



Comparative cohort analysis of sleep-disordered breathing in German and South Korean populations

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ABSTRACT

Background: Sleep-disordered breathing (SDB) is common and is closely associated with obesity, hypertension, diabetes, dyslipidaemia, and cardiovascular risk. However, most evidence has been generated in predominantly Western populations, and it remains unclear whether the relationship between SDB, adiposity, and cardiometabolic health is comparable across populations with different anthropometric and disease-risk profiles. Harmonised comparisons between geographically and ethnically distinct population-based cohorts are therefore needed to determine whether a similar level of SDB carries the same clinical implications across populations.

Methods: Data were drawn from the Study of Health in Pomerania (SHIP-TREND; Germany) and the Korean Genome and Epidemiology Study (KoGES; South Korea). Clinical, laboratory, and polysomnographic measures were harmonised. Participants aged ≥ 45 years with useable sleep recordings and ≥ 4 h of total sleep time were included. Inverse probability weighting balanced age and sex distributions between cohorts. Regression models examined associations of body mass index (BMI) and waist-to-height ratio (WHtR) with Apnea-Hypopnea Index (AHI), and associations of AHI with diabetes, hypertension, lipid markers, and Framingham 10-year cardiovascular risk scores.

Results: Analyses included 768 SHIP-TREND and 2867 KoGES participants. SDB severity increased with age and was higher in men. Higher adiposity was associated with higher AHI in both cohorts, but the BMI-AHI association was stronger in KoGES. After WHtR adjustment, hypertension remained associated with AHI in KoGES but not SHIP-TREND; diabetes, lipids, and cardiovascular risk associations were broadly comparable although there were population differences in absolute burden.

Conclusions: SDB carries distinct cardiometabolic implications across German and South Korean populations, reflecting differences in adiposity related susceptibility and underlying disease burden. AHI should therefore be interpreted alongside population appropriate measures of adiposity and cardiometabolic risk.

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1. Introduction

Sleep-disordered breathing (SDB) is a major global health concern. It affects nearly one billion people worldwide, with approximately 425 million experiencing clinically significant disease (Apnea–Hypopnea Index [AHI] ≥ 15 events per hour) [1,2]. Beyond its impact on sleep quality and daytime functioning [3], SDB is recognised as a systemic disorder with cardiometabolic consequences. Large epidemiological studies have demonstrated associations between SDB and outcomes, including cardiovascular complications, type 2 diabetes, and mortality [4–6]. However, much evidence derives from predominantly White cohorts from North America. As such, the prevailing models of SDB risk and cardiometabolic impact are shaped largely by Western population profiles.

Multi-ethnic cohort studies report variation in SDB prevalence and associated cardiometabolic risk across population groups. For example, the Multi-Ethnic Study of Atherosclerosis (MESA) reported differences in SDB prevalence across Hispanic, Chinese American, African-American and White participants, persisting after adjustment for body mass index (BMI) [7]. Similar heterogeneity has been observed in population-based cohorts such as HypnoLaus and Episono, as well as in a UK study reporting ethnic differences in diagnosed SDB and metabolic risk profiles [8,9]. Together, these findings suggest that population differences in body composition, cardiometabolic risk, and SDB burden are interconnected. However, evidence remains heterogeneous and difficult to compare across studies.

Study design also shapes interpretations of population differences. Multi-ethnic cohorts within a single national context allow investigation of ethnic variation under broadly shared environmental and healthcare conditions, whereas cohorts conducted in different countries provide insight into how SDB manifests across distinct societal and environmental settings [7,8]. While informative, these cohort studies are not initially designed for direct cross-cohort comparison and differ substantially in sampling strategies, sleep recording protocols, scoring conventions, and outcomes assessments [5–8]. Thus, harmonised comparisons between geographically and culturally distinct populations—particularly at the intercontinental level—remain scarce. This raises the possibility that population-specific differences in SDB, adiposity, lifestyle, and cardiometabolic risk remain under-recognised. Consequently, current SDB risk stratification and management rely largely on uniform frameworks that may insufficiently reflect population heterogeneity.

To address these gaps, the present study uses two well-characterised population-based cohorts from distinct continental and ethnic backgrounds: the Study of Health in Pomerania (SHIP-TREND) in Germany and the Korean Genome and Epidemiology Study (KoGES) in South Korea [10,11]. Both cohorts provide detailed phenotypic, clinical, and sleep data, enabling harmonised assessment of SDB severity and cardiometabolic correlates. Therefore, we investigated whether associations between SDB severity, adiposity, and cardiometabolic risk are consistent or whether distinct patterns emerge across these populations. We hypothesised that adiposity would be more strongly associated with SDB severity in KoGES than in SHIP-TREND, consistent with previous findings [12]. We further hypothesised that greater SDB severity would be associated with distinct cardiometabolic outcomes, with associations differing between populations.

2. Methods

2.1. Study design and cohorts

Data were drawn from two established cohort studies: SHIP-TREND in north eastern Germany and the KoGES Ansan cohort in South Korea [10,11]. SHIP-TREND predominantly represented a White/Caucasian population, and the KoGES Ansan cohort predominantly represented an ethnic Korean population. Participants in both cohorts were recruited

from the general population rather than on the basis of a specific disease or symptom profile. All cohort participants completed clinical, laboratory, and multidomain lifestyle assessments and were offered an optional sleep assessment. Those who agreed underwent overnight sleep monitoring, with SHIP-TREND conducting laboratory-based polysomnography (PSG) and KoGES implementing home-based recordings, including electroencephalography (EEG) [13–15]. The present study included participants with available demographic, anthropometric, cardiometabolic, and PSG-derived measures suitable for harmonised cross-population comparisons. Key cohort and sleep-study characteristics are summarised in Table 1.

