

Sleep Quality Moderates the Association between Diet and Blood Pressure in Middle-aged and Older Adults: A Cross-sectional Study

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Abstract

Objective

This study aimed to investigate the moderating effect of sleep quality on the relationship between dietary pattern and blood pressure.

Methods

Using cross-sectional survey data from 201 middle-aged and older adults aged 45 years and above in a community in Shijiazhuang, Hebei Province in 2023, the Mediterranean Diet Score (MDS) and the Pittsburgh Sleep Quality Index (PSQI) were used to assess diet and sleep. A moderation model was employed to examine the moderating effect of different levels of sleep quality on the association between diet and blood pressure.

Results

After controlling for covariates, the interaction between MDS and PSQI was significantly associated with systolic blood pressure ($\beta = 1.029$, $t = 2.137$, $P < 0.05$), indicating that sleep quality moderated the association between dietary pattern and blood pressure. Simple slope analysis showed that among participants with lower PSQI scores, indicating better sleep quality, higher MDS was significantly associated with lower systolic blood pressure ($\beta = -5.537$, $t = -2.530$, $P = 0.012$, 95% CI: -9.852 to -1.221). At the mean level of PSQI, the association between MDS and systolic blood pressure was no longer significant ($\beta = -2.027$, $t = -1.266$, $P = 0.210$, 95% CI: -5.184 to 1.131). Among participants with higher PSQI scores, indicating poorer sleep quality, the association became non-significant and positive in direction ($\beta = 1.483$, $t = 0.725$, $P = 0.470$, 95% CI: -2.554 to 5.519). Exploratory subgroup analyses suggested that this moderating effect was evident mainly among overweight/obese participants ($\text{BMI} \geq 24.9 \text{ kg/m}^2$) ($\beta = 0.734$, 95% CI: 0.214 to 1.255, $P = 0.006$).

Conclusion

In this cross-sectional study, better sleep quality appeared to strengthen the inverse association between a healthier dietary pattern and systolic blood pressure among middle-aged and older adults. This association was attenuated as PSQI scores increased, suggesting that poorer sleep quality may weaken the potential blood pressure-related benefit of a healthy diet. These findings are hypothesis-generating and support the need for longitudinal and intervention studies to clarify whether improving sleep quality can enhance the cardiovascular benefits of dietary modification, particularly among overweight or obese individuals.

1. Introduction

Hypertension (HTN) is a major risk factor in the pathogenesis of various cardiovascular diseases, including stroke, ischemic heart disease, heart failure^[1], ischemic stroke, and chronic kidney disease (CKD)^[2]. Among the global population aged 30–79 years, the prevalence of hypertension is 33%, with only 54% of individuals diagnosed, 42% receiving antihypertensive treatment, and 21% having their hypertension under control. With the aging of the population and the increase in lifestyle risk factors, including unhealthy dietary habits, the incidence of hypertension continues to rise globally. It is estimated that the global economic burden of hypertension accounts

for approximately 10% of the world's overall healthcare expenditure, ranging from about 22.6% of all healthcare spending in Eastern Europe and Central Asia to 7.2% in East Asia^[3]. Hypertension, as a risk factor and complication of various diseases, is a major preventable risk factor for cardiovascular disease (CVD) and all-cause mortality worldwide^[4]. Therefore, reducing the health burden of hypertension is a public health priority.

Existing studies have shown that unhealthy diet is a definite risk factor for hypertension, including high-salt^[5], high-fat, low fruit and vegetable^[6], and low-carbohydrate diets^[7–9]. High salt intake elevates blood pressure primarily through two core pathways: volume expansion and endothelial dysfunction^[10]. A high-fat diet affects blood pressure primarily through mechanisms such as promoting atherosclerosis, insulin resistance, and sympathetic nervous system activation^[11]. More importantly, high-salt and high-fat diets often coexist, and their blood pressure-elevating effects are synergistically amplified, jointly accelerating vascular dysfunction and blood pressure elevation. Healthy dietary patterns can effectively lower blood pressure, such as the Mediterranean diet^[12], Dietary Approaches to Stop Hypertension(DASH diet)^[13], Mediterranean-DASH Intervention for Neurodegenerative Delay(MIND diet)^[14], and intermittent fasting^[15].

In addition, sleep disorders have also been confirmed as important risk factors for hypertension, involving multiple pathophysiological pathways. Epidemiological studies have provided strong evidence for this association; a large-scale cohort study of US veterans showed that poor sleep quality significantly increases the risk of hypertension and cardiovascular diseases, such as insomnia and obstructive sleep apnea^[16]. Sleep structure itself is also closely related to cardiovascular risk factors^[17]. Studies have shown that there are sex-specific associations between different sleep stages and cardiovascular risk factors, and chronic sleep fragmentation can directly lead to adverse cardiovascular outcomes, possibly through sustained sympathetic activation and metabolic disturbances^[18].

