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ORIGINAL RESEARCH

Association Between Sleep and Vertigo Severity in Benign Paroxysmal Positional Vertigo: Mediating Role of Psychological Factors

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Objective: To investigate the relationship between sleep quality and vertigo severity among patients with benign paroxysmal positional vertigo (BPPV) and to elucidate the mediating effects of anxiety and depression on this association.

Methods: We analyzed baseline data from an ongoing cohort study of 1056 BPPV patients in Northwest China. Vertigo severity was assessed using the Dizziness Handicap Inventory (DHI), sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI), and psychological states were evaluated using the Hospital Anxiety and Depression Scale (HADS), Self-rating Anxiety Scale (SAS), and Self-rating Depression Scale (SDS). Multiple regression and mediation analysis were conducted to explore the relationships between sleep quality, psychological factors, and vertigo severity.

Results: Robust correlations were demonstrated between total PSQI scores and all DHI subscales ($p < 0.001$). Multivariate ordered logistic regression revealed that patients exhibiting sleep disorders manifested a substantially elevated risk of severe vertigo compared to those without (OR: 2.024; 95% CI: 1.571–2.608). Psychological factors emerged as significant mediators in this relationship, with anxiety accounting for 28.5% of the mediation effect, depression contributing 38%, and HADS mediating 37.7% of the association. A pronounced dose-response relationship was noted, with increased risk of vertigo severity as PSQI scores exceeded 7.

Conclusion: This study shows a strong correlation between poor sleep quality and increased vertigo severity in BPPV patients, with anxiety and depression as significant mediators. These findings emphasize the need to address sleep-related factors and psychological symptoms in BPPV management, suggesting integrated sleep therapy and psychological interventions.

Plain Language Summary:

Current Knowledge/Study Rationale: Benign paroxysmal positional vertigo (BPPV) is strongly linked to sleep disorders and psychological comorbidities, yet the mediating role of psychological factors in exacerbating vertigo severity remains underexplored. This study investigates how anxiety and depression modulate the relationship between poor sleep quality and vestibular disability in BPPV patients.

Study Impact: The results reveal that anxiety and depression mediate over one-third of the association between sleep disorders and vertigo severity, establishing a bidirectional pathway between psychological distress and vestibular dysfunction. These findings advocate for integrated clinical strategies targeting both sleep health and psychological well-being to optimize BPPV management and reduce vertigo-related disability.

Keywords: benign paroxysmal positional vertigo, sleep medicine, otology, neurotology, anxiety, depression

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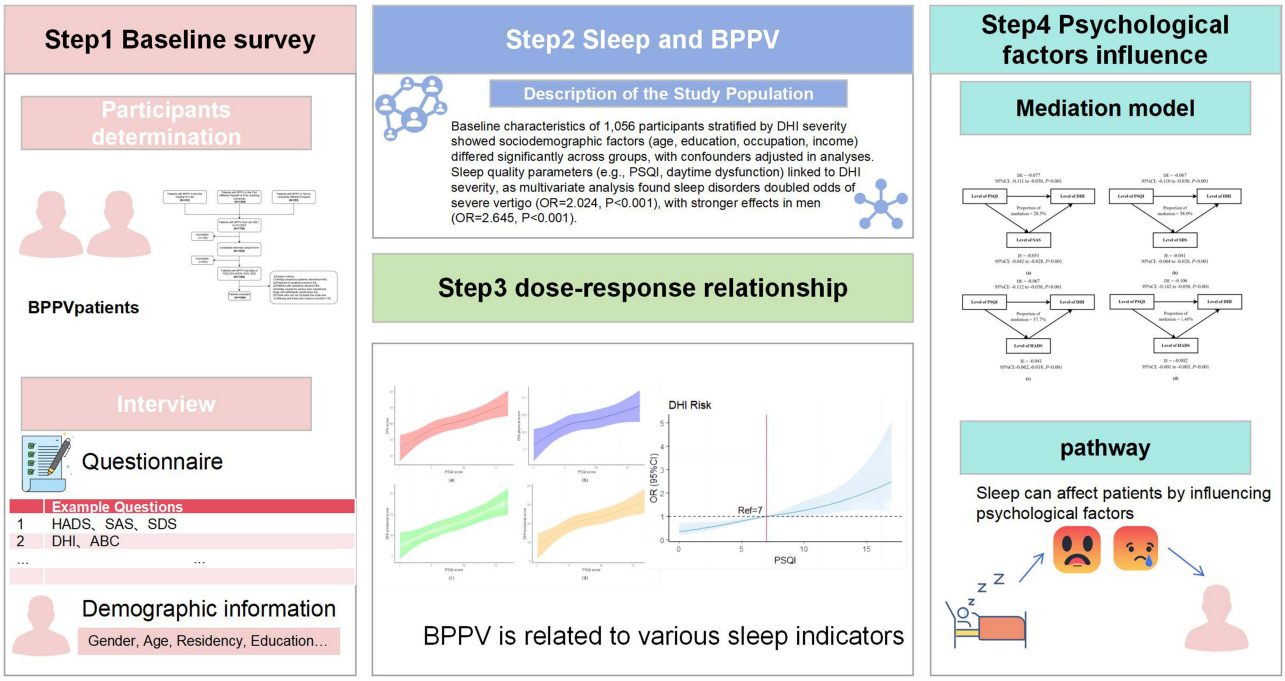
Graphical Abstract



Introduction

Benign Paroxysmal Positional Vertigo (BPPV) is the most common vestibular disorder among adults, affecting up to 2.4% of the population over their lifetime.[1] Characterized by brief, recurrent episodes of vertigo precipitated by specific head movements, BPPV often resolves spontaneously but has an annual recurrence rate of approximately 15%.[2,3] Its prevalence increases with age, rising from 0.5% in individuals under 40 to 3.4% in those over 60, and reaching nearly 10% by age 80.[3] The underlying pathophysiologic mechanisms primarily encompass canalithiasis, characterized by the displacement of otolithic debris into the semicircular canals, and cupulolithiasis, wherein otoliths material adheres to the juxtacanalicular ridge, both mechanisms eliciting vertigo through aberrant vestibular signaling.[4] In the geriatric population, BPPV not only induces vertigo but also causes vomiting and impair gait and balance, thereby elevating the risk of falls.[5]

Sleep disorders are common among patients with BPPV and have been shown to adversely affect their quality of life.[6] Although numerous investigations have documented diminished sleep quality among patients experiencing vertigo, the fundamental relationship between sleep impairment and vertigo severity, along with the intermediary influence of psychological factors, remains inadequately elucidated.[7,8] Of particular significance, psychiatric manifestations such as anxiety and depression exhibit a pronounced association with BPPV-approximately 73.5% of affected individuals present with anxiety symptomatology and 41% experience depressive states,[9,10] with the prevalence of generalized anxiety disorder substantially exceeding that observed in the general population.[11] Contemporary research has additionally established a robust correlation between vertigo-related quality of life indices and psychological distress parameters, specifically depression and anxiety.[12]

