beta}_1 \sum_{i=1}^{n} x_i^2 \tag{2}$$

and leading to the explicit form

$$\hat{\beta}_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}, \quad \hat{\beta}_0 = \frac{\sum_{i=1}^{n} y_i - \hat{\beta}_1 \sum_{i=1}^{n} x_i}{n}. \tag{3}$$

In this context, the explanatory power of the factor is assessed by R^2 with the formula

$$R^2 = 1 - \frac{RSS}{TSS}, \tag{4}$$

where RSS (Residual Sum of Squares) accounts for the stochastic errors that the model cannot explain; meanwhile, TSS stands for the Total Sum of Squares, i.e.,

$$TSS = \sum_{i=1}^{n} (y_i - \bar{y})^2, \quad RSS = \sum_{i=1}^{n} \left(y_i - \widehat{y_i}\right)^2. \tag{5}$$

Besides, prior to fitting the simple linear model, a z-transformation is performed with $z=(x-\mu)/\sigma$, and outliers were removed according to the 3- σ principle. By applying these principles, the model is not compromised by erroneous data or extreme outliers. Finally, the degree of certainty is quantified via confidence intervals, derived using the t-distribution.

3. Results

The descriptive statistics of the sample (Table 1) indicate that the average age of the participants was approximately 48 years old, with a wide range of ages (18-80 years old) and significant

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heterogeneity. The mean score for sleep quality was 5.83, showing a central tendency but with extreme values indicating significant individual differences in sleep patterns. The blood pressure data also exhibited similar dispersion, further supporting the diverse characteristics of the sample. This high variability beyond the standard boundaries also provides the dataset with strong representativeness, providing sufficient information to capture the linear correlation between sleep and blood pressure. Additionally, both sleep and stress perception are quantified using a 1–10 point subjective evaluation system, aiming to accurately benchmark the real health quality through the participants' self-perception.

Table 1. Descriptive statistics of the surveyed population's demographic characteristics, and physiological indicators

Variables	Mean	Maximum	Minimum	Std.Deviation
Age (year)	48.39	80.00	18.0	18.16
Sleep Duration(hours)	7.75	10.00	5.1	0.90
Quality of Sleep	5.83	10.00	1.0	1.78
Physical Activity Level (min)	59.19	180.00	0.0	38.27
Stress Level	6.01	10.00	1.0	2.37
Heart Rate (bpm)	74.76	109.00	43.0	12.24
Daily Steps (Number of steps)	6119.57	16036.00	1000.0	2823.00
Systolic_BP (mmHg)	120.24	148.00	97.0	10.66
Diastolic_BP (mmHg)	78.10	99.55	60.0	7.54

Linear regression analysis was performed on the aggregate data with result presented in Figure 1. The p-value of the obtained result is less than 0.001, which indicates that there is a negative correlation between sleep quality and blood pressure. From the above data, it can be observed that the better the sleep quality, the lower the blood pressure. With P less than 0.001, this suggests that the change in blood pressure is not due to random errors. The above model indicates that for every one-unit increase in sleep quality, the systolic blood pressure will decrease by an average of 0.57 units. Although it has certain significance in statistics, the obtained R^2 value is still relatively low, indicating its limited explanatory power. This means that blood pressure is affected by multiple interfering factors, not just a single factor, such as diet and lifestyle.