Notably, the effects of diet and sleep on blood pressure may not be independent of each other, possibly due to their shared pathways; both high-salt or high-fat diets and sleep disorders can activate the sympathetic nervous system and impair vascular endothelial function^[19; 20]. Therefore, it is reasonable to hypothesize that when unhealthy diet and sleep disorders co-exist, they may exert a synergistic activating effect on the sympathetic nervous system and vascular endothelium, thereby amplifying the risk of blood pressure elevation. In other words, sleep quality may modify the relationship between dietary patterns and blood pressure: the pressor effect of an unhealthy diet may be more pronounced in individuals with poor sleep quality. Previous studies have mostly examined diet and sleep as independent risk factors separately, while neglecting the possible interaction between them^[21; 22].

Based on the above research background, the present study proposes the following scientific hypothesis: sleep quality may moderate the association between dietary patterns and blood pressure. To test this hypothesis, we used cross-sectional survey data from a community-dwelling middle-aged and older adult population to examine the association between dietary pattern and blood pressure, with a focus on the moderating role of sleep quality in this relationship. The findings may provide preliminary epidemiological evidence for considering sleep quality as a contextual factor in diet-related blood pressure research and may help inform future longitudinal or intervention studies on integrated lifestyle strategies for hypertension prevention.

2. Methods

2.1 Study population

This study was based on survey data conducted by the Institute of Environmental Health, Shijiazhuang Center for Disease Control and Prevention, Hebei Province, which aimed to investigate the impact of environmental exposures on subclinical indicators in the population. According to the study objectives, the inclusion and exclusion criteria were applied. Participants were required to meet all of the following criteria simultaneously: (1) age ≥ 45 years; (2) complete data on key variables (dietary pattern, sleep quality, systolic blood pressure) and main covariates, including age, sex, body mass index (BMI), smoking, alcohol consumption, educational level; and (3) voluntary participation and signed informed consent. Exclusion criteria were: (1) current use of antihypertensive drugs or psychiatric medications affecting blood pressure; (2) presence of severe diseases such as malignant tumors or severe liver or kidney dysfunction; (3) diagnosed primary sleep disorders (e.g., severe sleep apnea) that were untreated; and (4) pregnant or lactating women. Ultimately, 201 eligible valid samples were included. Although this sample size is only a subset of the national project, all data collection procedures strictly followed the standardized operating procedures (SOP) of the national cohort and were completed by uniformly trained investigators, ensuring reliable data quality.

2.2 Dietary scale

Dietary pattern was assessed using the Mediterranean Diet Score (MDS), which includes nine components. Seven components were derived from a semi-quantitative food frequency questionnaire (FFQ) covering vegetables, fruits, legumes, cereals, fish, meat, and dairy products, each with five frequency categories ranging from “never or almost never” to “daily”; One component reflected moderate alcohol intake, defined as 5–25 g/day for women and 10–50 g/day for men, and one component reflected the ratio of monounsaturated to saturated fatty acids. For beneficial food components, participants with intake at or above the sex-specific median received 1 point; for components considered less beneficial, participants with intake below the median received 1 point. The total MDS ranged from 0 to 9, with higher scores indicating greater adherence to a Mediterranean-style dietary pattern.

2.3 Sleep scale

The researchers used the Pittsburgh Sleep Quality Index (PSQI)^[23] to assess sleep quality, aiming to subjectively measure sleep quality and disturbances over the past month. The PSQI includes 19 items that generate 7 component scores. Each component is scored from 0 (no difficulty) to 3, and these scores are summed to produce a global PSQI score ranging from 0 to 21, with higher scores indicating worse sleep quality^[24]. Scores from 0 to 5 indicate “good” sleep, scores from 6 to 10 indicate “fairly good” sleep, scores from 11 to 15 indicate “fairly poor” sleep, and scores from 16 to 21 indicate “poor” sleep. The Cronbach’s alpha for internal consistency of the PSQI was 0.83 for the English version and 0.82 for the Arabic version, indicating good reliability and validity^[25].

2.4 Blood pressure

The blood pressure measurement procedure strictly followed the standardized operating manual of the project. The measuring instrument was an OMRON HEM-7130 upper-arm electronic blood pressure monitor certified by national metrology. Measurements were taken between 8:00 and 11:00 AM to reduce the influence of circadian rhythm. Participants rested in a quiet room for at least 5 minutes before measurement, and were prohibited from smoking, consuming caffeinated beverages, or engaging in vigorous exercise within 30 minutes prior. During measurement, participants sat in a seated position with feet flat on the floor, the right upper arm bare and placed on a desk, keeping the cuff at heart level. For each participant, blood pressure was measured three times consecutively with at least 1-minute intervals between measurements; the three readings of systolic and diastolic blood pressure were recorded, and the average of the three systolic pressures was used as the final analytic indicator. All investigators

involved in the measurements received unified training from the national project and passed consistency tests, ensuring standardization and accuracy of data collection.

