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Moderating role of functional/ mobility limitations in the association between sleep problems and hypertension among middle-aged and older adults in India

Amiya Saha [a], T. Muhammad [b], Bittu Mandal [c,*], Dipti Govil [a], Waad Ali [d]

[a] Department of Family & Generations, International Institute for Population Sciences, Mumbai 400088, India
[b] Postdoctoral Scholar, Center for Healthy Aging, The Pennsylvania State University, PA 16802, USA
[c] School of Humanities and Social Sciences, Indian Institute of Technology, Indore 453552, India
[d] Department of Geography, Sultan Qaboos University, Muscat 123, Oman

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ABSTRACT

Hypertension has become a global health concern and is recognized as an important modifiable risk factor for cardiovascular diseases (CVDs). There are very limited studies in India and worldwide focused on sleep problems, activities of daily living (ADL), instrumental ADL (IADL) and mobility limitations, and their discrete and combined effects on hypertension. Therefore, this study examined whether sleep problems are associated with hypertension, and whether the association is more pronounced among middle-aged and older adults with functional/mobility limitations. This study used data from the Longitudinal Ageing Study in India (LASI) wave 1, 2017–18, with a total sample of 59,951 adults aged 45 years and above. Log-binomial regression, and interaction terms were used to assess the relationship between sleep problems and hypertension, and the moderating effect of functional/mobility limitations. Respondents with sleep problems had a 29 % higher prevalence of hypertension [PR (prevalence ratio): 1.29; CI (confidence interval): 1.20–1.39]. Those with ADL and IADL limitations had 20 % [PR: 1.20; CI: 1.09–1.32] and 9 % [PR: 1.09; CI: 1.00–1.18] greater prevalence of hypertension. Interaction analysis revealed that individuals with ADL, IADL, and mobility limitations had 58 %, 52 %, and 45 % higher prevalence of hypertension, respectively, and was especially pronounced among women. Our findings highlight that improved sleep can reduce the prevalence of hypertension in middle-aged and older adults. Individuals with functional/mobility limitations may need additional care and support from their family members or the community, which could lower the prevalence of elevated blood pressure due to their sleep problems.

1. Introduction

Hypertension, identified as a significant modifiable risk factor for cardiovascular diseases (CVDs) (Muli et al., 2020), has emerged as a global health concern, with the potential to increase CVD-related deaths by 33 percent (Sacco et al., 2016). Developing countries such as India are no exception, as they face an increasing number of deaths from CVDs and hypertension (Gupta et al., 2016; Gupta & Xavier, 2018). Hypertension is India's most important risk factor for CVDs (Gupta et al., 2019). Its prevalence was reported to be approximately 11.3 percent in the age group 15–54 and 33 percent among older persons, and it has also been reported that the prevalence of hypertension is positively correlated with age (Gupta et al., 2016, Gupta et al., 2019; Shivashankar et al., 2017). Older people are more likely to develop hypertension because they are more exposed to CVDs and experience disability-adjusted life-year losses (Chinnakali et al., 2012).

Smoking, alcohol consumption, lack of exercise, stress, and obesity are common risk factors for hypertension, and are highly prevalent among middle-aged and older populations (Warburton et al.,2017; Muli et al., 2020; Neuhauser et al., 2017; Shivashankar et al., 2017). Reductions in these risk factors are necessary to reduce the risks of CVDs and hypertension. Sleep problems are another important risk factor for hypertension, especially in middle and older ages (World health statistics, 2023). A recent study reported that proper sleep protects against hypertension (He & He, 2022). Another study reported that insufficient sleep and poor sleep quality were highly correlated with a higher prevalence of hypertension and poor health (Yang et al., 2021; Andreasson; 2021). Similarly, a growing body of literature suggests the

* Corresponding author.
E-mail addresses: amiyasaha4444@gmail.com (A. Saha), mbittu545@gmail.com (B. Mandal).

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negative effects of short sleep duration and insomnia (Jarrin et al., 2018) and the positive effects of physical activity on blood pressure in middle-aged and older adults (Warburton & Bredin, 2017). Studies have also reported that short sleep duration, trouble sleeping, and sleep problems are positively related to hypertension (Smith et al., 2023; Thomas & Calhoun, 2017; Van Ryswyk et al., 2018) and that factors such as improved physical activity and metabolic function modify this association (Duncun et al., 2021; Gangwisch et al., 2021; Reid et al., 2006).

However, few studies have examined the association between sleep problems and hypertension after adjusting for the effects of other physical and mental health problems (e.g., diabetes, hyperlipidaemia, coronary vessel disease, chronic hepatic failure, chronic renal failure, cerebral haemorrhage, cerebral infarction, and atrial fibrillation) (He & He, 2022; Shivashankar et al., 2017). Some studies have reported that problems with activities of daily living (ADL), instrumental activities of daily living (IADL), and mobility are correlated with sleep problems (Finn et al., 1998; Meguro et al., 1995; Pedraza et al., 2012; Reid et al., 2006; Stein et al., 2008; Washington et al., 2018). Studies among older adults reported that sleep problems were independently associated with mobility limitations (Stenholm et al., 2010) and falls (Muhammad et al., 2023a). Further, limitations in ADL are associated with insomnia, and it has a mediation role in the relation between insomnia and depression (Webb et al., 2018).

As ADL/IADL/mobility limitations are closely correlated with sleep problems and hypertension, one may anticipate that functional/mobility limitations may affect the relationship between sleep problems and hypertension. Most previous studies have focused on separate or adjusted associations among sleep problems, functional/mobility limitations, and hypertension. Therefore, the current study hypothesized that sleep problems are associated with hypertension, and that this association is more pronounced among individuals with functional/mobility limitations. First, we tried to understand the independent associations between sleep problems and hypertension, and then, examine the interaction effects of functional/mobility limitations and sleep problems on hypertension. Fig. 1 shows a conceptual model of the relationship between sleep problems and hypertension, after including the selected potential moderators based on the existing literature.

