



Original Article

Longitudinal study of the relationship between sleep duration and hypertension in Chinese adult residents (CHNS 2004–2011)

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ABSTRACT

Objective: To determine the associations between sleep duration and hypertension in Chinese adults.

Methods: This longitudinal study analyzed 9851 adults who had participated in at least two rounds of the CHNS (China Health and Nutrition Survey) during 2004–2011. Sleep duration was classified into ≤ 7 , 8, and ≥ 9 h. Age, sex, residence location, education level, smoking, drinking alcohol, drinking tea, drinking coffee, activity level, and body mass index were adjusted as confounders in a generalized linear mixed model.

Results: The unadjusted analysis showed that compared with a normal sleep duration (8 h), the odds ratios (ORs) for those with short (≤ 7 h) and long (≥ 9 h) sleep durations were 1.24 and 1.17, respectively (95% confidence intervals [CIs] = 1.14–1.36 and 1.06–1.29). After adjusting for confounding factors, the effect of a short sleep duration on hypertension was still statistically significant, with an OR of 1.13 (95% CI = 1.04–1.24), while a long sleep duration no longer had a statistically significant effect.

Conclusions: A short sleep duration is an independent risk factor for adult hypertension, whereas a long sleep duration is not in Chinese adults. The prevalence of hypertension should be prevented and controlled by improving the sleep status of adults.

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1. Introduction

Hypertension is a leading cause of cardiovascular death and disability, with 1.3 billion people suffering from this condition worldwide [1]. The traditional focus of hypertension prevention and management includes reducing sodium in the diet, avoiding obesity, increasing physical activity, and prescribing anti-hypertension drugs [2]. Moreover, there is a growing body of research suggesting that sleep is also closely related to the occurrence of hypertension [3].

Sleep is an important part of human life. However, the rapid developments and lifestyle changes in human society over the past

half century have resulted in the decrease of average sleep duration [4,5]. Sleep exerts important effects on the cardiovascular system function, as well as physiological pathology, sleep rhythm disorder [6], and long or short sleep duration [7]. In addition, hypoxemia caused by obstructive sleep apnea [8] can cause metabolic disorders, vascular endothelial function damage, sympathetic nervous system activation, and oxidative stress; which further induce cardiovascular damage and thereby increase the incidence and mortality of cardiovascular and cerebrovascular diseases.

However, the correlation between sleep duration and hypertension remains controversial. Some studies have found that both short and long sleep durations are independently associated with an increased risk of hypertension [9,10], supporting the presence of a U-shaped association between sleep duration and the risk of adverse health outcomes. In contrast, other studies have found that only a short sleep duration is associated with hypertension [11–14].

Most studies of the relationship between sleep duration and hypertension have applied cross-sectional analyses, resulting in

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small samples. This study analyzed data obtained from the China Health and Nutrition Survey (CHNS) spanning seven years with the purpose of elucidating the association between the prevalence of hypertension and self-reported sleep duration in a large survey population. A generalized linear mixed model was utilized while controlling confounding factors and reducing errors.

2. Methods

2.1. Study subjects

The CHNS [15] is a longitudinal cohort survey that is conducted to examine the health and nutritional status of the general population in China. The survey began in 1989, and comprised a total of nine waves (in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, and 2011) that surveyed the following nine provinces: Heilongjiang, Liaoning, Shandong, Jiangsu, Henan, Hubei, Hunan, Guangxi, and Guizhou. A multistage, random-cluster sampling design was used to select study samples. This survey was approved by the institutional review committees of the University of North Carolina at Chapel Hill, the National Institute of Nutrition and Food Safety, the Chinese Center for Disease Control and Prevention, and the China–Japan Friendship Hospital, Ministry of Health [16]. All participants provided written informed consent. Details about the study design are available elsewhere [17].

In order to explore the relationship between sleep duration and hypertension, this study selected Chinese residents aged between 18 and 80 years who participated in at least two rounds of surveys from 2004 to 2011 as longitudinal tracking subjects, while excluding pregnant women, lactating mothers, and subjects with incomplete records of key analysis variables. The number of subjects totaled 9851 person-years, with 29,777 records, comprising 4736 person-years (48.1%) for men and 5115 person-years (51.9%) for women.

2.2. Measurements of sleep duration and hypertension

Sleep duration was assessed using a self-reported questionnaire. The questionnaire on physical activity included the question: “How many hours each day do you usually sleep, including during both daytime and nighttime?”. The daily sleep duration was categorized into ≤ 7 h (short), 8 h (optimal), and ≥ 9 h (long).

Hypertension was defined as a blood pressure $\geq 140/90$ mmHg or currently taking antihypertension drugs.