The significance of systolic and diastolic blood pressure in hypertension assessment exhibits notable age-related differences^[26]. Epidemiological studies have shown that diastolic blood pressure changes nonlinearly with age: it generally peaks between ages 50 and 60 and then gradually declines, whereas systolic blood pressure continues to increase with age^[27]. Therefore, in middle-aged and older adults, elevated systolic blood pressure is a more prominent blood pressure characteristic, and the prevalence of isolated diastolic hypertension is significantly reduced^[28]. Current clinical guidelines have clearly established systolic blood pressure as a core indicator for hypertension diagnosis, treatment, and prognosis assessment. Given that our study population was middle-aged and older adults, and that systolic blood pressure has superior clinical significance and predictive validity in this age group, we selected systolic blood pressure as the primary outcome measure for blood pressure level.

2.5 Covariates

The covariates included in this study comprised sociodemographic characteristics, anthropometric measurements, and lifestyle factors, all derived from standardized questionnaires and physical examinations. Sociodemographic characteristics: age was included as a continuous variable; sex was categorized as male or female; educational level was classified as primary school or below (years of education ≤ 6) and junior high school or above (> 6 years); marital status was categorized as married or divorced/widowed. Anthropometric measurement: BMI was calculated from height and weight (kg/m^2) and was included as a continuous variable in the analysis. Lifestyle factors: smoking status was categorized as current smoker, former smoker, or never smoker; alcohol consumption status was categorized as current drinker, former drinker, or never drinker. All covariates were included as control variables in the multivariable linear regression models to adjust for potential confounding effects on systolic blood pressure.

2.6 Statistical approach

Data analysis was performed using SPSS version 27.0. Before hypothesis testing, data screening was conducted to ensure quality and reliability. Continuous variables were summarized as means and standard deviations, and categorical variables were presented as frequencies. Differences between blood pressure groups were examined using independent-samples *t* tests or chi-square tests. Pearson correlation analysis was used to examine bivariate associations among study variables. Multivariable linear regression models were then constructed to examine the associations of MDS, PSQI, and their interaction with systolic blood pressure. Moderation analysis was performed using the PROCESS macro (version 5.0) for SPSS, with 5,000 bootstrap resamples. Simple slope analyses were conducted at lower, mean, and higher levels of PSQI, defined as one standard deviation below the mean, the mean, and one standard deviation above the mean, respectively. Lower PSQI scores indicate better sleep quality, whereas higher PSQI scores indicate poorer sleep quality. A two-sided *P* value < 0.05 was considered statistically significant.

3. Results

3.1 Baseline analysis

The baseline characteristics of the included participants were compared between groups according to blood pressure status, as shown in Table 1. The results showed that the distribution differences of sex, age, MDS, PSQI, educational level, alcohol consumption history, and smoking history between groups were statistically significant. Specifically, the proportion of participants with elevated blood pressure was significantly higher in males than in

females ($\chi^2=11.329$, $P < 0.001$); comparisons among different age groups showed that the proportion of participants with elevated blood pressure in the age groups of 60 years and above was significantly increased compared with those under 60 years, with an overall significant difference ($\chi^2=6.929$, $P = 0.031$); in terms of educational level, the proportion of participants with elevated blood pressure in the junior high school or below group was significantly higher than that in the junior high school or above group ($\chi^2=6.557$, $P = 0.016$); the proportion of participants with elevated blood pressure in the alcohol-consuming group was significantly higher than that in the non-alcohol-consuming group ($\chi^2=11.337$, $P < 0.001$); the proportion of participants with elevated blood pressure in the smoking group was significantly higher than that in the non-smoking group ($\chi^2=8.715$, $P = 0.004$), The MDS score of the normotensive group was overall higher than that of the hypertensive group ($t = -2.315$, $P = 0.020$). In addition, the distribution differences of BMI, PSQI and marital status between groups were not statistically significant ($P > 0.05$).