2.2. Ethics and data governance

Ethical approval and informed consent in SHIP-TREND and KoGES were obtained by the respective study teams through their institutional review boards (University of Greifswald for SHIP-TREND and Korea University for KoGES). Participant consent covered the use of collected data for subsequent scientific analyses. The present study involved secondary analysis of de-identified data and required no direct participant contact. Access to both datasets was granted under formal data-sharing agreements, and all procedures adhered to the governance frameworks established by the original cohorts.

2.3. Data harmonisation and variable selection

Before analysis, variables from SHIP-TREND and KoGES were harmonised to ensure methodological consistency across cohorts. Biochemical markers were converted to common units and aligned to shared scaling conventions, lifestyle factors and comorbidities were recoded into unified categories, and socioeconomic indicators were grouped into comparable levels (Table S1). Hypertension was defined in SHIP-TREND as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive medication. In KoGES, hypertension was likewise derived from measured systolic and diastolic

Table 1
Key characteristics of the SHIP-TREND and KoGES sleep Substudies.

Characteristic	SHIP-TREND (Germany)	KoGES – Ansan (South Korea)
Study design	Population-based cohort	Population-based cohort
Geographical region	Northeast Germany	Ansan region, South Korea
Baseline cohort size	4420 adults	5012 adults
Age range at baseline	20–79 years	45–70 years
Sleep substudy sample	1249 participants	2867 participants
Sleep recording setting	Laboratory-based PSG	Home-based PSG
Polysomnography device	ALICE 5 (Philips Respironics)	Embletta X-100 (Embla Systems)
Scoring standard	AASM 2012, manually scored	AASM 2012, manually scored
Type of data available	Demographics; anthropometry; lifestyle factors; socioeconomic indicators; cardiometabolic biomarkers; clinical comorbidities; PSG-derived sleep measures	Demographics; anthropometry; lifestyle factors; socioeconomic indicators; cardiometabolic biomarkers; clinical comorbidities; PSG-derived sleep measures

Table 1. Key characteristics of the SHIP-TREND and KoGES sleep substudies. The table summarises the study design, geographical setting, baseline cohort size, age range, sleep substudy sample, polysomnography setting, recording device, scoring standard, and available demographic, anthropometric, lifestyle, socioeconomic, cardiometabolic, and sleep-related data in each cohort. AASM = American Academy of Sleep Medicine; KoGES = Korean Genome and Epidemiology Study; PSG = polysomnography; SHIP-TREND = Study of Health in Pomerania.

blood pressure together with antihypertensive medication use. Diabetes was harmonised across cohorts and defined as HbA1c $\geq 6.5\%$ or fasting glucose ≥ 126 mg/dL. PSG-derived measures and indices were also standardised to equivalent operational American Academy of Sleep Medicine (AASM) 2012 definitions [16]. Following harmonisation, variables were selected *a priori* based on established risk factors and commonly used indicators in SDB research [17]. The analytic set included demographic (age, sex), anthropometric (BMI and waist-to-height ratio [WHtR]), cardiometabolic (lipids, diabetes, hypertension, and Framingham 10-year cardiovascular disease risk [FRS]), and behavioural measures (smoking exposure and alcohol use), chosen for their clinical relevance and suitability for cross-population comparison.

2.4. Cohort selection and quality control

Since KoGES used home-based PSG with a single EEG channel, it was important to confirm that apnea and hypopnea events were identified consistently across cohorts. To assess comparability, experienced scorers from each study independently rescored 12 recordings from the other cohort following the AASM guidelines [16]. These recordings were randomly selected to reflect the full spectrum of SDB severity—four each from the mild, moderate, and severe AHI categories—with an equal distribution of men and women. This sample size is consistent with standard practice in sleep scoring reliability studies, where a limited number of recordings is sufficient because each contains hundreds of scored epochs and events [18].

Agreement was assessed using the continuous AHI values derived from the original and rescored recordings. Concordance was excellent when the SHIP-TREND team rescored KoGES recordings, with an intraclass correlation coefficient (ICC) for absolute agreement of 0.998. Agreement was also good to excellent when the KoGES team rescored SHIP-TREND recordings (ICC = 0.895) [19]. Overall, the high concordance supported the reliability of AHI derivation in both datasets and the validity of cross-cohort comparisons.

To further enhance comparability, SHIP-TREND participants younger than 45 years—the minimum age in KoGES—were excluded. Sleep studies with <4 h of total sleep time were removed to ensure adequate recording quality [16]. SDB severity was classified using standard AHI thresholds: None (<5 events/hour), Mild (≥ 5 to <15 events/hour), Moderate (≥ 15 to <30 events/hour), and Severe (≥ 30 events/hour). These thresholds follow established clinical criteria widely applied across diverse populations [16].

2.5. Descriptive analyses and identification of key determinants

Descriptive analyses were used to compare the prevalence and characteristics of SDB between cohorts. These analyses informed the assessment of cohort comparability. Prevalence was stratified by age, sex, and cohort, whilst characteristics were stratified by cohort and SDB severity.