2. Methods and materials

2.1. Data

This study utilized data from the nationally and regionally representative Longitudinal Ageing Study in India (LASI) wave 1, conducted in 2017–18. The survey focused on respondents aged 45 years or older, along with their spouses across India's 31 states and six Union Territories. Detailed information on the sampling framework and sample size selection is available in the national report of LASI wave 1, 2017–18 and other sources (Bloom et al., 2021; LASI, 2020; Patel et al., 2023). Ethical approval for LASI was obtained from the Central Ethics Committee on Human Research (CECHR) under the Indian Council of Medical Research (ICMR), as well as the Institutional Review Boards of collaborating entities, including the International Institute for Population Sciences (IIPS), Mumbai, and the Ministry of Health and Family Welfare, Government of India. All survey-related processes adhered to the applicable guidelines and regulations of ICMR.

The LASI provided information on 73,396 respondents aged 45 + years, and their spouses regardless of age. Respondents with missing information in the biomarker data were removed (n = 6,537) from this study. After excluding the sample with incomplete information, 59, 591 middle-aged and older adults were included in the study. Fig. 2 provides a detailed flowchart of the selection of the sample for the study.

2.2. Variable description

2.2.1. Outcome variable

Hypertension was dichotomized on the basis of three items: (i) *Has any health professional ever told you that you have hypertension or high blood pressure?,* the response was recoded as 0 for "not diagnosed with hypertension" and 1 for "diagnosed with hypertension." (ii) *Average systolic blood pressure (SBP) or diastolic blood pressure (DBP) of respondents at the time of the survey*, SBP was measured by computing the mean of 1st, 2nd and 3rd SBP readings which was coded as 0 for "no" if mean reading of SBP was < 140 mmHg and 1 for "yes" if mean reading of SBP was ≥ 140 mmHg and DBP was measured by computing the mean of 1st, 2nd and 3rd DBP readings which was coded as 0 for "no" if mean reading of DBP was < 90 mmHg" and 1 for "yes" if mean reading of DBP was ≥ 90 mm Hg (Chobanian et al., 2003) (iii) *In order to control your*

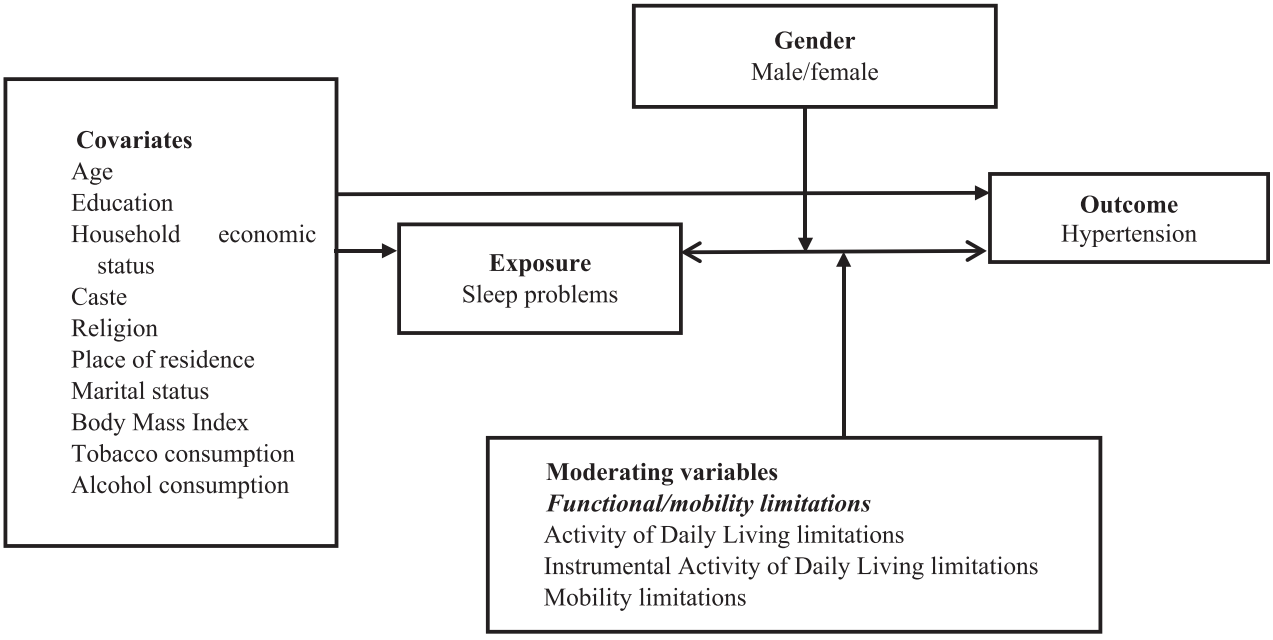

Fig. 1. Preliminary conceptual model of the relationship between sleep problems and hypertension and its potential moderators.