Table 1
Baseline characteristic of the study participants(*n* = 201)

Gender	Hypertension (<i>N</i> = 132)	Normal (<i>N</i> = 69)	Total (<i>N</i> = 201)	Statistic	<i>P</i> value
				11.329	<0.001
Male	77	23	100		
Female	55	46	101		
Age				6.929	0.031
<60	37	32	68		
60 to 75	45	16	61		
≥ 75	50	21	72		
BMI(kg/m ²)				0.999	0.358
<24.9	46	29	75		
≥ 24.9	86	40	126		
Marital status				0	1.000
Married	113	59	172		
Divorced/Widowed	19	10	29		
Education				6.557	0.016
Below junior high school	98	39	137		
Junior high school and above	34	30	64		
Alcohol				11.337	<0.001
Formor/Current drinker	39	6	45		
Never drinker	93	63	156		
Smoking				8.715	0.004
Formor/Current smoker	32	5	37		
Never smoker	100	64	164		
MDS	4.37 ± 1.18	4.76 ± 1.08	4.51 ± 1.16	-2.315	0.022
PSQI	4.13 ± 2.62	4.36 ± 3.34	4.21 ± 2.88	-0.504	0.615

3.2 Correlation analysis

Table 2 presents the correlation analysis among systolic blood pressure, MDS, PSQI, sex, age, education level, alcohol consumption, smoking, and BMI. The results showed that systolic blood pressure had a weak positive correlation with age ($r = 0.255$, $P < 0.01$) and BMI ($r = 0.215$, $P < 0.01$), and a weak positive correlation with alcohol consumption ($r = 0.188$, $P < 0.01$); sex showed moderate to weak positive correlations with alcohol consumption (r

= 0.540, $P < 0.01$), smoking ($r = 0.532$, $P < 0.01$), and MDS ($r = 0.340$, $P < 0.01$), indicating that males had higher rates of alcohol consumption, smoking, and higher dietary scores; age had a moderate negative correlation with education level ($r = -0.428$, $P < 0.01$), i.e., older age was associated with lower education level; specific P values are available in Tables S1 and S2. Additionally, MDS showed a weak positive correlation with PSQI ($r = 0.184$, $P < 0.01$), while the correlations of systolic blood pressure with PSQI, MDS, and other variables were weak or near zero, suggesting that the risk of collinearity among variables is low; therefore, these variables can be included in subsequent regression models for further analysis.

Table 2
Pearson correlation matrix among study variables($n = 201$)

Blood pressure	Blood pressure	Gender	Age	Education	Alcohol	Smoking	BMI	MDS	PSQI
	1								
Gender	-0.116	1							
Age	0.255**	-0.004	1						
Education	-0.090	-0.132	-0.428**	1					
Alcohol	0.188**	0.540**	0.160*	-0.145*	1				
Smoking	-0.093	0.532**	0.270**	-0.181*	0.466**	1			
BMI	0.215**	-0.065	-0.024	0.001	-0.087	-0.087	1		
MDS	-0.123	0.340**	-0.018	-0.059	.429**	0.169*	-.144*	1	
PSQI	-0.071	0.100	0.068	-0.046	0.056	0.034	-0.070	0.184**	1

*Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$. ***Significant difference at $P < 0.001$.

3.3 Moderating effect analysis

Hierarchical regression analysis was used to examine the effects of diet, sleep, and their interaction term on systolic blood pressure, and the results are shown in Table 3. Model 1 included sex, age, education level, smoking, alcohol consumption, and BMI. The results showed that age ($\beta = 0.592$, $t = 4.222$, $P < 0.001$) and BMI ($\beta = 1.392$, $t = 3.034$, $P < 0.01$) had significant positive predictive effects on systolic blood pressure, and the model explanatory power was adjusted $R^2 = 0.068$ ($F = 8.370$, $P < 0.001$). Model 2 added MDS and the PSQI to Model 1. The results showed that the main effects of MDS and PSQI were not significant ($\beta = 0.193$, $t = 0.115$, $P > 0.05$; $\beta = -0.652$, $t = -1.083$, $P > 0.05$), and the model explanatory power increased (adjusted $R^2 = 0.139$, $F = 6.415$, $P < 0.001$). Model 3 further included the interaction term of MDS and PSQI. The results showed that the interaction term significantly positively predicted systolic blood pressure ($\beta = 1.12$, $t = 2.368$, $P < 0.05$), and the model explanatory power further increased to adjusted $R^2 = 0.168$ ($F = 5.118$, $P < 0.001$), indicating an interaction between diet and sleep on systolic blood pressure, i.e., the effect of diet varies with sleep quality.

Table 3
The moderating effect of sleep quality and dietary type on systolic blood pressure(SBP)

	Model 1		Model 2		Model 3	
	β	<i>t</i>	β	<i>t</i>	β	<i>t</i>
Gender	3.358	0.752	3.771	0.831	3.842	0.856
Age	0.592	4.222***	0.604	4.275***	0.624	4.463***
Education	0.486	0.119	0.476	0.117	1.394	0.345
Smoking	-6.108	-1.172	-6.334	-1.208	-6.111	-1.179
alcohol	-12.979	-2.587**	-13.21	-2.480*	-14.126	-2.677**
BMI	1.392	3.034**	1.366	2.944**	1.198	2.584**
MDS			0.193	0.115	0.033	0.020
PSQI			-0.652	-1.083	-1.182	-1.859
MDS*PSQI					1.12	2.368*
R-sq	0.078		0.165		0.194	
Adjusted R-sq	0.068		0.139		0.168	
F	8.370***		6.415***		5.118***	

*Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$. ***Significant difference at $P < 0.001$.