Considering the established influence of both sleep quality and psychological factors on vertigo severity, a comprehensive investigation of their intricate interrelationships among BPPV patients is warranted. Extant literature has demonstrated that affective disorders deleteriously influence sleep architecture and potentiate vestibular symptomatology.[13,14] In addition, intermittent hypoxemic episodes associated with Obstructive Sleep Apnea (OSA), the predominant sleep-disordered breathing condition, may augment the susceptibility to BPPV manifestation and recidivism through pathophysiological mechanisms involving deterioration of cochlear hair cells or vestibular nuclear complexes.[15] Nevertheless, there remains a paucity of robust epidemiological evidence derived from substantial cohorts elucidating the precise mechanistic pathways through which

sleep quality modulates vertigo severity via psychological mediators such as anxiety and depression. This knowledge deficit is particularly pronounced within Chinese populations, where investigative efforts have been notably circumscribed.

Therefore, this study aims to assess the relationship between sleep quality and vertigo disability in BPPV patients, with a specific focus on the mediating role of psychological factors, such as anxiety and depression. By utilizing baseline data from a cohort of BPPV patients in Northwest China and accounting for participants' history of mood disorders and treatment histories, this research seeks to address the gaps identified in previous studies. By elucidating the complex interactions among sleep quality, psychological factors, and vertigo severity, this study aims to offer theoretical insights and clinical guidance for the effective management of BPPV.

Materials and Methods

Study Design and Population

This study utilized baseline data from an ongoing prospective cohort of BPPV patients in Northwest China, with data acquisition conducted from July 2022 through October 2023. Eligible participants were recruited from the First Affiliated Hospital of Xi'an Jiaotong University, the First Hospital of Yulin City, and the Affiliated Hospital of Yan'an University.

Inclusion Criteria

(1) definitive BPPV diagnosed in accordance with the 2015 Bárány Society diagnostic, confirmed through Supine Roll Test(SRT) and Dix-Hallpike maneuvers;[16] with precise semicircular canal involvement characterized as follows: Posterior canal BPPV: Positive Dix-Hallpike test eliciting upbeating-torsional nystagmus directed toward the dependent ear; Horizontal canal BPPV: Positive Supine Roll Test with horizontal-torsional nystagmus (velocity exceeding 10°/s) corresponding to the affected side; Patients exhibiting multiple canal involvements (≥2 canals) were incorporated provided there was comprehensive documentation of the predominant affected canal based on the most salient nystagmus characteristics and clinical manifestations. (2) age range between 18 and 70 years; (3) absence of abnormalities on cranial magnetic resonance imaging (MRI) or vascular imaging studies; (4) no evidence of significant cervical spine pathology; (5) provision of written informed consent; and (6) absence of pre-existing anxiety or depression antecedent to BPPV onset.[17]

Exclusion Criteria

Exclusion criteria encompassed (1) vertigo attributable to systemic diseases such as cardiovascular or endocrine diseases; (2) pregnant or lactation; (3) substance abuse issues, including alcohol or drugs; (4) vertigo induced by toxic substances, medications, or withdrawal syndrome; (5) inability to complete assessments due to illiteracy or refusal to participate; and (6) presence of other inner or middle ear diseases, including Meniere's disease, vestibular neuritis, labyrinthitis, or external vestibular loss.[15]

To address potential confounding factors highlighted in previous research,[9,10] we collected detailed histories of mood disorders, including anxiety and depression, as well as treatment histories for these conditions.

Participants provided written informed consent and completed baseline questionnaires upon enrollment. Data were managed using the REDCap system hosted by Xi'an Jiaotong University.[18,19] Treatment modalities were documented by trained research assistants and physicians through hospital information systems, and treatment efficacy was assessed using standardized scales. The cohort is registered on ChiCTR.org (ChiCTR2100053160). Ethical approval was obtained from the Ethical Committee of Xi'an Jiaotong University Health Science Center on November 2021 (Approval Number: 2021–1560).

From 2021 to 2023, 1756 participants were initially considered. After applying inclusion and exclusion criteria, 1056 patients were included in the final analysis (Figure 1). The included and excluded groups were generally comparable, although the included group had a slightly higher average age and fewer female participants (Supplementary Table 1).

Assessment of Vertigo Severity

Vertigo severity was quantified using the Dizziness Handicap Inventory (DHI) scale, developed by Jacobson and Newman.[20] The application of this instrument in this study adhered to appropriate academic citation practices, in accordance with its recognized