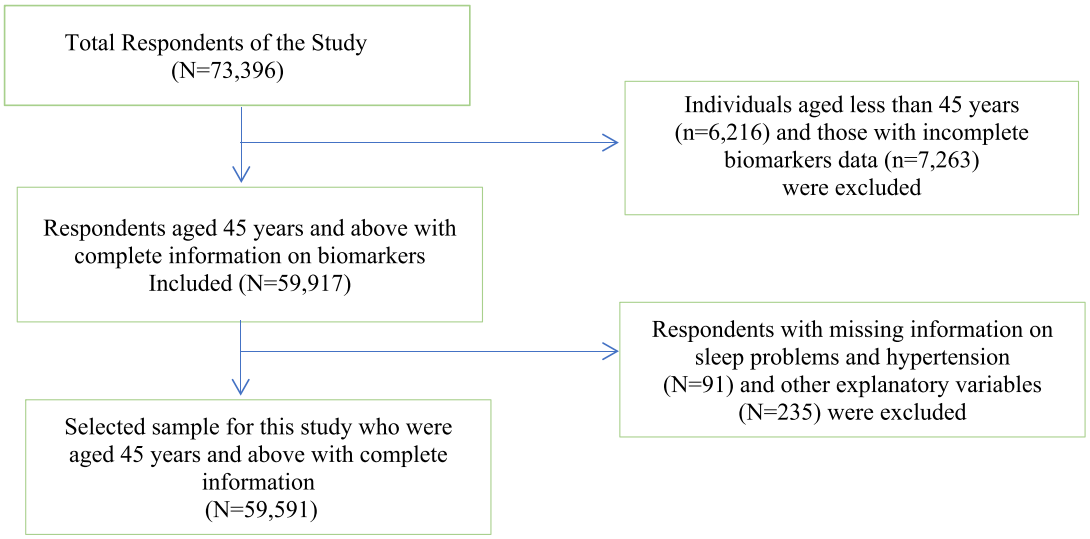

Fig. 2. Selection criteria of the sample study.

blood pressure or hypertension, are you currently taking any medication? Alternatively, to control your blood pressure, are you under salt or other dietary restrictions?, the response was coded as 0 for "not taking any medication or diet restriction" and 1 for "taking medications or diet restrictions." Further we constructed a single dichotomous variable where 0 included all the respondents reported "no" to all aforementioned items and 1 included the respondents reported "yes" to at least one item.

We have considered outcome variable as a stage 2 hypertension (≥140/90 mmHg) following the 2017 American College of Cardiology/ American Heart Association (ACC/AHA) blood pressure (BP) guideline (Wu et al., 2022). Our study aimed to contextualize the severe hypertension (stage 2 hypertension) and therefore, considered a binary outcome as 0 = no hypertension/ stage 1 hypertension and 1 = stage 2 hypertension.

2.2.2. Explanatory variables

The main explanatory variable for the study was the binary classification of having sleep problems or not. The LASI survey evaluated the variable 'sleep problems' using four questions, which were adapted from the Jenkins Sleep Scale (JSS-4) (Jenkins et al., 1988). The questions focus on the sleep problems of the participants over the last month. The items encompass: 1) "*how often do you have trouble falling asleep*?" 2) *"How often do you have trouble with waking up during the night?"* 3) *"How often do you have trouble with waking up too early and not being able to fall asleep again?"* 4) *"How often did you feel unrested during the day regardless of the number of hours of sleep you had?"* Response options (referring to the past one month) were "never", "rarely" (1–2 nights per week), "occasionally" (3–4 nights per week), and "frequently" (5 or more nights per week (Muhammad et al., 2023b). Utilizing this information, we constructed a dichotomous variable which was 'frequently' for any of the four symptoms and otherwise zero representing "no sleep problem" (Schubert et al., 2002).

Functional/mobility limitations included limitations in ADL, IADL or mobility. In the individual survey schedule, questions on ADL consisted of limitations in six activities related to dressing which includes putting on chappals or shoes, walking across a room, difficulties in bathing, eating, getting in or out of bed and using the toilet, including getting up and down. Further, combining these six ADLs into one variable, we constructed a variable coded as 0 for "no ADL" if the respondent had no limitations in performing any ADLs and 1 "ADL" if respondents had any limitation in performing any ADL (Ansari et al., 2021; Saha et al., 2022).

Furthermore, IADL consists of seven limitations related to instrumental activities: *difficulty preparing a hot meal (cooking and serving), shopping for groceries, making telephone calls, taking medications, doing work around the house or garden, and managing money, such as paying bills, keeping track of expenses, and getting around or finding addresses in unfamiliar places*. IADLs was also recoded as 0 "no IADL" if the respondent had no limitation in performing any IADLs and 1 "IADL" if respondents had any limitation in performing any IADL. Mobility limitations included nine different activities in daily life, such as *walking 100 yards, sitting for 2 h or more, getting up from a chair after sitting for long periods, climbing one flight of stairs without resting, stooping, kneeling, or crouching, reaching or extending arms above shoulder level (either arm), pulling or pushing large objects, lifting or carrying weights over 5 kilos, like a heavy bag of groceries, and picking up a coin from a table*. All nine limitations were combined into one binary variable and recoded as 0 for "no mobility" if the respondent had no limitation in performing any mobility and 1 "mobility" if respondents had any limitation in performing any mobility (Ansari et al., 2021; Saha et al., 2022).

2.2.3. Covariates

Other sociodemographic, economic, and health-related and behavioural factors included age, recoded as middle age (45–59 years) and older age (60 years and above); caste (SC, ST, OBC, and others) (Barman et al., 2023; Mandal et al., 2023), religion (Hindu, Muslim, Christian, and others (Barman et al., 2022) marital status (currently in union and currently not in union) (Saha et al., 2022); education (no education, up to primary, up to secondary and secondary & above) (Saha & Mandal et al., 2023a; Saha et al., 2023b) weight and height of the participants, measured as Body Mass Index, recoded as thin (≤18.5), healthy (18.5–24.9), overweight (25–29.9) and obese (≥30) (Tan, 2004; Saha et al., 2023, Muhammad, et al., 2023), tobacco consumption (no and yes), alcohol consumption (no and yes) and number of chronic diseases that was categorized into no morbidity which was considered as "0″; single morbidity as "1"; and multi-morbidity as "2+" (Saha et al., 2023, Muhammad, et al., 2023).