3.4 Stratified test of the moderating variable

The simple slope analysis results in Fig. 1 showed that PSQI significantly moderated the association between MDS and systolic blood pressure. At lower PSQI scores, indicating better sleep quality, higher MDS was significantly associated with lower systolic blood pressure ($\beta = -5.537$, $t = -2.530$, $P = 0.012$, 95%CI: -9.852 to -1.221). At the mean level of PSQI, this association was attenuated and no longer statistically significant ($\beta = -2.027$, $t = -1.266$, $P = 0.21$, 95%CI: -5.184 to 1.131). At higher PSQI scores, indicating poorer sleep quality, the association between MDS and systolic blood pressure became non-significant and positive in direction ($\beta = 1.483$, $t = 0.725$, $P = 0.47$, 95%CI: -2.554 to 5.519), as shown in Table 4.

Table 4
Conditional effects of Mediterranean Diet Score on systolic blood pressure at different levels of PSQI

PSQI level	PSQI score	Effect	SE	<i>t</i>	<i>P</i> value	95% CI
Lower PSQI score (Better sleep quality)	1.322	-5.537	2.188	-2.530	0.012	-9.852 to -1.221
Mean PSQI score	4.21	-2.027	1.601	-1.266	0.210	-5.184 to 1.131
Higher PSQI score (Poorer sleep quality)	7.096	1.483	2.047	0.725	0.470	-2.554 to 5.519

3.5 Subgroup analysis

To further examine whether the moderating effect of sleep quality is stable across different population subgroups, stratified analyses were performed by sex, age, education level, drinking history, smoking history, and BMI in Fig. 2. The results showed that the interaction between diet and sleep quality was significant only in the overweight/obese group (BMI ≥ 24.9 kg/m²) (interaction coefficient $\beta = 0.734$, 95% CI: 0.214 to 1.255, $P = 0.006$), while it was not significant in normal-weight individuals or other subgroups ($P > 0.05$). This result indicates that the moderating effect appeared to be more evident among overweight/obese individuals. Specifically, among overweight/obese individuals, poorer sleep quality was associated with a greater attenuation of the inverse association between MDS and systolic blood pressure, whereas no clear moderating effect was observed among normal-weight participants.

3.6 sensitivity analysis

To test the robustness of the results, the dependent variable was replaced from systolic blood pressure to diastolic blood pressure, and the hierarchical regression analysis was repeated, as shown in Table 5. After replacing the dependent variable with diastolic blood pressure, the interaction term between diet and sleep remained significant ($\beta = 0.533$, $t = 1.989$, $P < 0.05$), and the direction was consistent with that of the main analysis, suggesting that the interaction between diet and sleep quality showed a consistent direction when diastolic blood pressure was used as an alternative outcome. The results of the stratified analysis for diastolic blood pressure were consistent with the diastolic blood pressure results, as shown in Table S3.

Table 5
The moderating effect of sleep quality and dietary type on diastolic blood pressure(DBP)

	Model 1		Model 2		Model 3	
	β	t	β	t	β	t
Gender	-11.146	-3.240**	-10.829	-3.118**	-10.862	-3.138**
Age	-0.222	-2.057*	-0.244	-2.261*	-0.254	-2.354*
Education	-7.906	-2.527*	-8.016	-2.575*	-8.457	-2.712**
Smoking	-1.511	-0.376	-1.772	0.441	-1.879	-0.469
alcohol	1.335	3.866***	3.464	0.850	3.904	0.958
BMI	0.051	0.145	0.017	0.048	0.097	0.272
MDS			2.003	1.564	1.894	1.481
PSQI			-0.681	-1.478	-0.935	-1.991*
MDS*PSQI					0.533	1.989*
R-sq	0.109		0.127		0.136	
Adjusted R-sq	0.081		0.090		0.102	
F	3.955***		3.493***		3.365***	

*Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$. ***Significant difference at $P < 0.001$.

4. Discussion

This study found that sleep quality significantly moderated the association between dietary pattern and systolic blood pressure among middle-aged and older adults. A higher MDS was associated with lower systolic blood pressure only among participants with lower PSQI scores, indicating better sleep quality. As PSQI scores increased, this inverse association was attenuated and became non-significant. These findings suggest that poor sleep quality may weaken the favorable association between a healthy dietary pattern and systolic blood pressure.