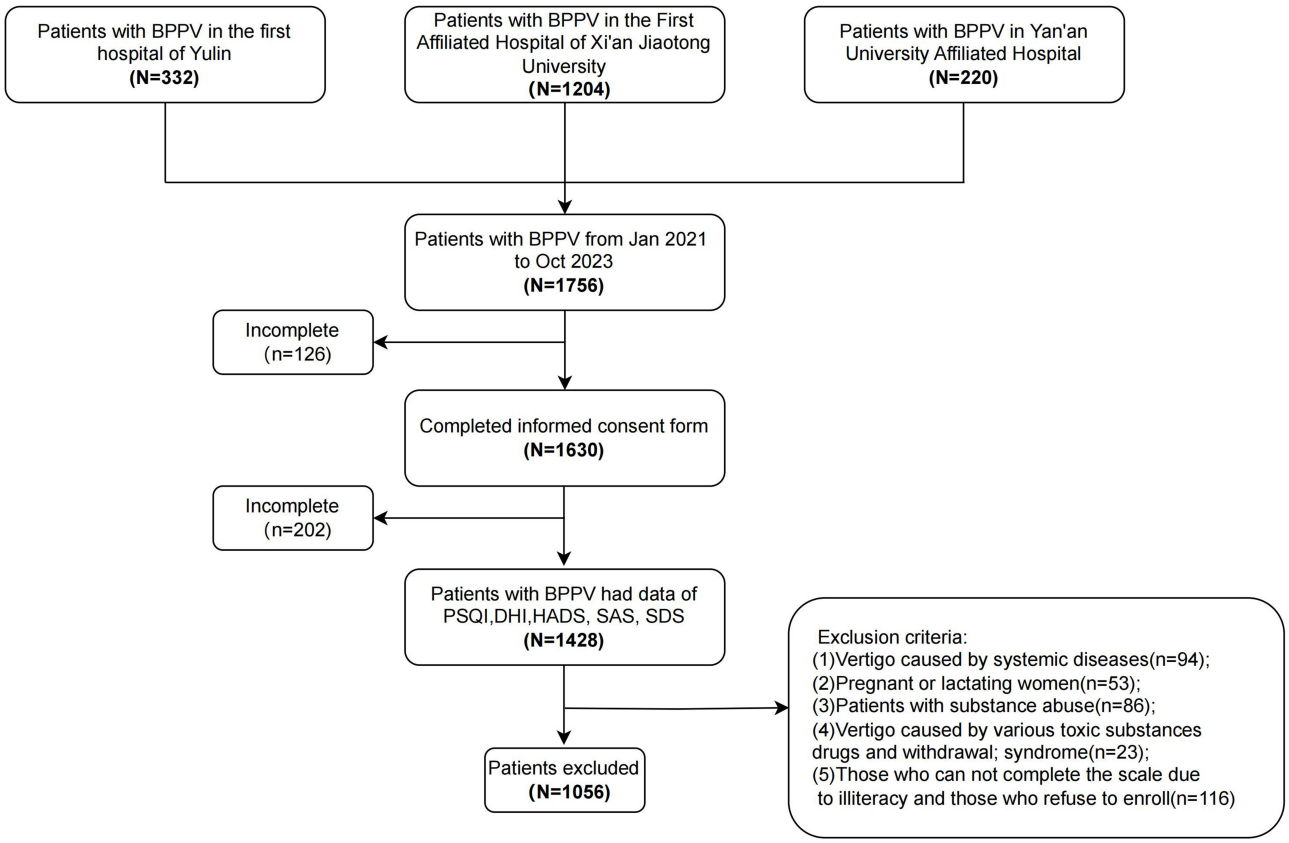


Figure 1 The inclusion and exclusion process for study participants.

status as a public domain tool for scholarly research, and its validity has been established in the primary language of the present study population.[21] The DHI comprehensively evaluates vertigo severity and its functional impact across three distinct domains: somatic manifestations (domain P), emotional consequences (domain E), and functional limitations (domain F). The scoring system classifies vertigo impairment into mild (0~30), moderate (31~60), and severe (61~100) categories, enabling a comprehensive assessment of the impact of vertigo on daily functioning.[22] Additionally, the Activities-specific Balance Confidence (ABC) Scale was employed to measure participants' confidence in performing daily activities without losing balance or experiencing a sense of unsteadiness. Typically used among older adults or individuals with balance impairments, the scale consists of 16 items that cover a range of daily activities, such as walking around the house, climbing stairs, or reaching for objects. Respondents rate their confidence on a scale from 0% (no confidence) to 100% (completely confident) for each activity. The overall score is calculated by averaging the responses, providing a quantitative measure of balance confidence that can help healthcare professionals identify individuals at risk of falls and tailor interventions to improve balance and mobility.[23,24] The ABC Scale was utilized with authorization from Mapi Research Trust under a non-commercial research license (5993380104728).

Psychological Evaluation

Psychological states were evaluated using the Hospital Anxiety and Depression Scale (HADS), the Self-rating Anxiety Scale (SAS), and the Self-rating Depression Scale (SDS). The HADS consists of two subscales for anxiety (HADS-A) and depression (HADS-D), each subscale comprising 7 items. Scores range from 0 to 21, with higher scores indicating more severe symptoms.[25] According to Chinese normative data, SAS scores below 50 are deemed normal, with scores from 50 to 59 indicating mild anxiety, 60 to 69 moderate anxiety, and 70 or above severe anxiety. Similarly, for the SDS, scores below 53 are considered normal, with scores from 53 to 59 reflecting mild depression, 60 to 69 moderates depression, and scores of 70 or higher indicating severe depression.[26] The HADS was employed with authorization from

Mapi Research Trust under a non-commercial research license (1591527–1). The SDS and SAS instruments were utilized with proper academic citation as they are considered public domain for scholarly research, with their original publications[27,28] containing all questionnaire items without commercial use restrictions.

Sleep Quality Measurement

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), which evaluates sleep patterns over the past month through 19 questions. The first four questions are open-ended, asking about subjective resting time, time to fall asleep, wake-up time, and total sleep time. Total sleep time is calculated by subtracting wake-up time from falling asleep time, with points assigned as follows: ">7 hours" earns 0 points, "6–7 hours" earns 1 point, "5–6 hours" earns 2 points, and "<5 hours" earns 3 points. The PSQI covers aspects like subjective sleep quality, sleep latency, and sleep duration, with responses ranging from "never in the past month" to "three or more times a week", scored from 0 to 3. Medication use before sleep is recorded as a single dose regardless of amount. Higher cumulative scores indicate poorer sleep quality, with a total PSQI score over five denoting poor sleep quality. The PSQI's reliability for evaluating patients with BPPV is validated, with a Cronbach's alpha of 0.83.[29]

Definition of Covariates

Participants completed detailed questionnaires at baseline, covering demographic and health-related factors. In this study, smoking was defined as the consumption of more than one cigarette per day over the past six months. Alcohol consumption was characterized by drinking alcohol at least once a week during the same period. Marital status was categorized into five categories: unmarried, married or in-union, divorce or separated, widowed, and unknown. Body Mass Index (BMI) was calculated by dividing the individual's weight in kilograms by their height in meters squared.

Statistical Analysis

The characteristics of participants were delineated based on vertigo severity levels. Normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables with normal distribution were presented as mean ± standard deviation and compared using the *t*-test for two-groups comparisons and analysis of variance (ANOVA) for multiple groups. Non-normally distributed data were expressed as median and interquartile range and compared using the Kruskal–Wallis test. Categorical variables were reported as count and percentages and analyzed using Chi-square test.

Pearson's correlation coefficients were calculated to assess association between DHI scores and PSQI components. Multiple linear regression models were employed to examine the relationship between DHI and PSQI scores, adjusting for confounders such as age, occupation, income, and education that were significant in univariate analyses ($P < 0.05$). Ordered logistic regression was used to analyze the association between sleep disturbance (PSQI > 5) and vertigo severity levels, adjusting for aforementioned confounders and with DHI scores categorized into three levels (0–30, 31–60, 61–100). Moreover, This model was designed to determine the relationship between sleep level and DHI level by conducting separate analyses for the overall dataset and for subgroups stratified by gender.

Mediation analyses were conducted to explore the roles of anxiety and depression (as measured by HADS, SAS, and SDS scores) and balance confidence (ABC score) in the relationship between sleep quality and vertigo severity. Restricted cubic spline (RCS) curves based on logistic models were used to evaluate the dose-response relationship between sleep quality and vertigo severity on a continuous scale using.

All statistical analyses were performed using R Statistical Software (version 4.1.2; R Core Team 2021). Two-sided *p*-values less than 0.05 were considered statistical significance.