2.2.4. Statistical analysis

We used descriptive statistics and bivariate analysis to report the prevalence of sleep problems and hypertension by socioeconomic and demographic characteristics of the participants. Further, log binomial regression (Wado et al., 2014) was used to examine the association between sleep problems and functional/mobility limitations and hypertension among middle-aged and older adults using unadjusted and adjusted models with 95 % confidence interval. Log binomial regression

was preferred over logistic regression because hypertension is highly prevalent among the participants and therefore, odds ratio could exaggerate the probability of the outcome. Interaction effect of functional/mobility limitations and sleep problems on hypertension in adults aged 45 years and above was also examined by adjusting for caste, gender, marital status, education and health and behavioural factors.

The equation that was used to perform log binomial regression is as follow:

$$lnp = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_K X_K$$

Here, the left-hand side is the log of the probability (***lnp***). β_0 is the constant and β_1 to β_K is coefficients and the model described by the above equation is used to estimate a Prevalence Ratio (PR) for each predictor variables, X_1 to X_K. All the statical analysis was performed in STATA version 16.0 (Stata Corp, LP, college station, Texas). We used sampling weights to account for the multistage sampling design and to provide population-level estimates.

3. Results

Table 1 unveils the sociodemographic characteristics of participants in this study. Around half of the participants were aged 45–59 years, 54 % were women, and one-third were urban residents. 74.36 % were currently in a marital union, and 51 % had no formal education and 10 % completed higher education. Sleep problems were more prevalent among those age 60+ (14.5 %), females (13.8 %), and those with no formal education (14.1 %). Hypertension was more prevalent in those age 60+ (56 %) compared to the 45–59 age group (41 %). Urban residents, unmarried individuals, those with higher education, and the obese showed higher rates of hypertension, at 59 %, 57 %, 54 %, and 69 %, respectively. Additional insights on sleep problems and hypertension across genders and various factors are detailed in **Supplementary Table 1** (**S1**).

Fig. 3 presents an overview of middle-aged and older individuals with hypertension, categorized by functional or mobility limitations. Those with ADL constraints had a higher hypertension prevalence (57 % vs. 47 %), as did those with IADL limitations (53 %). Individuals with mobility issues also exhibited a higher hypertension prevalence compared to those without (52 % vs. 42 %). In Fig. 4, the prevalence of sleep problems is depicted based on functional/mobility constraints. Among adults with ADL limitations, 23 % reported sleep problems, contrasting with 11 % without ADL limitations. Similarly, respondents with IADL limitations reported sleep problems at 18 %, and participants with mobility limitations reported sleep problems at 16 %, compared to 7 % without mobility constraints.

Table 2 presents regression estimates for hypertension among middle-aged and older adults in India. In the unadjusted Model-1, respondents with sleep problems had a significantly higher prevalence of hypertension [PR: 1.08; CI: 1.04–1.13]. In the adjusted **model 2**, accounting for functional health status, the prevalence of hypertension was insignificantly higher among those with sleep problems [PR: 1.02; CI: 0.98–1.06]. **Model 3**, controlling for age and sex, showed a similar pattern with a 1.02 times higher prevalence of hypertension for those with sleep problems [PR: 1.02, CI: 0.98–1.06]. **Model 4**, adjusted for sociodemographic factors, indicated a significantly higher prevalence of hypertension among respondents with sleep problems [PR: 1.07, CI: 1.01–1.14]. Furthermore, older adults [PR: 1.84, CI: 1.71–1.98], female [PR: 1.16, CI: 1.06–1.28], urban residence [PR: 1.34, CI: 1.23–1.46], and primary educated [PR: 1.14, CI: 1.03–1.26] were associated with higher hypertension prevalence. Obesity was strongly associated to hypertension [PR: 3.85; CI: 3.20–4.64], while tobacco consumption showed a significantly lower prevalence [PR: 0.94; CI: 0.87–0.99]. However, alcohol consumption was associated with a higher prevalence of hypertension [PR: 1.35; CI: 1.23–1.48]. Those with 1 and 2 + chronic diseases had 1.39 times [PR: 1.39, CI: 1.29–1.50] and 2.15 times [PR: 2.15, CI: 1.78–2.60] greater prevalence of hypertension, respectively,

Table 1
Descriptive statistics of socio-demographic characteristics of middle-aged and older adults in India, LASI 2017–18.

Background Characteristics	Sample	Sleep problems		Hypertension	
	N (%)	**N (%)**	***p* value**	**N (%)**	***p* value**
Age			< 0.001		< 0.001
Middle aged (45–59)	29,850 (50.09)	3,344 (11.2)		12,307 (41.23)	
Older age (60 & above)	29,741 (49.91)	4,311 (14.49)		16,565 (55.7)	
Gender			< 0.001		< 0.001
Male	27,290 (45.80)	3,203 (11.74)		12,350 (45.26)	
Female	32,301 (54.20)	4,452 (13.78)		16,522 (51.15)	
Residence			< 0.001		< 0.001
Rural	41,667 (69.92)	5,760 (13.82)		18,355 (44.05)	
Urban	17,924 (30.08)	1,895 (10.57)		10,518 (58.68)	
Household economic status			< 0.01		< 0.001
Poor	25,240 (42.36)	3,185 (12.62)		11,364 (45.02)	
Middle	12,152 (20.39)	1,555 (12.8)		5,856 (48.19)	
Rich	22,198 (37.25)	2,914 (13.13)		11,652 (52.49)	
Caste			< 0.001		< 0.001
SC	11,593 (19.45)	1,740 (15.01)		5,167 (44.57)	
ST	5,140 (8.63)	570 (11.09)		2,178 (42.37)	
OBC	27,198 (45.64)	3,363 (12.36)		13,269 (48.79)	
Others	15,660 (26.28)	1,982 (12.66)		8,258 (52.73)	
Religion			0.643		< 0.001
Hindu	49,205 (82.57)	6,259 (12.72)		23,323 (47.4)	
Muslim	6,553 (11.0)	937 (14.30)		3,538 (52.99)	
Christian	1,749 (2.93)	152 (8.66)		830 (47.45)	
Others	2,084 (3.50)	307 (14.74)		1,182 (56.7)	
Marital status			< 0.001		< 0.001
Currently in union	44,313 (74.36)	5,256 (11.86)		20,199 (45.58)	
Currently not in union	15,278 (25.64)	2,399 (15.7)		8,673 (56.77)	
Education			< 0.001		< 0.001
No education	36,855 (61.85)	5,191 (14.08)		17,158 (46.56)	
Up to primary	7,249 (12.16)	940 (12.97)		3,697 (51)	
Up to secondary	5,070 (8.51)	581 (11.45)		2,444 (48.21)	
Secondary & above	10,417 (17.48)	943 (9.06)		5,573 (53.5)	
BMI (Kg/m^2)			< 0.001		< 0.001
Underweight (≤18.5)	13,002 (21.82)	1,933 (14.87)		4,448 (34.21)	
Healthy (18.5–24.9)	30,260 (50.78)	3,780 (12.49)		13,998 (46.26)	