In the present study, the directions of the associations of diet and sleep with systolic blood pressure were consistent with previous literature. Numerous randomized controlled trials have confirmed that the DASH diet and the Mediterranean diet can lower systolic blood pressure by at least 5–7 mmHg. Meta-analyses of the Mediterranean diet have also shown that adherence to this diet is significantly associated with lower blood pressure levels^[29]. Large-scale cohort studies have also found that a higher dietary quality index is inversely associated with the incidence of hypertension^[30]. These studies have established healthy diet as a cornerstone of non-pharmacological treatment of hypertension. Meanwhile, the relationship between sleep quality and blood pressure has been widely confirmed^[31]. A meta-analysis including over 200,000 individuals showed that short sleep duration (< 6 hours) was associated with approximately a 20% increased risk of hypertension, and poor sleep quality (PSQI > 5) with approximately a 30% increased risk^[32]. Studies focusing on middle-aged and older adults further found that sleep structure disturbances such as sleep fragmentation, difficulty falling asleep, and early morning awakening can independently predict elevated systolic blood pressure^[33].

Although diet and sleep have each been confirmed as independent factors influencing blood pressure, most previous studies have included them as parallel, additive risk or protective factors in multivariable models, and few have systematically examined the interaction between the two. In a cohort study^[34] including over 400,000 participants aged 38–73 years, it was found that the inverse association between healthy diet adherence and blood pressure was more pronounced among individuals with longer sleep duration; however, the MDS*PSQI duration interaction term did not reach statistical significance. That study focused only on sleep duration and did not use a multidimensional scale such as the PSQI to assess global sleep quality; moreover, 54.10% of its participants were premenopausal women, differing from our mixed middle-aged and older adult population, which may explain the inconsistency in results. Another study from Ethiopia reported that the association between higher dietary fiber intake and lower blood pressure existed only in individuals with good sleep quality^[35]; however, that study did not conduct a formal interaction test and only demonstrated the trend through stratified analysis. The systematic review by Keiser et al^[36] first proposed the concept of “temporal behavior”, finding that both later eating time and later sleep midpoint were associated with higher blood pressure, providing indirect evidence for a possible synergistic effect between diet and sleep. Our results showed a significant interaction between diet and sleep in relation to systolic blood pressure, and the simple slope analysis further indicated that the inverse association between MDS and systolic blood pressure was evident only at lower PSQI scores.

In terms of potential mechanisms, the observed interaction is biologically plausible in light of existing evidence. Poor sleep quality has been linked to autonomic imbalance and sympathetic activation^[37; 38], which may influence peripheral vascular resistance, renal sodium handling, and neuroendocrine regulation. Healthy dietary patterns may support vascular function through nitric oxide bioavailability and antioxidant pathways^[39; 40], but these favorable associations may be less evident in the context of poor sleep-related physiological stress. Poor sleep quality has also been associated with endothelial dysfunction and low-grade inflammation^[41; 42], which may attenuate the

vascular benefits typically associated with healthier dietary patterns. In addition, sleep fragmentation and circadian disruption may be related to HPA-axis activation, altered cortisol rhythm, and metabolic disturbances^[43–45]. Dietary components such as potassium, magnesium, and dietary fiber may contribute to blood pressure regulation through sodium excretion, insulin sensitivity, and vascular function^[46–48]. These pathways may interact with one another, as sympathetic activation, inflammation, HPA-axis dysregulation, and metabolic abnormalities are closely connected^[49; 50]. These biological pathways may help explain why the inverse association between MDS and systolic blood pressure was observed mainly among participants with better sleep quality and was attenuated as PSQI scores increased.

Subgroup analyses further suggested that the moderating effect of sleep quality on the diet–blood pressure relationship may differ by metabolic status. The interaction between MDS and PSQI was significant only in the overweight/obese subgroup, whereas no significant interaction was observed among normal-weight individuals or in other subgroups defined by sex, age, education level, drinking history, or smoking history. This pattern may be partly related to the metabolic context of excess adiposity. Overweight and obesity are commonly accompanied by low-grade inflammation, insulin resistance, and sympathetic overactivity^[51], which overlap with pathways linking poor sleep quality to elevated blood pressure. In addition, overweight or obese individuals may have a higher likelihood of sleep-disordered breathing, such as obstructive sleep apnea, which can contribute to sleep fragmentation and intermittent hypoxia^[52]. These factors may help explain why the interaction between diet and sleep quality was more apparent in overweight/obese participants, and that the combined effect of multiple behavioral factors is often amplified in the presence of obesity.