As adiposity is a key determinant of SDB severity [20], appropriate adjustment for body composition was required to ensure valid cross-cohort comparisons. While BMI is commonly used as a general index of adiposity, its interpretation can differ across ethnic groups due to variation in body-fat distribution and population-specific BMI thresholds [21]. To address these differences, WHtR was selected as the primary covariate for adiposity adjustment. WHtR provides a standardised measure of central adiposity that is less affected by ethnic variation in body size and composition, and has been shown to offer more comparable risk stratification across diverse populations [22]. This approach minimised the risk of misclassification that may arise when relying solely on BMI-derived cut-offs.

2.6. Statistical analysis

All statistical analyses were conducted using R version 4.5.2 (The R Foundation, Vienna Austria). Inverse probability weighting (IPW) was implemented using the R *survey* package, and model-based estimated predictions and marginal effects were derived using the R *emmeans* package.

2.6.1. Inverse probability weighting (IPW) and covariate adjustment

To improve cohort comparability in the regression analyses, IPW was applied to balance the age and sex distributions of SHIP-TREND and KoGES participants while retaining the full analytic sample. Weights were derived from a cohort-membership model including age and sex, thereby creating a pseudo-population with comparable demographic structure across cohorts [23]. Age and sex were complete for all included participants, allowing weights to be estimated for the full sample. Primary regression models were fitted using these IPW weights and additionally adjusted for age and sex to account for any residual demographic differences after weighting. Cohort interaction terms were included to evaluate whether associations between SDB, adiposity, and cardiometabolic outcomes differed between SHIP-TREND and KoGES. For continuous AHI models, effects were reported per 5-unit increase in AHI. WHtR effects were reported per 0.05-unit increase, as WHtR is measured on a narrow decimal scale and this increment represents a clinically interpretable difference in central adiposity within the observed cohort distributions.

Missing data were handled using complete-case analysis within each model. Participants with missing values in the exposure, outcome, or covariates required for a given analysis were excluded from that specific model, resulting in variable-specific analytic sample sizes. No imputation was performed.

2.6.2. Domain-specific modelling

Analyses were conducted across anthropometric and cardiometabolic domains. Anthropometric analyses examined associations of BMI and WHtR with AHI. BMI was retained because it remains the most widely used anthropometric measure in epidemiological and clinical sleep apnea research, allowing comparability with previous studies, whereas WHtR was included as the primary central-adiposity measure given its stronger conceptual relevance to SDB risk. In these models, AHI was modelled as the outcome and log-transformed to account for its skewed distribution, with estimates back-transformed for presentation in predicted-value plots. Interaction terms between cohort and adiposity measures were used to assess whether the strength of association differed between populations.

Analyses of cardiometabolic risk included distinct outcomes of diabetes, hypertension, lipid markers, and FRS. In these models, AHI was included as a continuous exposure and retained on its original scale to support clinical interpretability of effect estimates per 5-unit increase in AHI. Logistic regression models were used for binary outcomes, including diabetes and hypertension, while linear regression models were used for continuous outcomes, including lipid markers and FRS, as well as in supporting analyses of glycaemic indices. Two adjustment models were applied. The first adjusted for age and sex; the second additionally adjusted for WHtR to assess whether associations between AHI and cardiometabolic outcomes remained after accounting for central adiposity. Cohort $\times$ AHI interaction terms were included to test whether associations differed between populations. Sensitivity analyses additionally adjusted for smoking exposure and alcohol use to assess the robustness of the primary findings to these lifestyle-related covariates.

3. Results

3.1. Participant characteristics

A total of 1249 SHIP-TREND participants and 2867 KoGES

participants completed a sleep assessment. In SHIP-TREND, 327 participants <45 years-old were excluded to align the sample with the age range in KoGES. An additional 114 participants were excluded because their sleep recordings contained <4 h of total sleep time or had insufficient signal quality. Afterwards, 768 SHIP-TREND participants remained eligible for analysis. In KoGES, all 2867 participants met the age criterion and had recordings of sufficient quality.

Participant characteristics stratified by SDB severity are shown in Table 2 and Table S2–S3. Age and sex were broadly comparable between cohorts within each SDB category. SHIP-TREND participants had consistently higher BMI and WHtR than KoGES participants. Cardiometabolic and lifestyle profiles differed, with higher diabetes prevalence in KoGES and higher hypertension prevalence and current alcohol use in SHIP-TREND. Cumulative smoking exposure was generally higher in KoGES, whereas education levels were generally higher in SHIP-TREND. Most between-cohort differences were statistically significant, except for several comparisons in the severe SDB stratum, where smaller group sizes limited precision.

3.2. Distribution of sleep-disordered breathing severity

The distribution of SDB severity across groups defined by age and sex is illustrated in Fig. 1. In both cohorts, men had higher AHI values than women, and SDB severity increased progressively across increasing age, with a corresponding shift towards moderate and severe categories. This pattern was consistent in SHIP-TREND and KoGES, although the relative distribution of severity differed slightly between cohorts. The highest prevalence of moderate-to-severe SDB (AHI ≥ 15 events/hour) was observed among SHIP-TREND men aged ≥ 70 years.