(*continued on next page*)

Table 1 (*continued*)

Background Characteristics	Sample	Sleep problems		Hypertension	
Overweight (25–29.9)	12,213 (20.49)	1,439 (11.79)		7,584 (62.1)	
Obese (≥30)	4,116 (6.91)	502 (12.19)		2,842 (69.07)	
Tobacco consumption			0.869		< 0.001
No	37,112 (62.28)	4,635 (12.49)		18,900 (50.93)	
Yes	22,479 (37.72)	3,020 (13.43)		9,972 (44.36)	
Alcohol consumption			0.190		0.396
No	50,565 (84.85)	6,536 (12.93)		24,610 (48.67)	
Yes	9,026 (15.15)	1,119 (12.39)		4,262 (47.22)	
No. of chronic diseases			< 0.001		< 0.001
0	39,153 (65.70)	4,192 (10.71)		16,647 (42.52)	
1	15,240 (25.57)	2,345 (15.58)		8,562 (56.18)	
2+	5,198 (8.72)	1,088 (20.92)		3,663 (70.47)	
ADL limitation			< 0.001		< 0.001
No	50,356 (84.50)	5,537 (11)		23,609 (46.89)	
Yes	9,235 (15.50)	2,118 (22.93)		5,263 (56.99)	
IADL limitation			< 0.001		< 0.001
No	37,847 (63.51)	3,670 (9.7)		17,343 (45.82)	
Yes	2,1744 (36.49)	3,985 (18.33)		11,529 (53.02)	
Mobility limitation			< 0.001		< 0.001
No	21,588 (36.23)	1,495 (6.92)		9,051 (41.92)	
Yes	38,003 (63.77)	6,160 (16.21)		19,822 (52.16)	

Note: **%**: Percentage; **ADL**: *Activities of Daily Living*; **IADL**: *Instrumental Activities of Daily Living* **BMI**: *Body Mass Index*.

compared to those without any chronic disease.

Supplementary Table 2 **(S2)** includes additional details on the prevalence ratio derived from log binomial regression, specifically examining the association between sleep problems and hypertension in middle-aged and older adults, encompassing both male and female respondents.

Table 3 displays the interaction effects of functional/mobility limitations and sleep problems on hypertension among middle-aged and older Indian adults. Both adjusted and unadjusted estimates indicate notable positive associations. Individuals facing ADL limitations and sleep problems exhibited 1.28 times higher prevalence of hypertension (PR: 1.28; CI: 1.09–1.52) compared to those without sleep problems. Likewise, respondents with IADL limitations and sleep problems had a higher prevalence of hypertension (PR = 1.21; CI: 1.08–1.37) compared to those without such challenges. Besides, individuals with mobility limitations and sleep problems showed 1.21 times significantly increased prevalence of hypertension (PR: 1.21; CI: 1.08–1.34) compared to their counterparts without sleep problems and mobility limitations.

Additional information regarding the interaction effect of functional/mobility limitations and sleep problems on hypertension among middle-aged and older adults, including both male and female participants, is provided in **Supplementary table 3 (S3)**.

4. Discussion

This study explored the association between sleep problems and hypertension risk, along with the moderating effect of functional/mobility limitations in middle-aged and older adults. Analyzing data from a large survey of community-dwelling individuals, the findings indicate a significant association between sleep problems and an increased risk of hypertension in this demographic. Notably, the prevalence of hypertension is more pronounced in individuals with both sleep problems and any type of functional/mobility limitations, including ADL, IADL, and mobility issues. Gender differences were observed, with higher prevalence of sleep problems and hypertension in older age groups (≥60 years) and among females. Female respondents with functional/mobility limitations had a higher risk of hypertension, while this association was only evident in men with ADL limitations. Assessing socioeconomic status revealed that individuals with the highest economic standing reported a higher prevalence of hypertension and encountered more challenges with sleep.