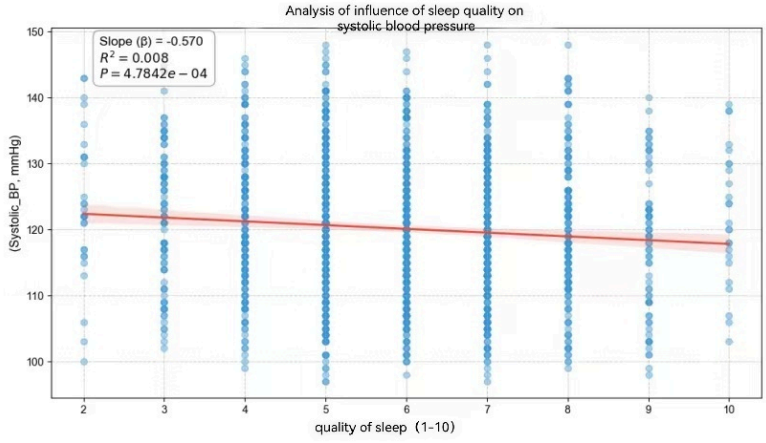

Figure 1. The relationship between sleep quality and BP

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Subsequently, the samples were analyzed according to age, as there are certain differences in physiological functions among different age groups (Figure 2). The samples were divided into three groups: the young group, the middle-aged group, and the elderly group. Although the explanatory power and regression coefficients of these groups decreased, a significant difference emerged: the regression coefficient of the young group was significantly higher than that of the middle-aged and elderly groups. This suggests that sleep quality has a more pronounced impact on the blood pressure of younger individuals. Furthermore, as illustrated in the figures, the confidence intervals for the youth group are markedly wider than those of the other cohorts.

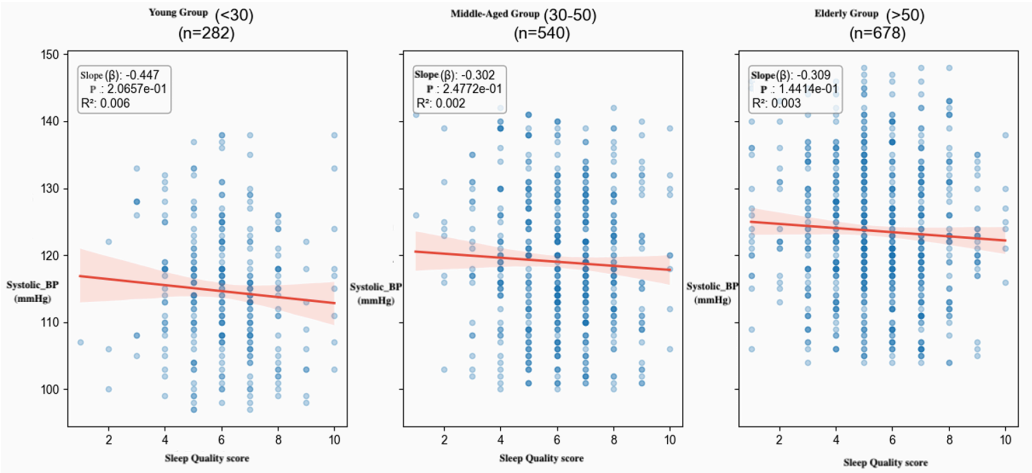

Figure 2. The relationship between sleep quality and BP in different age group in hypertensive patients

Consequently, the participants of non-hypertensive groups (Figure 3). In the non-hypertensive group, it is evident that the impact of sleep quality on blood pressure is significantly more pronounced in the youth cohort compared to the other two groups.

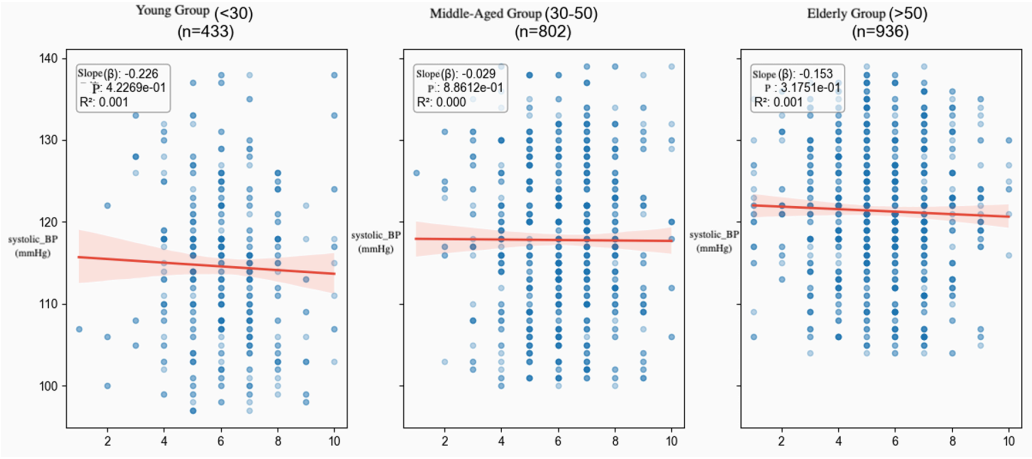

Figure 3. The relationship between sleep quality and BP in different age groups in non-hypertensive patients

Additionally, a heightened sensitivity to sleep quality was observed among younger participants, whereas this effect remained relatively unchanged in the middle-aged and elderly cohorts. To interpret these structural findings, the impact of sleep quality may affect blood pressure through an

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increase in heart rate. In data from all age groups, it has been shown that heart rate has an effect on blood pressure levels. It can be observed that the influence of sleep quality on heart rate is particularly significant in the adolescent population.