2.3. Potential confounders

Several variables were included as covariates in the adjusted models. The sociodemographic characteristics included age (categorized into 18–30, 31–44, 45–59, and 60–80 years), sex (male or female), and education level (primary school and below, junior high school, and senior high school and above). The examined health-related variables included smoking (yes or no), drinking alcohol (yes or no), drinking tea (yes or no), drinking coffee (yes or no), activity level (light, moderate, or heavy), and body mass index (BMI) based on the self-reported height and weight.

2.4. Statistical analysis

The longitudinal tracking data in this study presented a nested structure, with level 1 being the repeated observation value of each subject, and level 2 being the individual research object. The potential for aggregation in such data means that they do not conform to the assumptions of data independence and homogeneity of variance in traditional analysis methods. Multilevel analysis

methods can be used in this situation to estimate parameters and apply statistical tests more accurately. Taking the hypertension as the dichotomous dependent variable, a generalized linear mixed model was used to analyze the effect of sleep duration on the risk of developing hypertension.

Data were extracted, merged, and cleaned using SPSS (version 20.0) and Microsoft Excel. The generalized linear mixed model analysis was implemented using the *glmer* function in R software (version 3.5.1). For descriptive analyses, categorical variables were presented using percentages, while means and standard deviations were calculated for continuous variables. Three different models were used to investigate the association between sleep duration and hypertension: model 1 only included sleep duration; model 2 was adjusted for sleep duration, age, sex, education level, and residence location as confounders; and model 3 was further adjusted for BMI, smoking, drinking alcohol, drinking tea, drinking coffee, and activity level. Odds ratios (ORs) with 95% confidence intervals (CIs) are presented, and $P < 0.05$ was considered indicative of statistical significance.

3. Results

3.1. Basic characteristics of study subjects

The study subjects were Chinese adult residents who participated in at least two rounds of the CHNS during 2004–2011 and for whom complete data were available. There were 6,533, 7,673, 8,125, and 7446 subjects in 2004, 2006, 2009, and 2011, respectively. The basic characteristics of subjects included in the longitudinal study are presented in Table 1. There was a gradual reduction in the sleep duration of the subjects during the seven year analysis period, and the prevalence of hypertension also showed a downward trend, from 27.5% in 2004 to 21.2% in 2011. There was a slight upward trend in BMI. Most (70%) of the subjects were aged between 31 and 59 years. The predominant education level was primary school and below, followed by junior high school and then senior high school and above. According to the residence location, the included subjects mainly resided in rural areas.

3.2. Classification of variables

In order to better fit the multilevel model, the variables involved in the analysis were transformed into numerical values, with a value of 0 assigned to the control group and other values assigned as listed in Table 2.

3.3. Association between sleep duration and hypertension

The unadjusted analysis showed that compared with a normal sleep duration (8 h), the ORs for those with short (≤ 7 h) and long (≥ 9 h) sleep durations were 1.24 and 1.17, respectively [95% CI = 1.14–1.36 ($P < 0.001$) and 1.06–1.29 ($P < 0.01$).

After adjusting for confounding factors including age, sex, residence location, education level, smoking, drinking alcohol, drinking tea, drinking coffee, activity level, and BMI, a short sleep duration still exerted a statistically significant effect on hypertension (OR = 1.13, 95% CI = 1.04–1.24, $P < 0.01$), while a long sleep duration did not ($P = 0.10$).

The specific results are presented in Table 3, which indicates that age and BMI were risk factors for hypertension (both $P < 0.001$), with the risk of hypertension increasing with age and BMI. Education level and activity level were protective factors for hypertension ($P < 0.001$ and $P < 0.05$, respectively), with the risk of hypertension being lower for higher education and activity levels. The risk of hypertension was higher in men than in women

Table 1
Basic characteristics of study participants of the China Health and Nutrition Survey (2004–2011), stratified by study wave.