A study from the NHANES survey in the USA reported that sleep problems lead to an increased risk of developing hypertension (Li & Shang, 2021). A systematic review-based study also found a significant association between short sleep duration or sleep problems with the higher prevalence of hypertension (Guo et al., 2013). Many studies from LMICs also found a strong association between sleep problems and hypertension in young (Peltzer & Pengpid, 2015) and older adults (Stranges et al., 2012). However, this association varies across countries as shown in some studies (Koyanagi et al., 2014; Stranges et al., 2012). Such a relationship between sleep problems and risk of hypertension has been explained by several biological mechanisms. The ability of the central nervous system to regulate itself can be affected by sleep disorders (Tamisier et al., 2018), as can hemodynamics (Yang et al., 2019), and biological rhythms (Friedman et al., 2009; Makarem et al., 2019), all of which can alter physiological functions and cause pathological changes in blood pressure. Additionally, it has been proposed that the association between sleep issues and hypertension may be influenced by issues related to emotion regulation (Baglioni et al., 2010). Along with sleep problems, age, sex, marital status, BMI, and alcohol consumption were risk factors for hypertension among middle-aged and older adults, which is consistent with previous studies (Li & Shang, 2021; Thomas & Calhoun, 2017; Van Ryswyk et al., 2018). On the contrary, tobacco consumption was observed to be a protective factor of hypertension which is inconsistent with previous studies (Huxley & Woodward, 2011) and needs to be further investigated. Further, a significant positive association was observed between hypertension, urban place of residence and household economic status. This observation may be elucidated by the adverse lifestyle behaviours among wealthy and urban-dwelling people such as poor dietary pattern and sedentary lifestyle (Muhammad et al., 2022; Patel et al., 2023).

Importantly, in this study, ADL and IADL limitations were significant moderating factors and affected the prevalence of hypertension. In line with previous research, we found that people with functional limitations suffered from sleep problems and hypertension was highly pronounced among those with ADL and IADL limitations (Wu et al., 2021; Richadale & Baker; 2014). Our study found the prevalence of sleep problems and mobility limitations as an important predictor of the elevated risk of hypertension in both men and women. Though women had higher risk of hypertension when having mobility limitations than their male peers (**S3**). This finding is in concordance with previous research that found that woman aged 65 years or more with mobility restrictions were at higher risk of developing hypertension than men (Stenholm et al., 2010). As shown in previous studies, when respondents experience ADL limitations and reduced social interactions, the prevalence of hypertension increases (Yang et al., 2015). The present study confirmed the elevated role of all functional/mobility limitations in the relationship between sleep problems and hypertension among middle-aged and older Indian adults.

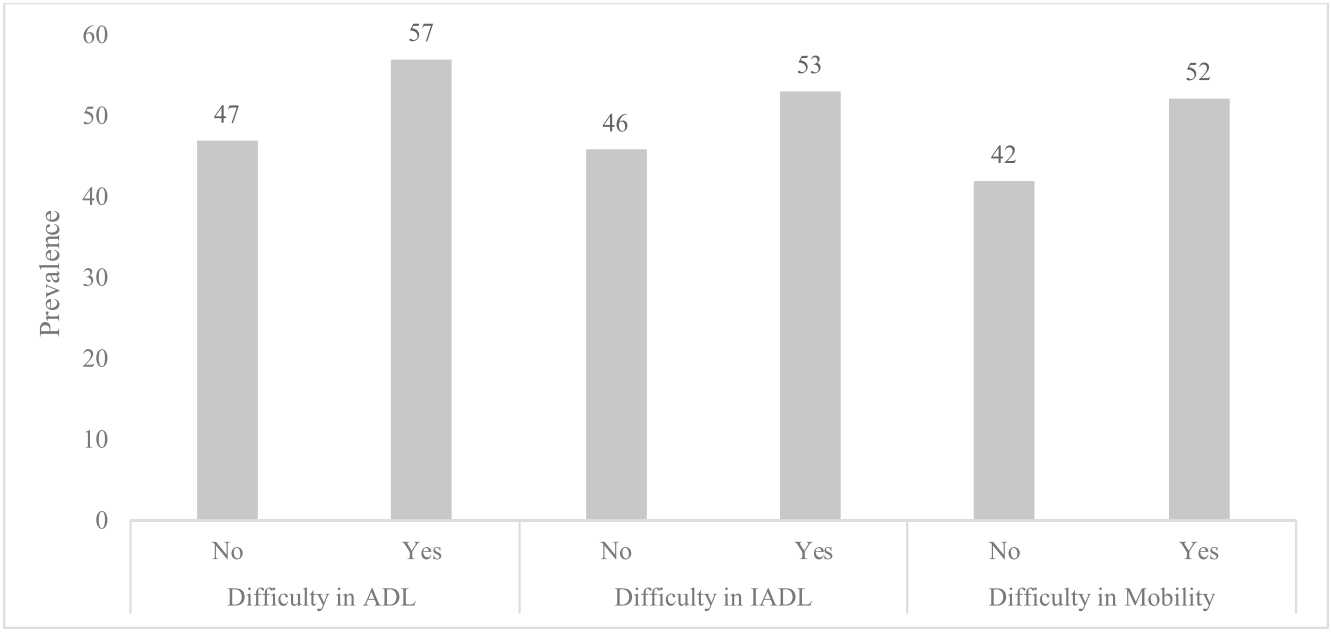

Fig. 3. Prevalence estimates of hypertension by functional/ mobility limitations among middle-aged and older adults in India, LASI 2017–18.