3.3. Anthropometric associations with sleep-disordered breathing

Higher adiposity was associated with higher predicted AHI in both cohorts (Fig. 2). Each 5 kg/m² increase in BMI was associated with an increase in log-transformed AHI of 0.43 in SHIP-TREND (95% CI: 0.36,

0.50; $p < 0.001$) and 0.54 in KoGES (95% CI: 0.49, 0.60; $p < 0.001$). Predicted AHI increased from 3.70 events/hour at a BMI of 25 kg/m² to 6.16 events/hour at a BMI of 30 kg/m² in SHIP-TREND, and from 4.76 to 8.92 events/hour in KoGES. The cohort $\times$ BMI interaction was significant ($p = 0.013$), indicating a stronger BMI–AHI association in KoGES. Similarly, each 0.05-unit increase in WHtR was associated with an increase in log-transformed AHI of 0.28 in SHIP-TREND (95% CI: 0.23, 0.32; $p < 0.001$) and 0.31 in KoGES (95% CI: 0.27, 0.34; $p < 0.001$). Predicted AHI increased from 3.92 events/hour at a WHtR of 0.50 to 5.44 events/hour at a WHtR of 0.55 in SHIP-TREND, and from 4.15 to 5.98 events/hour in KoGES. The cohort $\times$ WHtR interaction was not significant ($p = 0.283$), supporting the use of WHtR as the primary adiposity covariate in cross-cohort models.

3.4. Effect of sleep-disordered breathing on cardiometabolic outcomes

3.4.1. Diabetes associations with sleep-disordered breathing

Predicted diabetes probabilities increased with AHI in both cohorts and were higher in KoGES than in SHIP-TREND (Fig. 3). In age- and sex-adjusted models, each 5 events/hour increase in AHI was associated with higher odds of diabetes in SHIP-TREND (OR = 1.12; 95% CI: 1.05, 1.18; $p < 0.001$) and KoGES (OR = 1.16; 95% CI: 1.11, 1.22; $p < 0.001$). The cohort $\times$ AHI interaction was not significant ($p = 0.245$), indicating comparable associations despite higher diabetes probabilities in KoGES. After additional adjustment for WHtR, the association was attenuated in both cohorts, with a larger attenuation in SHIP-TREND (OR = 1.04; 95% CI: 0.98, 1.11; $p = 0.184$) than in KoGES (OR = 1.09; 95% CI: 1.04, 1.14; $p < 0.001$). The interaction remained non-significant after WHtR adjustment ($p = 0.266$), suggesting similar patterns across cohorts. These findings indicate that central adiposity accounted for part of the AHI–diabetes association, particularly in SHIP-TREND, while a residual association persisted in KoGES. Supplementary HbA1c analyses showed a consistent pattern, with associations attenuated after WHtR adjustment in SHIP-TREND but persisting in KoGES (Supplementary Appendix).

Table 2

Descriptive characteristics of SHIP-TREND and KoGES participants stratified by AHI severity.

Variable	KoGES				SHIP-TREND				Between-Cohort Comparison P Value			
	No SDB (N = 1516)	Mild SDB (N = 931)	Moderate SDB (N = 315)	Severe SDB (N = 105)	No SDB (N = 347)	Mild SDB (N = 229)	Moderate SDB (N = 113)	Severe SDB (N = 79)	No SDB	Mild SDB	Moderate SDB	Severe SDB
Age (years)	57.81 (6.21)	60.75 (7.25)	61.18 (7.25)	60.41 (7.05)	57.13 (8.57)	60.30 (8.41)	60.96 (8.66)	62.66 (9.25)	0.161	0.462	0.805	0.074
Sex (male, %)	638 (42.1%)	486 (52.2%)	214 (67.9%)	77 (73.3%)	155 (44.7%)	134 (58.5%)	71 (62.8%)	62 (78.5%)	0.413	0.101	0.384	0.528
Education	3.65 (1.70)	3.49 (1.82)	3.64 (1.88)	4.04 (1.92)	4.29 (1.51)	4.26 (1.53)	4.27 (1.59)	4.30 (1.40)	<0.001	<0.001	<0.001	0.281
AHI (events/hr)	1.98 (1.42)	8.81 (2.76)	20.39 (4.03)	41.14 (9.91)	1.86 (1.43)	8.97 (2.80)	21.02 (3.96)	47.39 (16.46)	0.161	0.436	0.154	0.003
BMI (kg/m ²)	23.88 (2.74)	25.20 (2.85)	25.81 (2.99)	27.21 (3.65)	27.67 (3.94)	29.81 (4.38)	30.95 (5.20)	32.10 (4.82)	<0.001	<0.001	<0.001	<0.001
WHtR	0.50 (0.05)	0.52 (0.05)	0.53 (0.05)	0.55 (0.05)	0.53 (0.07)	0.57 (0.07)	0.58 (0.07)	0.61 (0.06)	<0.001	<0.001	<0.001	<0.001
Hypertension (%)	416 (27.5%)	402 (43.2%)	158 (50.2%)	63 (60.0%)	169 (48.7%)	157 (68.6%)	75 (66.4%)	56 (71.8%)	<0.001	<0.001	0.004	0.134
Diabetes (%)	239 (16.4%)	239 (26.3%)	98 (31.5%)	43 (42.2%)	31 (8.9%)	47 (20.6%)	23 (20.4%)	24 (30.4%)	<0.001	0.091	0.033	0.141
Current drinker (%)	654 (43.1%)	433 (46.5%)	172 (54.6%)	54 (51.4%)	322 (92.8%)	206 (90.0%)	103 (91.2%)	69 (87.3%)	<0.001	<0.001	<0.001	<0.001
Smoking exposure (pack-years)	13.47 (17.85)	16.98 (19.12)	18.94 (22.85)	20.23 (23.08)	7.55 (14.03)	13.34 (20.77)	11.52 (15.48)	17.38 (19.36)	<0.001	0.047	0.002	0.465