Variable	2004	2006	2009	2011
Age (%)				
18–30	583 (8.9)	569 (7.4)	512 (6.3)	369 (5.0)
31–44	2089 (32.0)	2389 (31.1)	2179 (26.8)	1653 (22.2)
45–59	2488 (38.1)	2831 (36.9)	3168 (39.0)	3010 (40.4)
60–80	1373 (21.0)	1884 (24.6)	2266 (27.9)	2414 (32.4)
Sex (%)				
Male	3073 (47.0)	3599 (46.9)	3879 (47.7)	3568 (47.9)
Female	3460 (53.0)	4074 (53.1)	4246 (52.3)	3878 (52.1)
Residence location (%)				
City	1886 (28.9)	2283 (29.8)	2494 (30.7)	2317 (31.1)
Rural	4647 (71.1)	5390 (70.2)	5631 (69.3)	5129 (68.9)
Smoking (%)				
Yes	1928 (29.5)	2130 (27.8)	2342 (28.8)	2068 (27.8)
No	4605 (70.5)	5543 (72.2)	5783 (71.2)	5378 (72.2)
Drinking alcohol (%)				
Yes	2186 (33.5)	2461 (32.1)	2723 (33.5)	2472 (33.2)
No	4347 (66.5)	5212 (67.9)	5402 (66.5)	4974 (66.8)
Drinking tea (%)				
Yes	2531 (38.7)	2679 (34.9)	2938 (36.2)	2662 (35.8)
No	4002 (61.3)	4994 (65.1)	5187 (63.8)	4784 (64.2)
Drinking coffee (%)				
Yes	112 (1.7)	130 (1.7)	190 (2.3)	182 (2.4)
No	6421 (98.3)	7543 (98.3)	7935 (97.7)	7264 (97.6)
Education level (%)				
Primary school and below	2947 (45.1)	3357 (43.8)	3562 (43.8)	3218 (43.2)
Junior high school	2059 (31.5)	2335 (30.4)	2648 (32.6)	2422 (32.5)
Senior high school and above	1527 (23.4)	1981 (25.8)	1915 (23.6)	1806 (24.3)
BMI (kg/m ²)	23.24 ± 3.37	23.29 ± 3.57	23.46 ± 3.44	23.93 ± 4.69
Sleep duration (h)	8.12 ± 1.27	8.05 ± 1.26	7.93 ± 1.23	7.82 ± 1.23
Activity level (%)				
Light	2994 (45.8)	3639 (47.4)	4270 (52.6)	4056 (54.5)
Moderate	1063 (16.3)	1122 (14.6)	1106 (13.6)	1076 (14.5)
Heavy	2476 (37.9)	2912 (38.0)	2749 (33.8)	2314 (31.1)
Hypertension (%)				
Yes	1795 (27.5)	2108 (27.5)	1793 (22.1)	1576 (21.2)
No	4738 (72.5)	5565 (72.5)	6332 (77.9)	5870 (78.8)
Total	6533 (100)	7673 (100.0)	8125 (100.0)	7446 (100.0)

BMI: body mass index.

Table 2
Variable assignment table for multilevel models.

Variable	Primitive type	Sorting classification
Time	Categorical variables	2004 = 0, 2006 = 1, 2009 = 2, 2011 = 3
Age	Continuous variable	18–30 = 0, 31–44 = 1, 45–59 = 2, 60–80 = 3
Sex	Categorical variables	Male = 0, Female = 1
Education level	Categorical variables	Primary school and below = 0, Junior high school = 1, Senior high school and above = 2
Residence location	Categorical variables	Rural = 0, city = 1
Smoking	Categorical variables	No = 0, Yes = 1
Drinking alcohol	Categorical variables	No = 0, Yes = 1
Drinking tea	Categorical variables	No = 0, Yes = 1
Drinking coffee	Categorical variables	No = 0, Yes = 1
Activity level	Categorical variables	Light = 0, Moderate = 1, Heavy = 2
Body mass index (kg/m ²)	Continuous variable	
Sleep duration(h)	Continuous variable	8 h = 0, ≤7 h = 1, ≥9 h = 2

($P < 0.001$). The residence location, smoking, drinking alcohol, drinking tea, and drinking coffee did not significantly affect the risk of hypertension.

4. Discussion

Sleep is an active physiological state characterized by dynamic fluctuations in the central nervous system, hemodynamics, respiration, and metabolic factors. Sleep can affect cardiovascular function and pathophysiology in various ways [6,7]. The present longitudinal study explored the association between sleep duration and the prevalence of hypertension in Chinese adults. The multi-factor analysis included sex, age, education level, smoking, drinking

alcohol, drinking coffee, drinking tea, and activity level as covariates. All three analyzed models suggested that short sleep is a risk factor for hypertension, whereas a long sleep duration produced inconsistent effects on hypertension in the three models. However, in model 3, which had the largest number of confounding factors, a long sleep duration was not associated with hypertension. This indicates that a short sleep duration was significantly associated with an increased prevalence of hypertension among Chinese adult residents, while a long sleep duration was not.

The reported association between sleep duration and hypertension has not been entirely consistent across different countries and ethnicities. Studies performed in Norway [18], South Korea [19,20], France [21], and the United States [1,11,22] found that a

Table 3

Results of a mixed liner regression analysis investigating the association between sleep duration and the risk of hypertension among Chinese adults (2004–2011).