These findings may have implications for integrated lifestyle assessment in community-based hypertension prevention, while also requiring cautious interpretation. Rather than considering diet and sleep as isolated behavioral factors, our results suggest that sleep quality may represent an important contextual factor when interpreting the association between dietary pattern and blood pressure. In practice, brief sleep quality assessment may help identify individuals for whom dietary guidance alone may be insufficient, particularly among overweight or obese adults. This perspective is consistent with the broader direction of lifestyle-based chronic disease prevention emphasized in the Chinese Dietary Guidelines^[53], which encourages comprehensive health behaviors rather than isolated dietary changes. Therefore, incorporating sleep assessment alongside dietary counseling may be a practical consideration in community-based hypertension prevention programs.

However, several limitations should be acknowledged. First, the cross-sectional design precludes causal inference, and these findings should be interpreted as hypothesis-generating rather than evidence for a causal or intervention effect. Second, the sample size was relatively small, particularly for subgroup analyses, which may limit statistical power and the stability of interaction estimates. Third, dietary intake and sleep quality were assessed using self-reported instruments, which may be subject to recall bias and measurement error. Finally, participants were recruited from a single community, which may limit the generalizability of the findings to other populations. Future longitudinal studies and randomized lifestyle intervention trials are needed to determine whether improving sleep quality can enhance the blood pressure-related benefits of healthy dietary patterns, particularly among overweight or obese adults.

5. Conclusions

In this cross-sectional study of middle-aged and older adults, a healthier dietary pattern was associated with lower systolic blood pressure primarily among participants with better sleep quality. This moderating effect appeared to

be more pronounced among overweight or obese individuals. These findings suggest that sleep quality may be an important contextual factor in the association between diet and blood pressure, and that integrated diet–sleep approaches deserve further evaluation in future longitudinal and intervention studies.

Abbreviations

Abbreviation	Full Form
BMI	Body Mass Index
CKD	Chronic Kidney Disease
CVD	Cardiovascular Disease
DASH	Dietary Approaches to Stop Hypertension
DBP	Diastolic Blood Pressure
FFQ	Food Frequency Questionnaire
HTN	Hypertension
MDS	Mediterranean Diet Score
MIND	Mediterranean-DASH Intervention for Neurodegenerative Delay
PSQI	Pittsburgh Sleep Quality Index
SBP	Systolic Blood Pressure
SOP	Standardized Operating Procedures

Declarations

Human Ethics approval and consent to participate

The studies involving human participants were reviewed and approved by the Research Ethics Committee of the Shijiazhuang Center for Disease Control and Prevention. The participants provided their written informed consent to participate in this study.

Consent for publication

Not applicable

Availability of data and materials

The datasets analysed during the current study are not publicly available due to confidentiality requirements of the public health project commissioned by the Shijiazhuang Center for Disease Control and Prevention, as the data contains sensitive individual health information. but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Ruiting Wu and Beibei Shi contributed equally to this work and share first authorship. Ruiting Wu: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing. Beibei Shi: Methodology, Formal analysis, Investigation, Data curation, Writing. Hui Kang: Investigation, Data collection, Project administration. Yanxin Yang: Data curation, Formal analysis, Visualization. Ruirui Yang: Investigation, Data curation. Zhichao Liang: Methodology, Validation. Wenlong Chen: Supervision, Project administration. Fengge Chen: Conceptualization, Funding acquisition, Supervision, Project administration. All authors have read and approved the final version of the manuscript.