Table 2. Descriptive characteristics of SHIP-TREND and KoGES participants stratified by apnea–hypopnea index (AHI) severity. Values are presented as mean (standard deviation) for continuous variables and n (%) for categorical variables. Between-cohort p-values compare KoGES and SHIP-TREND participants within each AHI severity category. Statistically significant p-values are shown in bold. KoGES = Korean Genome and Epidemiology Study, SHIP-TREND = Study of Health in Pomerania, SDB = Sleep Disordered Breathing, BMI = Body Mass Index, WHtR = Waist-to-height-ratio, No SDB (AHI <5 events/hour), mild SDB (AHI ≥ 5 to <15), moderate SDB (AHI ≥ 15 to <30), and severe SDB (AHI ≥ 30).

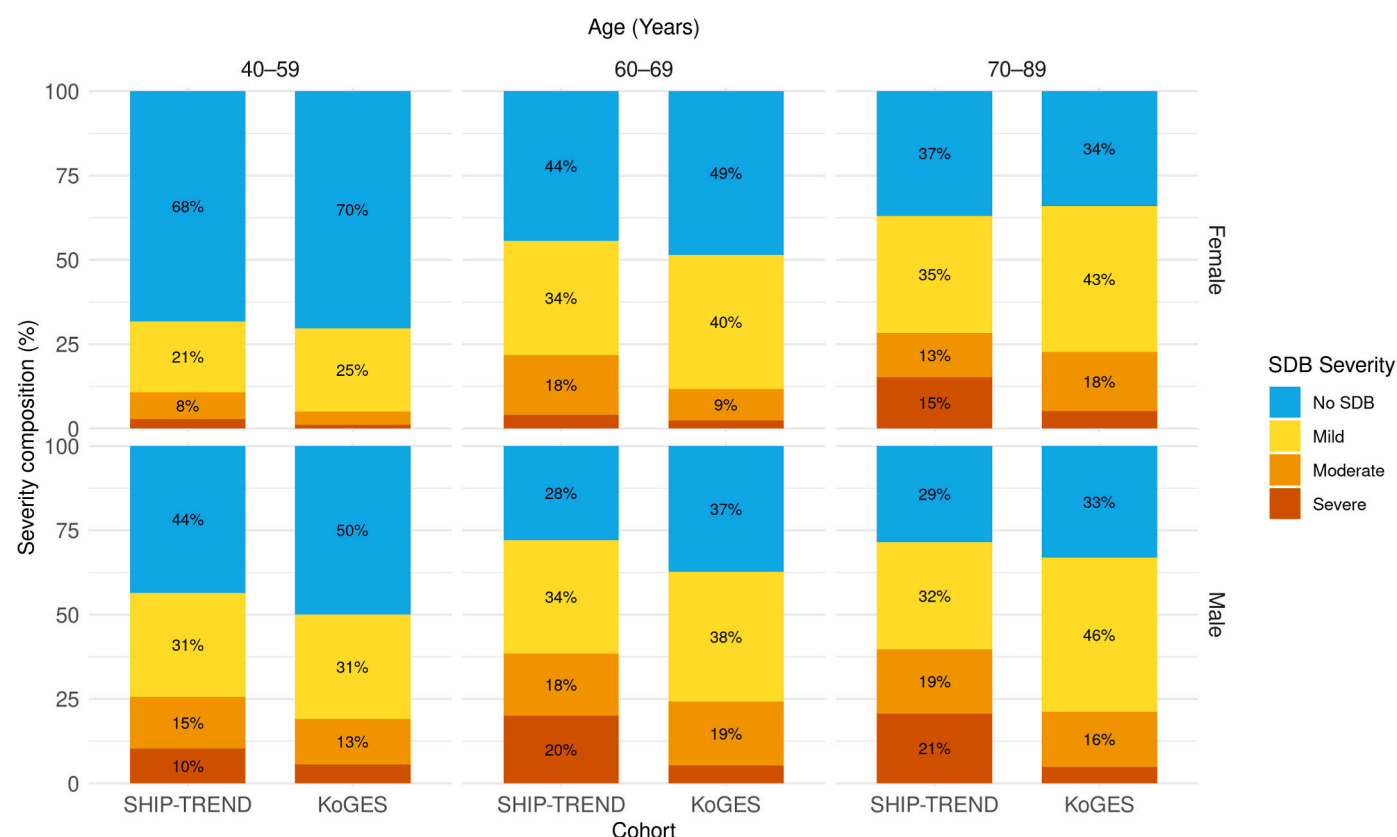


Fig. 1. Distribution of Apnea-Hypopnea Index defined sleep-disordered breathing (SDB) severity across age and sex groups in the SHIP-TREND and KoGES cohorts. *KoGES = Korean Genome and Epidemiology Study, SHIP-TREND = Study of Health in Pomerania. Age was initially grouped into 10-year categories; given the small numbers in the 40–49 and 80–89 year groups, these categories were combined with adjacent age groups.