Results

Description of the Study Population

Table 1 presents the baseline demographic and clinical characteristics of the 1056 participants, stratified according to DHI severity classifications (mild: ≤30; moderate: 31–60; severe: >60). The cohort was distributed across three distinct

Table 1 The Baseline Characteristics of Population

	Total (n=1056)	Mild Impairment* (n=410)	Moderate Disorder (n=381)	Severe Disorder (n=265)	*P* value
Sex (n (%))					
Male	294 (27.8)	119 (29.0)	113 (29.7)	62 (23.4)	0.172
Female	762 (72.2)	291 (71.0)	268 (70.3)	203 (76.6)	
Marital status (n (%))					
Unmarried	78 (7.4)	37 (9.0)	24 (6.3)	17 (6.4)	0.089
Married or in-union	903 (85.5)	347 (84.6)	328 (86.1)	228 (86.0)	
Divorce or separation	27 (2.6)	14 (3.4)	9 (2.4)	4 (1.5)	
Widow	43 (4.1)	11 (2.7)	16 (4.2)	16 (6.0)	
Unknown	5 (0.5)	1 (0.2)	4 (1.0)	0	
Age	50.0 (38.0–60.0)	47.0 (36.0–58.0)	52.0 (39.0–61.0)	51.0 (39.0–61.0)	0.001**
BMI	22.0 (19.6–24.5)	21.9 (19.7–24.5)	22.0 (19.5–24.5)	22.6 (19.5–24.9)	0.413
Education (n(%))					
Below primary school	47 (4.5)	9 (2.2)	10 (2.6)	28 (10.6)	<0.001***
Primary school or low	79 (7.5)	17 (4.1)	34 (8.9)	28 (10.6)	
Secondary school	194 (18.4)	62 (15.1)	76 (19.9)	56 (21.1)	
High school or technical secondary school	221 (20.9)	77 (18.8)	86 (22.6)	58 (21.9)	
Junior college	448 (42.4)	206 (50.2)	153 (40.2)	89 (33.6)	
Master degree or above	67 (6.3)	39 (9.5)	22 (5.8)	6 (2.3)	
Occupation (n(%))					
Full time work	520 (49.2)	238 (58.0)	176 (46.2)	106 (40.0)	<0.001***
Part-time job	41 (3.9)	19 (4.6)	15 (3.9)	7 (2.6)	
No fixed work	222 (21.0)	68 (16.6)	70 (18.4)	84 (31.7)	
Retirement	273 (25.9)	85 (20.7)	120 (31.5)	68 (25.7)	
Proactive or passive smoking (n(%))					
Yes	163 (15.4)	64 (15.6)	63 (16.5)	36 (13.6)	0.589
None	893 (84.6)	346 (84.4)	318 (83.5)	229 (86.4)	
Annual household income per capita (yuan) (n(%))					
Below 12000	87 (8.2)	27 (6.6)	31 (8.1)	29 (10.9)	0.008**
12,000~35,999	188 (17.8)	57 (13.9)	79 (20.7)	52 (19.6)	
36,000~59,999	289 (27.4)	107 (26.1)	107 (28.1)	75 (28.3)	
60,000~83,999	194 (18.4)	81 (19.8)	65 (17.1)	48 (18.1)	
84,000~107,999	115 (10.9)	45 (11.0)	37 (9.7)	33 (12.5)	
108,000~12,0000	31 (2.9)	18 (4.4)	8 (2.1)	5 (1.9)	
Above 120000	152 (14.4)	75 (18.3)	54 (14.2)	23 (8.7)	

Notes: *Mild impairment: a DHI score less than or equal to 30; Moderate disorder: a DHI score greater 30 and less than or equal to 60; Severe disorder: a DHI score greater than 60.Continuous variables are presented as mean (standard deviation) and compared using t-tests; categorical variables are presented as n (%) and compared using chi-square tests.), with statistical significance defined as $P < 0.05$. All values are reported to three decimal places.**p < 0.01,***p < 0.001.

severity groups: mild impairment (n=410, 38.8%), moderate disorder (n=381, 36.1%), and severe disorder (n=265, 25.1%). Participants exhibited a mean age of 50.0 years, with males constituting 27.8% of the sample. The mean BMI was calculated at 22.0 kg/m².

Significant sociodemographic gradients were observed across the severity spectrum (mild/moderate/severe groups), with statistically significant differences in age (P=0.001), educational attainment (P<0.001), occupational status (P<0.001), and annual household income (P=0.008). Median age demonstrated a positive correlation with severity (mild: 47.0 vs severe: 51.0 years). Tertiary education attainment (junior college or higher) exhibited an inverse relationship with severity, declining from 59.7% in the mild cohort to 35.9% in the severe cohort. High-income households (annual income exceeding 120,000 yuan) manifested 2.1-fold greater prevalence in the mild cohort (18.3%) compared to the severe (8.7%). All identified confounding variables (age, educational attainment, occupational status, and household income) were subsequently adjusted for in multivariable analytical models.

Association Between Sleep Quality and Severity of Vertigo

Significant correlations were demonstrated between multiple PSQI subcomponents—specifically total PSQI score, time to fall asleep, sleep efficiency, sleep disorders, and daytime dysfunction—and specific four DHI parameters (total DHI score, somatic manifestations [domain P], emotional consequences[domain E], and functional limitations [domain F]) (Table 2). Multivariate analyses elucidated distinct sleep-vertigo associations across DHI domains. Daytime dysfunction exhibited the most pronounced positive association with total DHI scores (β=4.754, 95% CI: (3.023,~6.485), P<0.001), while sleep disorders constituted a substantial secondary contributor (β=4.700, P<0.001). Within the somatic domain, sleep efficiency demonstrated moderate positive effects (β=0.539, P=0.018), juxtaposed against nonsignificant outcomes for hypnotic pharmacotherapy utilization (β=−0.341, P=0.349). Protracted sleep latency significantly exacerbated somatic symptomatology (β=0.384, P=0.026). The emotional consequences domain analysis identified daytime dysfunction (β=1.826, P<0.001) and sleep disorders (β=1.510, P=0.006) as predominant factors. Furthermore, hypnotic pharmacotherapy exhibited no significant association with emotional impairment (β=0.371, 95% CI: (−0.603~1.345), P=0.454). Functional disability patterns manifested notable divergence; daytime dysfunction exerted the most substantial impact (β=2.020, P<0.001), whereas diminished sleep duration demonstrated modest protective effects (β=−0.898, 95% CI: (−1.600~ −0.196), P=0.012). Hypnotic pharmacotherapy displayed no significant association with functional outcomes (β=−0.113, P=0.832).