	Model 1	Model 2	Model 3
Fixed effects			
Sleep duration (ref = 8 h)			
≤7 h	1.24 (1.14–1.36)***	1.10 (1.01–1.20)*	1.13 (1.04–1.24)**
≥9 h	1.17 (1.06–1.29)**	1.02 (0.93–1.12)	1.08 (0.98–1.18)
Time (ref = 2004)			
2006		0.93 (0.84–1.02)	0.94 (0.85–1.03)
2009		0.50 (0.46–0.56)***	0.50 (0.46–0.55)***
2011		0.42 (0.38–0.46)***	0.39 (0.36–0.44)***
Age (ref = 18–30)			
31–44		2.81 (2.19–3.61)***	2.41 (1.92–3.03)***
45–59		7.92 (6.18–10.15)***	6.02 (4.82–7.54)***
60–80		20.63 (15.90–26.75)***	15.90 (12.63–20.01)***
Sex (ref = Male)			
Female		0.70 (0.64–0.78)***	0.63 (0.56–0.71)***
Education level (ref = Primary school and below)			
Junior high school		0.85 (0.76–0.95)**	0.83 (0.74–0.92)***
Senior high school and above		0.70 (0.61–0.80)***	0.64 (0.57–0.74)***
Residence location (ref = Rural)			
City		1.17 (1.04–1.32)**	1.09 (0.97–1.22)
Smoking (ref = Non-smokers)			1.01 (0.91–1.13)
Drinking alcohol (ref = Non-drinkers)			1.08 (0.98–1.20)
Drinking tea (ref = No)			0.92 (0.85–1.01)
Drinking coffee (ref = No)			0.78 (0.57–1.07)
Activity level (reference = Light)			
Moderate			0.88 (0.78–0.99)*
Heavy			0.91 (0.82–1.00)
BMI			1.13 (1.12–1.15)***
Random effects			
Intercept (variance)	3.89	2.94	2.39

Model 1 is included in the variable sleep duration; Model 2 is based on the model 1, including the time, sex, gender, education level, and residence location; Model 3 is based on the model 2, including variables such as smoking, drinking alcohol, drinking tea, drinking coffee, activity level, and BMI (body mass index). The OR value and 95% confidence interval are listed in the table.

*P < 0.05, **P < 0.01, ***P < 0.001.

short sleep duration increases the risk of hypertension, which is consistent with the results of the present study. However, some studies have shown that sleep duration in adults and adolescents has a U-shaped relationship with hypertension, which means that both short and long sleep durations are positively associated with the prevalence of hypertension [9,23]. In the present study we also observed a U-shaped relationship between sleep duration and the prevalence of hypertension, however, the relationship between a long sleep duration and hypertension was not statistically significant. Possible causes for these discrepancies include differences in race, sample size, average age of the population, correction factors, and differences in the grouping of sleep durations.

This study found a short sleep duration to be an independent risk factor for hypertension, which might be due to the following mechanisms:

1. As a source of mental stress, an insufficient sleep duration can activate the sympathetic-adrenal medulla system and the renin-angiotensin-aldosterone system [24,25], resulting in increased vascular tone and the retention of sodium and water.
2. Sleep deprivation can stimulate the body's appetite for high-sodium foods [26].
3. Insufficient sleep increases the release of inflammatory factors in the body and damages the endothelial function of blood vessels, which in the long term leads to vascular sclerosis and cardiac hypertrophy, thus maintaining an elevated blood pressure [27–29].
4. Lack of sleep can also increase the appetite for starch and sweet foods [30], increase caloric intake, and reduce daily exercise, with together will lead to weight gain [31,32] and thereby increase the risk of hypertension.
5. Insulin resistance caused by sleep deprivation is also one of the important mechanisms leading to elevated blood pressure [33,34].

The greatest strength of this study was the largeness of the sample, which means that the results of the single-factor and multivariate logistic regression analyses are stable. However, compared with related research performed in other countries, the study was limited by the contents of the CHNS questionnaire, and it did not consider other relevant information related to sleep such as the sleep quality. Some studies have considered the interaction between sleep duration and sleep quality, and a separate investigation of the relationship between sleep duration and the prevalence of hypertension revealed that simple sleep deficiency does not induce changes in the prevalence of hypertension, and so must involve other sleep problems [35]. In addition, these conclusions are based on subjective reports of sleep duration from a single questionnaire rather than objective data, such as that obtained from supervised monitoring. Although it has been demonstrated that the self-reported sleep duration approximates objective measures of sleep length, there have been suggestions of overestimation bias [36].

In summary, a short sleep duration may be one of the significant risk factors for hypertension in adults. This suggests that adequate sleep and appropriate physical activity can help to reduce damage to the cardiovascular system and prevent the occurrence of hypertension.

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Conflict of interest

The author reports no conflicts of interest in this work.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <https://doi.org/10.1016/j.sleep.2019.01.006>.

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