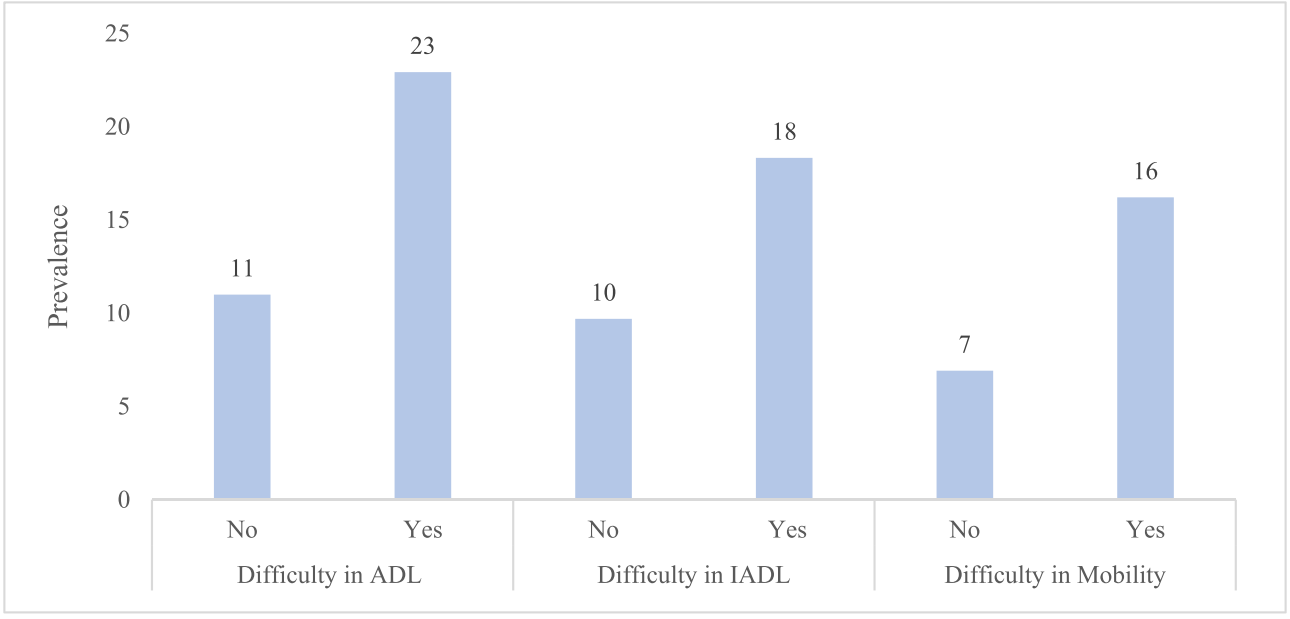

Fig. 4. Prevalence estimates of sleep problems by functional/mobility limitations among middle- aged and older adults in India, LASI 2017–18.

5. Strength and limitations

To date, there has been limited research on the association between sleep problems, hypertension prevalence, and the moderating role of functional/mobility limitations, which can significantly affect overall health and well-being. This study aims to fill this gap by assessing the association between sleep problems and the risk of hypertension on a national scale, utilizing the latest data from the extensive LASI survey. The inclusion of clinical data alongside questionnaire responses enhances the study's robustness. Importantly, the study recognizes the critical role of a person's functional/mobility limitations in determining their hypertension risk, particularly when experiencing sleep problems. Notably, this research is pioneering as it is the first to explore the association between sleep problems and hypertension risk, considering the moderating effect of functional/mobility limitations, among community-dwelling individuals.

Despite its contributions, this study has several limitations. Notably, sleep problem data were gathered through self-reports rather than polysomnography (Ferrie et al., 2011), potentially affecting the accuracy of the information. Previous studies indicate that individuals with depression may tend to report sleep issues (Argyropoulos et al., 2003; Matousek et al., 2004), inducing blood pressure levels. The study also lacked information on antihypertensive medications, which could affect the findings. The exclusion of samples with missing information in the complete-case analysis introduces potential bias. Additionally, the cross-sectional nature of the study limits the ability to establish causal relationships between sleep problems and hypertension with ADL, IADL, and mobility limitations among middle-aged and older individuals in

Table 2
Prevalence ratio from log binomial regression estimates of the association between sleep problems and hypertension among middle-aged and older adults in India, LASI 2017–18.

	Model 1		Model 2		Model 3		Model 4	
Background Characteristics	PR	95 % CI	PR	95 % CI	PR	95 % CI	PR	95 % CI
Sleep problems								
No	ref		ref		ref		ref	
Yes	1.08 ***	[1.04–1.13]	1.02	[0.98–1.06]	1.02	[0.98–1.06]	1.07**	[1.01–1.14]
Functional limitations								
ADL limitations								
No			ref		ref		ref	
Yes			1.11***	[1.06–1.16]	1.08***	[1.03–1.13]	1.14**	[1.03 – 1.25]
IADL limitations								
No			ref		ref		ref	
Yes			1.05*	[1.01–1.10]	1.00	[0.96–1.04]	1.10**	[1.02 – 1.19]
Mobility limitations								
No			ref		ref		ref	
Yes			1.19***	[1.14–1.24]	1.12***	[1.08–1.17]	1.07*	[1.00 – 1.16]
Age								
Middle age (45–59)					ref		ref	
Older age (60 & above)					1.31***	[1.26–1.36]	1.84***	[1.71 – 1.98]
Gender								
Male					ref		ref	
Female					1.13***	[1.09–1.17]	1.16***	[1.06 – 1.28]
Residence								
Rural							ref	
Urban							1.34***	[1.23–1.46]
Household economic status								
Poor							ref	
Middle							1.08*	[1.00 – 1.19]
Rich							1.13***	[1.04 – 1.22]
Caste								
SC							0.94	[0.86–1.04]
ST							1.04	[0.91–1.18]
OBC							0.96	[0.88–1.05]
Others							ref	
Religion								
Hindu							0.78***	[0.68–0.90]
Muslim							0.99	[0.83–1.17]
Christian							0.75**	[0.57–0.99]
Others							ref	
Marital status								
Currently in union							0.73***	[0.66–0.79]
Currently not in union							ref	
Education								
No education							ref	
Up to primary							1.14**	[1.03–1.26]
Up to secondary							1.03	[0.92–1.16]
Secondary & above							1.02*	[1.00–1.28]
Clinical status								
BMI (Kg/m^2)								
Thin (≤18.5)							ref	
Healthy (18.5—–24.9)							1.78**	[1.64—–1.93]
Overweight (25—–29.9)							3.28***	[2.90—–3.71]
Obese (≥30)							3.85***	[3.20—–4.64]
Health behaviors								
Tobacco consumption								
No							ref	
Yes							0.94*	[0.87—–0.99]
Alcohol consumption								
No							ref	
Yes							1.35***	[1.23—–1.48]
No. of chronic diseases								
0							ref	
1							1.39***	[1.29—–1.50]
2+							2.15***	[1.78 – 2.60]