Figure 4 shows the impact of sleep quality on heart rate in different populations. For young people: Poor sleep quality leads to an increase in heart rate (correlation = -0.34). For the elderly: This correlation is weaker than that of young people. This indicates that sleep quality has an effect on the blood pressure of young people, possibly achieved through heart rate. Young people's heart rate is more sensitive to sleep quality.

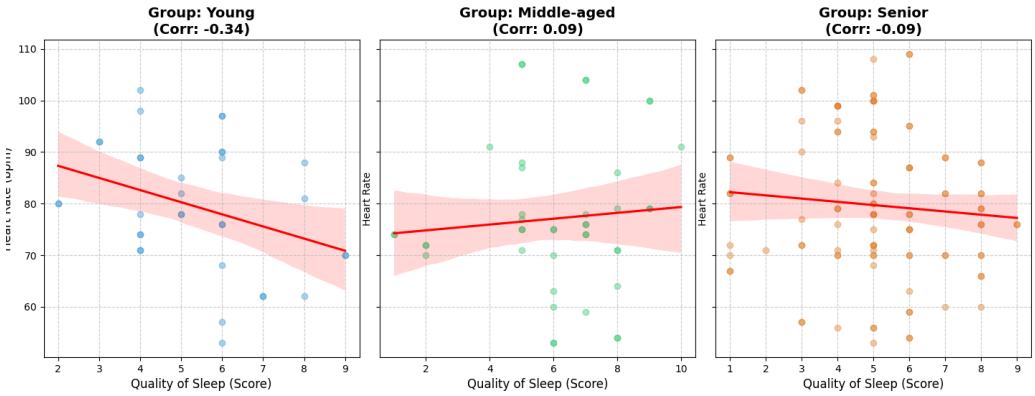

Figure 4. The relationship between sleep quality and heart rate

4. Discussion

This study includes a dataset with age distribution, allowing for the investigation under age stratification. The results show that younger individuals are more sensitive to blood pressure fluctuations caused by changes in sleep quality.It fills the gap in previous studies that often studied one or homogeneous groups [1, 3, 5, 13]. The limitations of this analysis are primarily the use of linear regression . Other research too have proposed a nonlinear U-shaped relationship between vascular health and sleep duration. For example, being too long or too short can induce high blood pressure. But this sophisticated non-linear factor can not be described by the basic linear model. This research is limited by the data collection and cannot account for important variables such as hereditary factors, salt intake and exercise. Sleep quality is measured by subjective self-report. This is standard technique, the measure may not be accurate. In this study, some progresses have been made in the following aspects too. (1) It describes possible causes of early-onset hypertension. The results indicate a factor that can sensitively trigger the trend of hypertension in young people, due to their higher sensitivity to sleep loss. Understanding this link and this harmful behaviour is important for young people to understand the main risks and biological reasons. Second, the data also suggested particular preventative strategies. It is important to teach young people good sleeping habits and how to deal with stress. Third, it provides some evidence for a healthy sleep policy and stresses the need of public health action for the promotion of a healthy sleep-wake cycle, which is an important component of cardiovascular health. This is especially relevant in today's fast-paced professional environment where sleep often takes a backseat. Finally, heart rate variability and sleep quality may be employed as indications of early cardiovascular stress in seemingly healthy young adults for clinical screening suggestions.

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5. Conclusion

This study employs linear regression models to analyze the relationships between sleep quality and heart rate and between systolic blood pressure, revealing particularly sensitive associations within the young population. Future research is encouraged to incorporate objective sleep assessment methods, such as polysomnography or wearable activity trackers, and to apply advanced statistical techniques, such as structural equation modelling or generalized additive models, to validate and extend these findings.

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