Table 2 Multiple Linear Regression Analysis for Relationship Between Sleep Parameters and DHI Score

Implicit Variable	Independent Variable	β Estimates	Standard Error of β	95% CI of β	P *value*
Total DHI score	Total PSQI Score	1.509	0.230	(1.058, 1.960)	<0.001***
	Sleep Quality	0.380	0.303	(−0.214, 0.974)	0.422
	Time to Fall a Sleep	2.347	0.954	(0.478, 4.216)	0.014*
	Sleep Duration	−2.461	0.492	(−3.425, −1.497)	<0.001***
	Sleep Efficiency	1.758	0.799	(0.192, 3.324)	0.028*
	Sleep Disorders	4.700	0.408	(3.900, 5.500)	<0.001***
	Hypnotic Pharmacotherapy	−0.083	0.270	(−0.612, 0.446)	0.759
	Daytime Dysfunction	4.754	0.883	(3.023, 6.485)	<0.001***
Somatic Disorder Score (domain P)	Total PSQI Score	0.519	0.114	(0.296, 0.742)	<0.001***
	Sleep Quality	−0.084	0.372	(−0.813, 0.645)	0.822
	Time to Fall a Sleep	0.384	0.172	(0.047, 0.721)	0.026*
	Sleep Duration	−0.374	0.312	(−0.986, 0.238)	0.231
	Sleep Efficiency	0.539	0.228	(0.092, 0.986)	0.018*
	Sleep Disorders	1.219	0.402	(0.431, 2.007)	0.002**
	Hypnotic Pharmacotherapy	−0.341	0.363	(−1.053, 0.371)	0.349
	Daytime Dysfunction	0.908	0.252	(0.414, 1.402)	<0.001***
Mood disorder score (domain E)	Total PSQI Score	0.624	0.082	(0.463, 0.785)	<0.001***
	Sleep Quality	0.471	0.510	(−0.529, 1.471)	0.356
	Time to Fall a Sleep	1.040	0.373	(0.309, 1.771)	0.005**
	Sleep Duration	−0.189	0.427	(−1.026, 0.648)	0.658
	Sleep Efficiency	0.421	0.213	(0.004, 0.838)	0.048*
	Sleep Disorders	1.510	0.551	(0.430, 2.590)	0.006**
	Hypnotic Pharmacotherapy	0.371	0.497	(−0.603, 1.345)	0.454
	Daytime Dysfunction	1.826	0.345	(1.150, 2.502)	<0.001***
Dysfunction score (domain F)	Total PSQI Score	0.665	0.088	(0.492, 0.838)	<0.001***
	Sleep Quality	−0.007	0.547	(−1.079, 1.065)	0.990
	Time to Fall a Sleep	0.924	0.400	(0.140, 1.708)	0.021*
	Sleep Duration	−0.898	0.358	(−1.600, −0.196)	0.012*
	Sleep Efficiency	0.799	0.335	(0.142, 1.456)	0.017*
	Sleep Disorders	1.971	0.591	(0.813, 3.129)	<0.001***
	Hypnotic Pharmacotherapy	−0.113	0.533	(−1.158, 0.932)	0.832
	Daytime Dysfunction	2.020	0.371	(1.293, 2.747)	<0.001***

Notes: All values are reported to three decimal places. *p < 0.05, **p < 0.01, ***p < 0.001.

Abbreviations: DHI, Dizziness Handicap Inventory; PSQI, Pittsburgh Sleep Quality Index; 95% CI, 95% confidence interval; Domain P, Somatic Disorder domain; Domain E, Mood Disorder domain; Domain F, Dysfunction domain.

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Table 3 Ordered Logistic Regression Analysis of DHI Level and Sleep Level

	PSQI Score	Unadjusted Analysis			Adjusted Analysis*		
		OR	95% CI	p-value	OR	95% CI	p-value
Total	0–5	Reference			Reference		
	>5	1.924	(1.504, 2.461)	<0.001	2.024	(1.571, 2.608)	<0.001
Men	0–5	Reference			Reference		
	>5	2.177	(1.368, 3.467)	0.001	2.645	(1.617, 4.324)	<0.001
Women	0–5	Reference			Reference		
	>5	1.825	(1.364, 2.443)	<0.001	1.820	(1.346, 2.461)	<0.001

Notes: *Adjusted: age, occupation, income, education, SAS, SDS.
Abbreviations: DHI, Dizziness Handicap Inventory; PSQI, Pittsburgh Sleep Quality Index; OR, odds ratio; 95% CI, 95% confidence interval.

Multivariate ordered logistic regression analysis identified age, occupation, income, and education as significant confounders ($p<0.05$). These variables were included in subsequent evaluations of the relationship between sleep quality and DHI level. As illustrated in Table 3, univariate analyses revealed a significant association between the presence of sleep disorders and vertigo disability status (odds ratio [OR]: 1.924; 95% CI: 1.504~2.461; $P < 0.001$). Adjusted multivariate regression indicated that individuals with sleep disorders had more than twice the odds of severe vertigo compared to those without sleep disorders (OR: 2.024; 95% CI: 1.571~2.608; $P < 0.001$). Gender-specific analyses indicated a more pronounced in men (OR: 2.645; 95% CI: 1.617~4.324; $P < 0.001$).

Mediation Analysis

Mediation analysis was conducted to evaluate whether anxiety and depression mediated the relationship between sleep quality and vertigo disability status. The results indicated that the SAS significantly mediated this relationship, with an indirect effect of −0.031 (95% CI: −0.042 ~ −0.028; P value <0.001), accounting for 28.5% of the total effect. Both mediated and direct effects were statistically significant. Similarly, the SDS and HADS demonstrated substantial mediating effects, accounting for 38% and 37.7% of the association between sleep disturbance and vertigo disability, respectively. In contrast, the ABC scale mediated only 1.5% of the effect. These findings, detailed in Table 4 and

Table 4 The Mediating Role of Anxiety and Depression Between Sleep and the Degree of Dizziness

	Estimate	95% CI	p-value
SAS			
ACME	−0.031	(−0.042, −0.028)	<0.001
ADE	−0.077	(−0.111, −0.030)	<0.001
Total Effect	−0.108	(−0.150, −0.070)	<0.001
Prop.Mediated	0.285	(0.134, 0.590)	<0.001
SDS			
ACME	−0.041	(−0.064, −0.020)	<0.001
ADE	−0.067	(−0.110, −0.030)	<0.001
Total Effect	−0.108	(−0.150, −0.070)	<0.001
Prop.Mediated	0.380	(0.196, 0.710)	<0.001
HADS			
ACME	−0.041	(−0.062, −0.018)	<0.001
ADE	−0.067	(−0.112, −0.030)	<0.001
Total Effect	−0.108	(−0.150, −0.070)	<0.001
Prop.Mediated	0.377	(0.187, 0.650)	<0.001

(*Continued*)

Table 4 (Continued).