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Figures

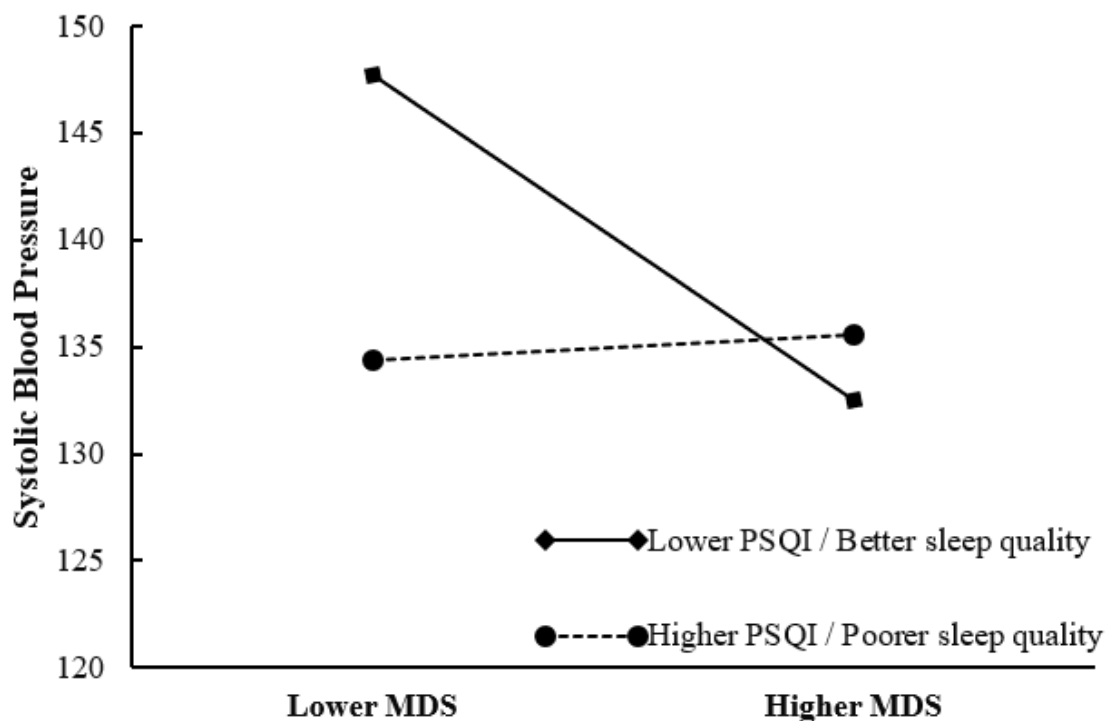


Figure 1

Simple slopes for the association between MDS and systolic blood pressure at lower and higher PSQI scores.

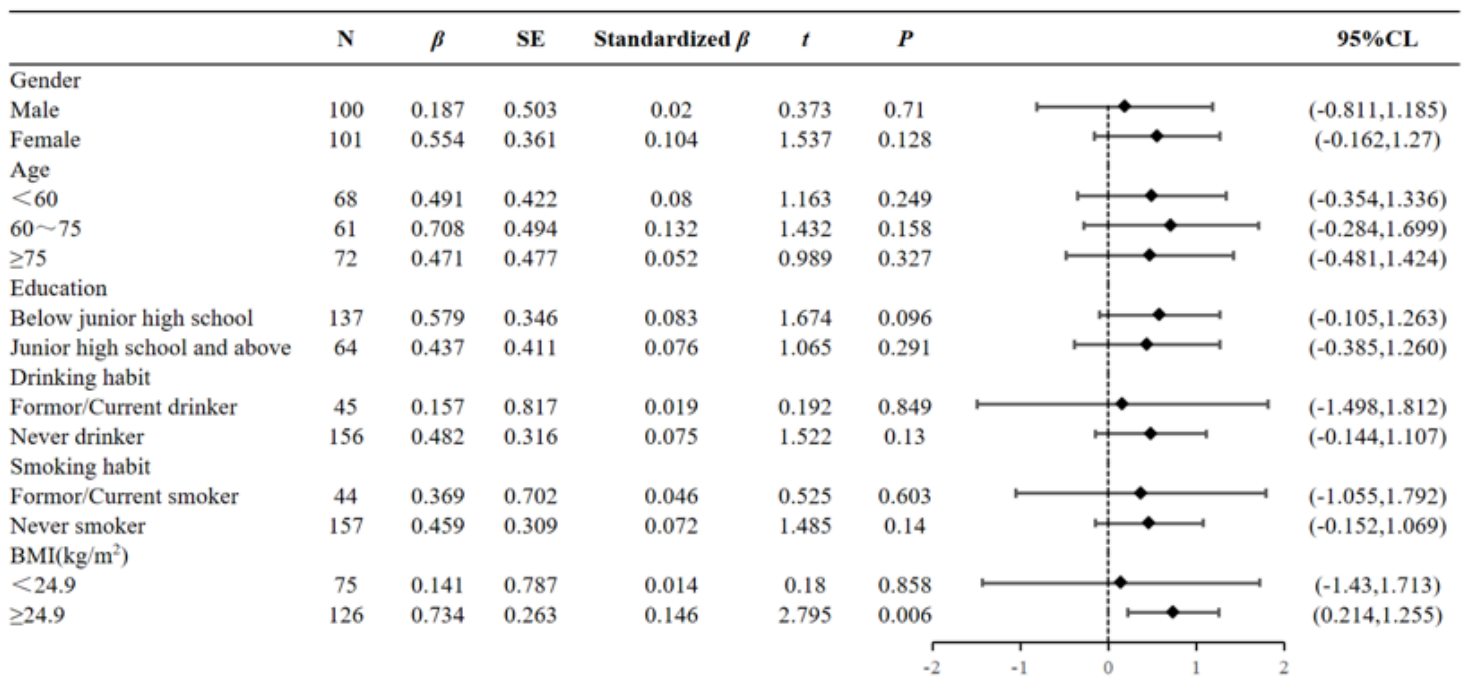


Figure 2

Subgroup analysis of the moderating role of sleep quality

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