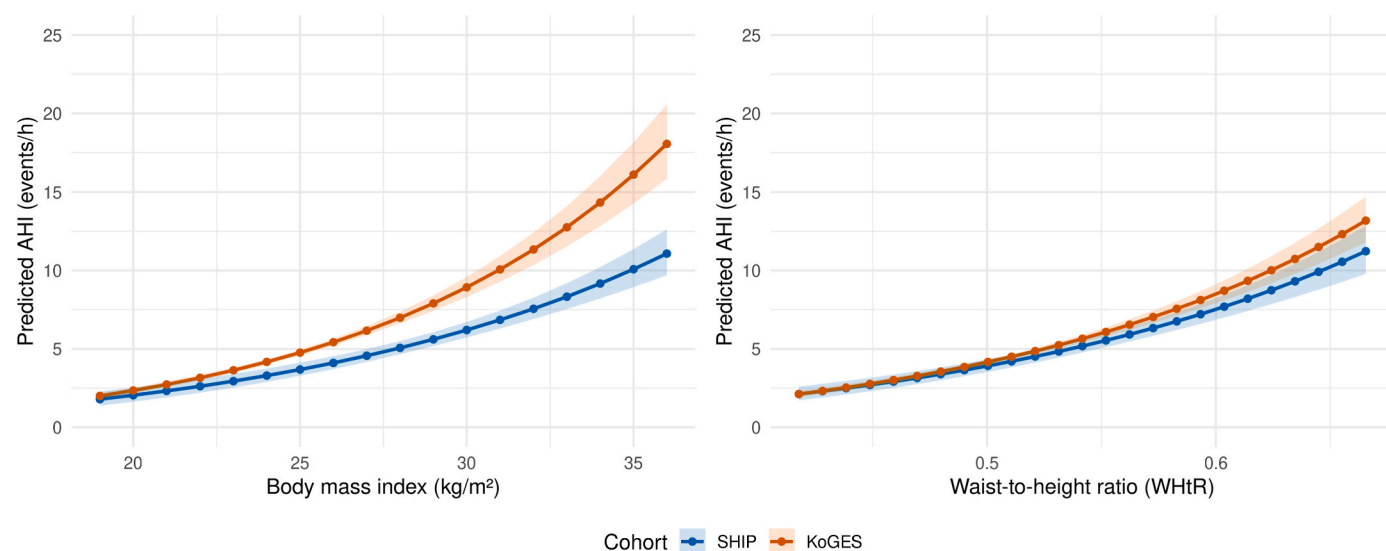


Fig. 2. Predicted Apnea-Hypopnea Index (AHI) across the range of body mass index (BMI; panel a) and waist-to-height ratio (WHtR; panel b) in the Study of Health in Pomerania (SHIP-TREND) and the Korean Genome and Epidemiology Study (KoGES). Estimates are based on inverse probability weighted regression models adjusted for age and sex. AHI was log-transformed for modelling and back-transformed for presentation. Lines represent model-based predictions and shaded areas indicate 95% confidence intervals. Model fit was comparable across specifications, with slightly better fit for BMI ($R^2 = 0.248$, adj. $R^2 = 0.247$) than WHtR ($R^2 = 0.243$, adj. $R^2 = 0.242$) (both models $p < 0.001$).

3.4.2. Hypertension associations with sleep-disordered breathing

Predicted hypertension probabilities increased with AHI in both cohorts but were consistently higher in SHIP-TREND than in KoGES (Fig. 4). However, the AHI-related increase was steeper in KoGES,

resulting in larger between-cohort differences at lower AHI and more similar hypertension prevalence with increasing AHI. In age- and sex-adjusted models, each 5 events/hour increase in AHI was associated with higher odds of hypertension in SHIP-TREND (OR = 1.09; 95% CI:

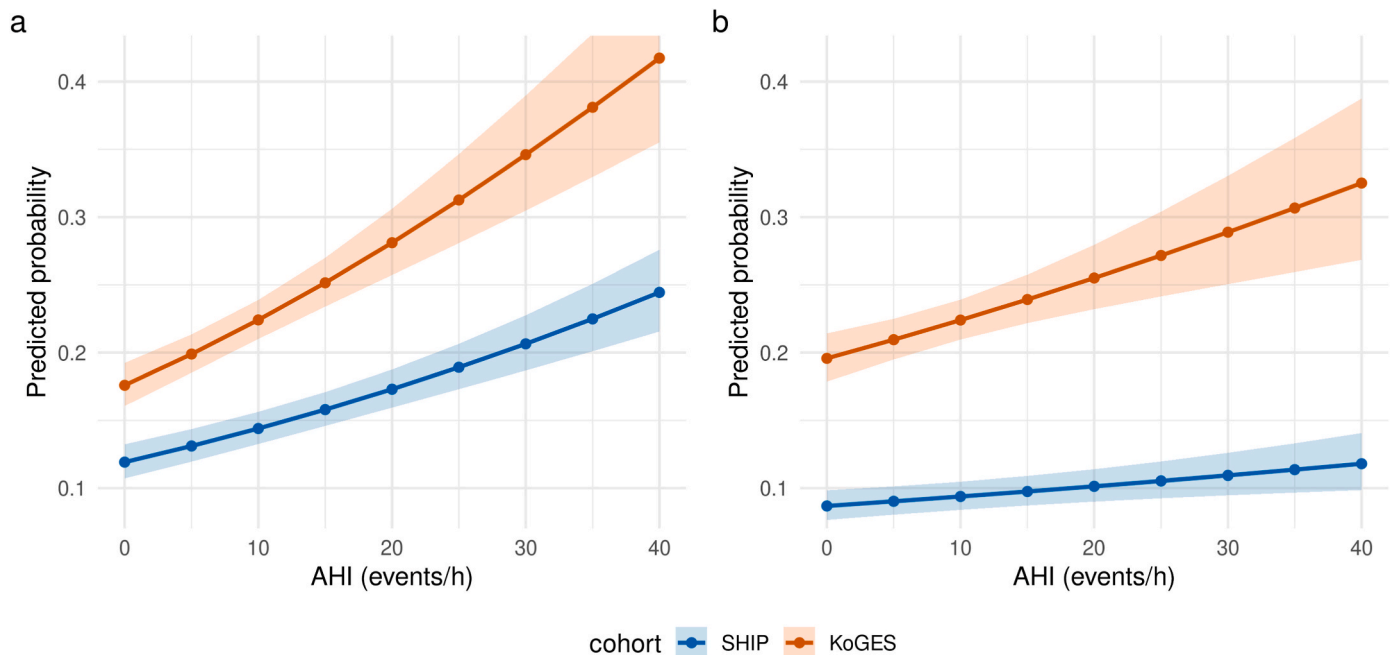


Fig. 3. Predicted probability of diabetes across the range of Apnea-Hypopnea Index (AHI) in the Study of Health in Pomerania (SHIP-TREND) and the Korean Genome and Epidemiology Study (KoGES), adjusted for age and sex (left panel) and additionally for waist-to-height ratio (WHtR) (right panel). Estimates are based on inverse probability weighted logistic regression models. Points represent predicted values and shaded areas indicate 95% confidence intervals. Diabetes probability increased with AHI in both cohorts and remained higher in KoGES; WHtR adjustment substantially attenuated this association in SHIP-TREND but less so in KoGES.

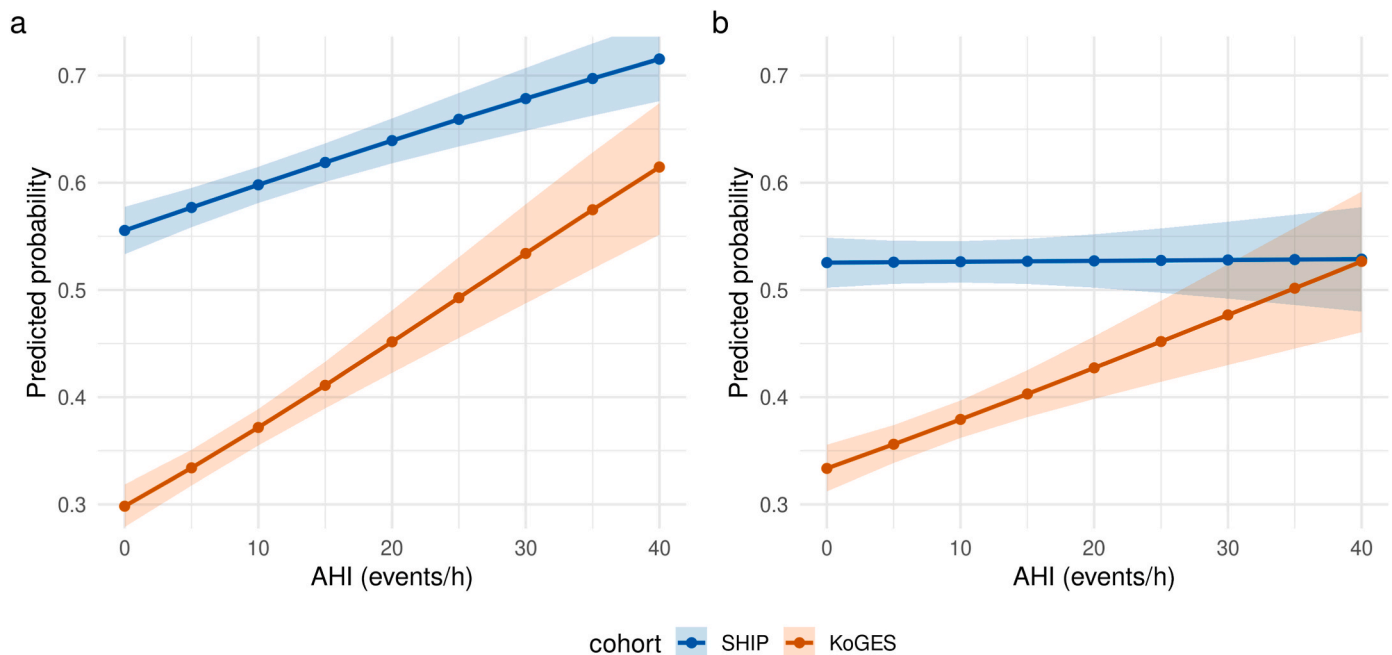


Fig. 4. Predicted probability of hypertension across the range of Apnea-Hypopnea Index (AHI) in the Study of Health in Pomerania (SHIP-TREND) and the Korean Genome and Epidemiology Study (KoGES), adjusted for age and sex (left panel) and additionally for waist-to-height ratio (WHtR) (right panel). Estimates are based on inverse probability weighted logistic regression models. Points represent predicted values and shaded areas indicate 95% confidence intervals. Hypertension probability was higher in SHIP-TREND at lower AHI values, but after WHtR adjustment, the association with AHI persisted only in KoGES.