	Estimate	95% CI	p-value
ABC			
ACME	−0.002	(−0.003, −0.001)	<0.001
ADE	−0.106	(−0.142, −0.030)	<0.001
Total Effect	−0.108	(−0.153, −0.070)	<0.001
Prop.Mediated	0.015	(0.006, 0.023)	<0.001

Notes: All estimates are reported to three decimal place.Adjusted: age, occupation, income, education.
Abbreviations: SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale; HADS, Hospital Anxiety and Depression Scale; Activities-specific Balance Confidence (Scale); ACME, Average Causal Mediation Effect; ADE, Average Direct Effect; Prop. Mediated, Proportion of Total Effect Mediated; 95% CI, 95% confidence interval.

illustrated in Figure 2, highlight the critical role of anxiety and depression in how sleep quality affects vertigo severity, suggesting that psychological factors has a greater impact than somatic symptoms.

Dose-Response Relationship of PSQI and DHI Risk

Utilizing a restricted cubic spline (RCS) model, we analyzed the dose-response relationship between PSQI scores and DHI risk. Mild vertigo impairment, as assessed by the DHI, served as the reference. The analysis, adjusted for age, occupation,

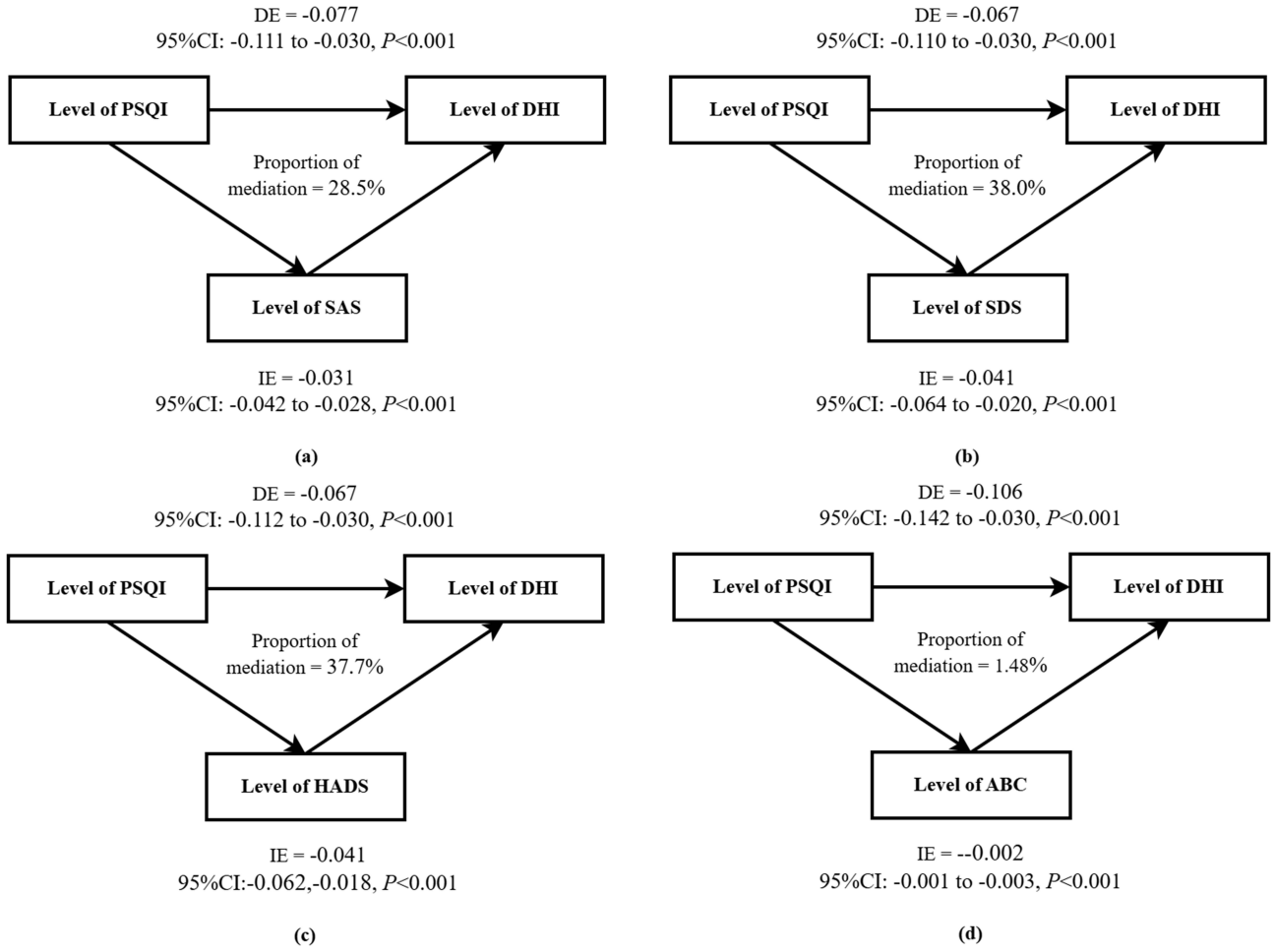

Figure 2 Mediation of emotional disorder in the association between sleep quality and dizziness. (**a**) Mediation of score of Hads in the association between sleep quality and dizziness; (**b**) Mediation of score of SAS in the association between sleep quality and dizziness; (**c**) Mediation of score of SDS in the association between sleep quality and dizziness; (**d**) Mediation of score of ABC in the association between sleep quality and dizziness.

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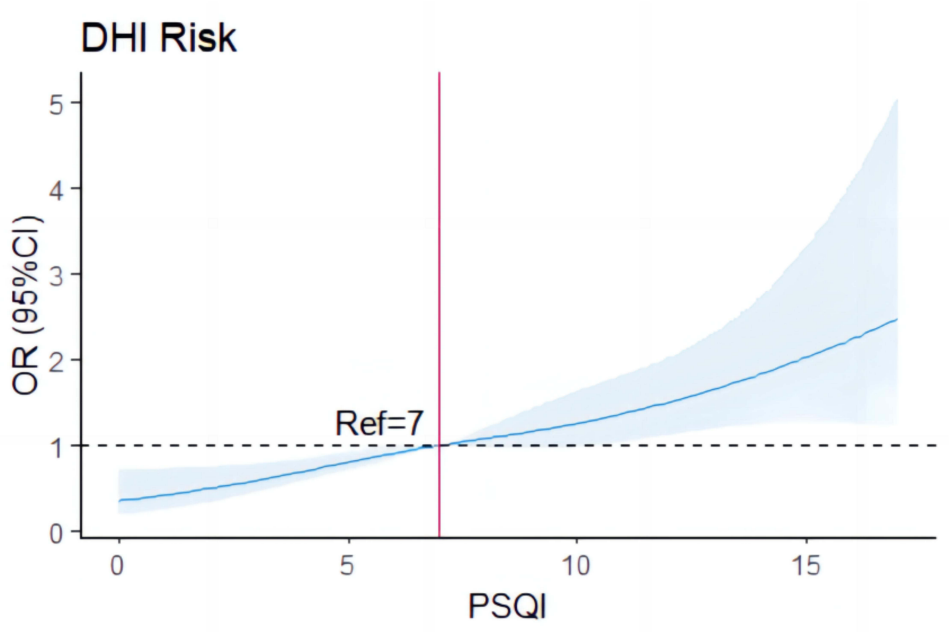