Note: **ADL**: *Activities of Daily Living*; **IADL**: *Instrumental Activities of Daily Living*; **BMI**: *Body Mass Index*; **ref**: *reference category*; **Model 1** is unadjusted; **Model 2** is adjusted for functional /mobility limitations; **Model 3** is additionally adjusted for age and sex; **Model 4** is a full model and is additionally adjusted for socioeconomic, demographic and health-related factors; **PR**: Prevalence Ratio; ***p-value*** of ≤ 0.001 is denoted by ***; ***p-value*** of ≤ 0.01 is denoted by **; and ***p-value*** of ≤ 0.05 is denoted by *.

India. Future research, incorporating prospective studies and addressing these limitations, is essential for a more comprehensive understanding of the observed associations.

6. Conclusion

The current study suggests that sleep problems are associated with an increased risk of hypertension among middle-aged and older adults in India. However, this association was weaker among middle-aged adults

Table 3
Interaction effects between sleep problems and functional/mobility limitations on hypertension among middle-aged and older adults in India, LASI 2017–18.

Main variable	Unadjusted PR (95 % CI)	Adjusted PR (95 % CI)
ADL limitations # sleep problems		
No ADL limitations * no sleep problems	ref	ref
No ADL limitations * sleep problems	1.06 ** [1.01—1.12]	1.07 [0.97—1.17]
ADL limitations * no sleep problems	1.22 ** [1.16—1.27]	1.21 *** [1.08—1.34]
ADL limitations * sleep problems	1.25 *** [1.17—1.33]	1.28 *** [1.09—1.52]
IADL limitations # sleep problems		
No IADL limitations * no sleep problems	ref	ref
No IADL limitations * sleep problems	1.10 ** [1.03—1.16]	1.10 [0.98—1.23]
IADL limitations * no sleep problems	1.16 *** [1.12—1.21]	1.17 *** [1.08—1.26]
IADL limitations * sleep problems	1.19 *** [1.13—1.25]	1.21 *** [1.08—1.37]
Mobility limitations # sleep problems		
No mobility limitations * no sleep problems	ref	ref
No mobility limitations * sleep problems	1.03 [0.94—1.13]	1.06 [0.90—1.25]
Mobility limitations * no sleep problems	1.24 *** [1.18—1.30]	1.12 *** [1.04—1.22]
Mobility limitations * sleep problems	1.29 *** [1.22—1.36]	1.21 *** [1.08—1.34]

Note: # Interaction effect ADL: Activities of Daily Living; IADL: Instrumental Activities of Daily Living; ref: reference category; **PR**: Prevalence Ratio; ***p-value*** of ≤ 0.001 is denoted by ***; ***p-value*** of ≤ 0.01 is denoted by **; and ***p-value*** of ≤ 0.05 is denoted by *.

aged $\leq$ 60 years. Functional/mobility limitations were a strong moderator in the association between sleep problems and hypertension, and this association was high among female adults. Our results highlight the need for better sleep habits to reduce the prevalence of hypertension among middle-aged and older adults. Individuals with physical limitations require help from family members or the community, which can, to some extent, reduce the prevalence of hypertension. Moreover, prospective studies are required to fully understand the intricate interactions between sleep and hypertension. With improved confounding controls in various ethnic or age groups using a prospective longitudinal study, further investigation is required to uncover the processes underlying the association between sleep problems and hypertension. If sleep problems contribute to the aetiology of hypertension, increasing the quantity of sleep through intervention could aid in the treatment and prevention of hypertension while also enhancing public health.

7. Implications for policy and practice

Our findings suggest that hypertension is synergistically affected by sleep problems and functional/mobility limitations. This showed that in addition to actively and effectively managing the core ailment and physical limitations, efforts should be made to address people's psychological states and sleep disturbances.

The moderating role of functional/mobility limitations in the association between sleep problems and hypertension among middle-aged and older adults in India has several implications for policy and practice. The following are some recommendations.

- Promotion of a healthy lifestyle: Encouraging healthy lifestyle practices, such as regular exercise, healthy eating habits, and stress management to prevent hypertension and sleep problems. This can be achieved through public health campaigns and programs targeting middle-aged and older adults.
- Encouragement of regular check-ups: Encourage regular health check-ups for middle-aged and older adults to identify hypertension and sleep problems at an early stage. This can help prevent the development of serious health conditions and enable timely interventions.
- Education on sleep hygiene: Educate middle-aged and older adults on the importance of good sleep hygiene practices such as creating a conducive sleep environment, avoiding stimulants before bedtime, and developing a regular sleep routine. This can help to reduce sleep problems and potentially lower the risk of hypertension.
- Integration of mental health services: Integrating mental health services into primary healthcare for middle-aged and older adults with hypertension and sleep problems. This can help address the underlying mental health issues that may contribute to their symptoms.
- Focus on reducing health disparities: Address health disparities that affect middle-aged and older adults in India, such as access to healthcare services, poverty, and education. These factors can influence functional/mobility limitations and increase the risk of developing hypertension and sleep problems.

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CRediT authorship contribution statement

Amiya Saha: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **T. Muhammad:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Bittu Mandal:** Writing – review & editing, Writing – original draft, Supervision. **Dipti Govil:** Writing – review & editing, Writing – original draft, Supervision. **Waad Ali:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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