Figure 3 Multivariable-adjusted ORs and 95% CIs for risk of moderate and high vertigo damage assessed by DHI according to PSQI score. Adjusted by age, occupation, income, and education. The mild vertigo damage assessed by DHI was set as reference (dotted lines) (OR=1.00). The red line indicates the PSQI score when OR=1.
Abbreviation: CI, confidence interval.

income, and education level, confirmed a dose-response relationship between PSQI scores and DHI risk. As PSQI scores increased, the risk of elevated DHI scores progressively rose, indicating that poor sleep quality is a significant risk factor for increased vertigo severity. Notably, the risk of DHI increased when PSQI score exceeded 7, displaying a clear linear progression (Figure 3).

Figure 4 illustrates the relationship between various DHI domains and PSQI scores. Higher PSQI scores were consistently associated with greater risks of elevated scores across different DHI domains, suggesting a consistent upward trend in the risk associated with poor sleep quality in BPPV patients.

Discussion

In 2018, BPPV was officially recognized in the 11th beta of the World Health Organization's International Classification of Diseases (ICD-11).[30] Despite this recognition, BPPV remains under-researched, particularly in China, where its clinical characteristics and management are not well understood. This study aimed to elucidate the relationship between sleep disturbance and vertigo severity in individuals with BPPV to enhance prognostic and therapeutic strategies.

Our findings revealed a significant correlation between the severity of sleep disorders and vertigo disability status. Analysis of data from 1056 participants, stratified by the DHI into mild, moderate, and severe categories, demonstrated significant disparities in education, occupation and annual income across these groups. The median age exhibited a positive correlation with severity progression, while tertiary educational attainment demonstrated an inverse relationship, declining precipitously from 59.7% in the mild cohort to 35.9% in the severe cohort. Notably, high-income households manifested 2.1-fold greater prevalence in the mild vertigo classification (18.3%) compared to the severe classification (8.7%). This underscores the influence of socioeconomic factors on vertigo severity, aligning with the observations of Kim et al.[31] Socioeconomic status may impact patients' access to healthcare resources, stress levels, and overall health behaviors, thereby influencing the degree of vertigo impairment. Individuals with superior socioeconomic indicators may benefit from expedited clinical intervention, potentially attenuating the progression of vestibular dysfunction.

Additionally, our analysis confirmed a robust correlation between all DHI domains and sleep quality metrics, with sleep quality and duration being the most predictive of DHI scores. As PSQI scores increased, there was a corresponding rise in the risk of elevated DHI scores among patients with BPPV. Notably, the risk increased significantly when PSQI

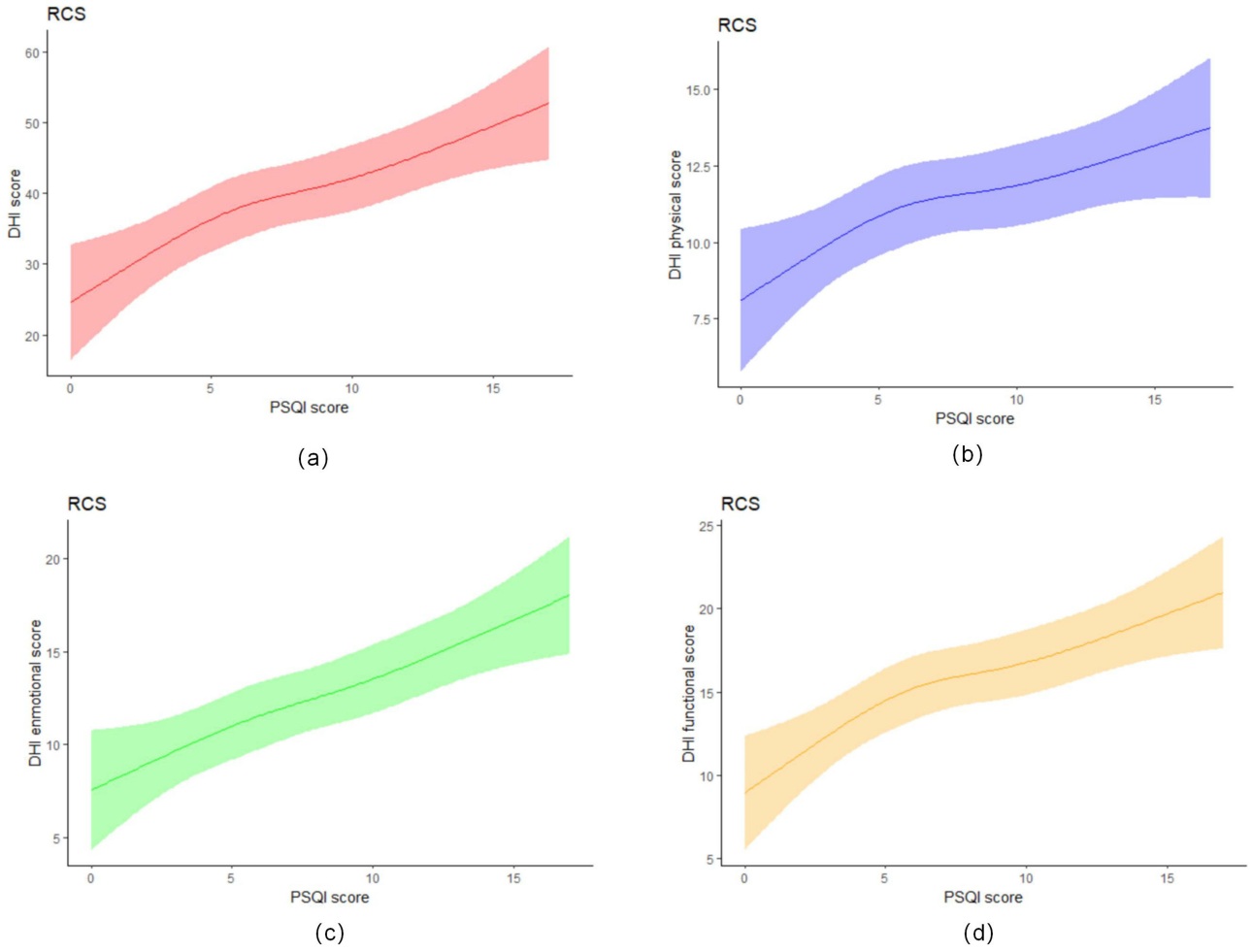

Figure 4 Association between PSQI scores and different dimensions DHI scores. (**a**) Association between DHI scores and PSQI scores; (**b**) Association between DHI physical scores and PSQI scores; (**c**) Association between DHI emotional scores and PSQI scores; (**d**) Association between DHI functional scores and PSQI scores.

scores exceed 7, indicating a strong linear dose-response relationship between poor sleep quality and vertigo severity. These results affirm the critical role of sleep management in the clinical handling of BPPV, emphasizing that poor sleep quality is a significant risk factor for increased vertigo-related disability.

Psychological factors such as anxiety and depression have been suggested to predispose individuals to BPPV,[32] and the impact of sleep disorders on psychological states is well-documented.[33–36] However, limited research has explored the interrelationship among sleep disorders, psychological factors, and vertigo severity. In this study, mediation analysis revealed that more severe sleep disorders were associated with higher level of anxiety and depression, which in turn exacerbated dizziness. Anxiety and depression acted as significant mediators in the relationship between sleep quality and vertigo severity. This finding is consistent with existing literature highlighting the bidirectional relationship between sleep disruption and psychological distress.[37–39]

Effective clinical interventions for BPPV patients may thus benefit from strategies aimed at improving sleep quality and addressing psychological factors. Abnormal vestibular stimulation can lead to mood changes, including increased tension and anxiety. Monoaminergic inputs to the vestibular system, as well as networks involving the parabrachial nucleus and locus coeruleus, may influence anxiety levels and emotional responses associated with vestibular dysfunction.[40–43] Neurotransmitters systems incorporating dopaminergic, 5-hydroxytryptamine (serotonergic), and adenosinergic pathways likely constitute integral components within this intricate neurobiological framework, potentially establishing a self-perpetuating neural circuit between sleep disruption fragmentation and anxiety symptomatology.[44,45] Understanding these mechanisms is crucial for developing targeted therapies that address the multifaceted nature of BPPV, potentially improving patient outcomes through comprehensive management that includes psychological support and sleep interventions.

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This study contributes to the literature by providing data from a large cohort of BPPV patients in Northwest China, addressing the gap created by the scarcity of large-scale, specialized studies in this demographic. The study's strengths include standardized data collection, regular follow-ups, meticulous data management, and rigorous quality control processes.

Limitation

However, despite these strengths, certain limitations should be acknowledged. Due to potential recall bias among patients, some self-reported data derived from the PSQI may not accurately reflect specific time points, introducing a degree of error. Additionally, while we collected information on participants' histories of mood disorders and treatments, unmeasured confounding factors may still exist. Future analysis should using longitudinal follow-up data to establish causal relationships and explore the underlying biological mechanisms linking sleep disorders, psychological factors, and vertigo severity in BPPV patients.

Conclusion

Our study reveals a significant association between poor sleep quality and increased severity of vertigo patients with BPPV, with anxiety and depression mediating this relationship. The findings underscore the importance of addressing sleep-related factors in the management of BPPV, including the incorporation of sleep therapy interventions to mitigate psychological symptoms. Nonetheless, there remains an urgent need for more comprehensive investigations into the pathophysiological mechanisms linking sleep disorders and dizziness. Such research is essential to refine therapeutic strategies and enhance patient outcomes.

Abbreviations

ABC, Activities-specific Balance Confidence (Scale); ANOVA, Analysis of Variance; BMI, Body Mass Index; BPPV, Benign Paroxysmal Positional Vertigo; CI, Confidence Interval; DHI, Dizziness Handicap Inventory; HADS, Hospital Anxiety and Depression Scale; ICD-11, International Classification of Diseases, 11th Revision; MRI, Magnetic Resonance Imaging; OR, Odds Ratio; PSQI, Pittsburgh Sleep Quality Index; RCS, Restricted Cubic Spline; REDCap, Research Electronic Data Capture; SAS, Self-rating Anxiety Scale; SDS, Self-rating Depression Scale; SRT, Supine Roll Test.

Data Sharing Statement

The datasets generated during and/or analyzed during the current study are not publicly available due to ethical restrictions imposed by the Institutional Review Board but are available from the corresponding author upon reasonable request.

Ethics Committee Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Xi'an Jiaotong University Health Sciences Institute's Non-Interventional Clinical Research Ethics Committee (decision number: 2021-1560, date: 05.01.2021).

Informed Consent

Electronic informed consent with legally valid digital signatures was obtained from all participants through the REDCap (Research Electronic Data Capture) platform prior to data collection. This secure, HIPAA-compliant web application provided a standardized consent interface that included: Full disclosure of study objectives, potential risks/benefits, and data confidentiality measures; Explicit opt-in confirmation for participation and data sharing; Automated audit trails documenting consent timestamp and IP address. Participant data were stored in REDCap's encrypted servers hosted at Xi'an Jiaotong University, with access restricted to authorized investigators through two-factor authentication.

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Author Contributions

Conceptualization: X.J.L., X.X.Y., and M.B.B.; Methodology: X.J.L., M.B.B., S.W.Y. and S.H.Y.; Investigation: W.J.Q., R.P.H. and L.P.Y.; Formal Analysis: L.J.L., H.Y.G and X.X.Y., Resources: X.J.L. and M.B.B.; Writing – Original Draft: X.J.L., X.X.Y., S.H.Y.,W.J.Q.,P.Y.L,S.W.Y.,R.P.H., H.Y.G.,L.J.L. and M.B.B.; Writing – Review & Editing: W.J.Q., X.X.Y., M.B.B., S.W.Y., L.J.L., L.P.Y.,H.Y.G. and S.H.Y.; Visualization (Figures/Tables): X.J.L.,X.X.Y. and W.J.Q.; Supervision: M.B.B. and X.J.L.; Project Administration: M.B.B.; Funding Acquisition: M.B.B.

All authors have agreed on the journal to which the article will be submitted; reviewed and approved the final version of the manuscript; agreed to be accountable for all aspects of the work and consent to its submission to the journal and accept full responsibility for the accuracy and integrity of this work.

Juanli Xing and Xinyu Xu are co-first authors and contributed equally to the study.

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Disclosure

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