1.03, 1.16; $p = 0.005$) and KoGES (OR = 1.18; 95% CI: 1.13, 1.24; $p < 0.001$). The cohort $\times$ AHI interaction supported a stronger association in KoGES ($p = 0.045$). After WHtR adjustment, the association was fully attenuated in SHIP-TREND (OR = 1.00; 95% CI: 0.94, 1.06; $p = 0.957$), indicating that central adiposity accounted for the observed association. In KoGES, the association persisted after WHtR adjustment

(OR = 1.10; 95% CI: 1.05, 1.16; $p < 0.001$). The WHtR-adjusted cohort $\times$ AHI interaction was significant ($p = 0.009$), indicating that the association between AHI and hypertension differed between cohorts after accounting for central adiposity and was more pronounced in KoGES.

3.4.3. Lipid associations with sleep-disordered breathing

Increasing AHI was associated with a less favourable lipid profile (Fig. S2–S3). In age- and sex-adjusted models, each 5 events/hour increase in AHI was associated with higher triglycerides in SHIP-TREND ($\beta = 4.68$ mg/dL; 95% CI: 1.52, 7.85; $p = 0.004$) and KoGES ($\beta = 5.52$ mg/dL; 95% CI: 3.05, 8.00; $p < 0.001$) and lower HDL in SHIP-TREND ($\beta = -0.77$ mg/dL; 95% CI: $-1.06, -0.48$; $p < 0.001$) and KoGES ($\beta = -0.66$ mg/dL; 95% CI: $-0.89, -0.44$; $p < 0.001$). After WHtR adjustment, triglyceride associations were attenuated in SHIP-TREND ($\beta = 1.35$ mg/dL; 95% CI: $-1.66, 4.36$; $p = 0.380$) and KoGES ($\beta = 2.66$ mg/dL; 95% CI: 0.10, 5.21; $p = 0.041$). Similarly, HDL cholesterol associations were attenuated and no longer significant in SHIP-TREND ($\beta = -0.22$ mg/dL; 95% CI: $-0.51, 0.07$; $p = 0.141$) or KoGES ($\beta = -0.19$ mg/dL; 95% CI: $-0.42, 0.04$; $p = 0.104$). There was no evidence of cohort $\times$ AHI interaction for triglycerides or HDL cholesterol in either model and LDL cholesterol showed no significant association with AHI before or after WHtR adjustment. These findings suggest that the adverse lipid profile associated with higher AHI is largely explained by central adiposity and is broadly similar across cohorts. Additional details are provided in the **Supplementary Appendix**.

3.4.4. Framingham 10-year cardiovascular risk (FRS) associations with sleep-disordered breathing

FRS was higher in SHIP-TREND than in KoGES, with a greater proportion of SHIP-TREND participants classified as high risk (Fig. S4). In age- and sex-adjusted models, each 5 events/hour increase in AHI was associated with higher predicted FRS in SHIP-TREND ($\beta = 0.57$; 95% CI: 0.26, 0.88; $p < 0.001$) and KoGES ($\beta = 0.51$; 95% CI: 0.30, 0.72; $p < 0.001$), with no evidence of a cohort $\times$ AHI interaction ($p = 0.741$). After additional adjustment for WHtR, associations were attenuated, with similar effect estimates in SHIP-TREND ($\beta = 0.25$; 95% CI: $-0.06, 0.57$; $p = 0.113$) and KoGES ($\beta = 0.23$; 95% CI: 0.02, 0.45; $p = 0.035$). The cohort $\times$ AHI interaction remained non-significant after WHtR adjustment ($p = 0.904$), indicating the association between SDB severity and FRS was similar between cohorts after accounting for central adiposity. Thus, although absolute FRS was higher in SHIP-TREND, higher SDB severity was similarly associated with greater cardiovascular risk in both cohorts. This association was largely explained by central adiposity. Additional details are provided in the **Supplementary Appendix**.

3.4.5. Sensitivity analyses

Sensitivity analyses additionally adjusting for cumulative smoking exposure and alcohol use did not materially alter the overall pattern of cardiometabolic findings. These analyses showed that the primary findings remained broadly consistent after accounting for additional lifestyle-related factors. Further details are provided in the **Supplementary Appendix**.

4. Discussion

This harmonised comparison of Korean and German population-based cohorts identified important similarities and differences in how SDB relates to adiposity and cardiometabolic health. Collectively, these findings suggest that the clinical impact of a given AHI can differ between populations. Although greater adiposity was associated with more severe SDB in both cohorts, the relationship between BMI and AHI was stronger in the Korean cohort, consistent with previous evidence suggesting greater susceptibility to SDB at lower levels of adiposity in East Asian populations. [24]. Cardiometabolic patterns also differed. Hypertension was more prevalent in the German cohort, but increasing AHI was more strongly associated with the risk of hypertension in the Korean cohort even after adjustment for central adiposity. While diabetes was consistently more prevalent in the Korean cohort, its relative association with AHI was similar in Germans and Koreans. Associations of AHI with lipid markers and predicted cardiovascular risk were

broadly comparable and partly explained by adiposity. These findings have important implications for the population-specific public health impact of SDB, highlighting the importance of weight-related prevention and management in Germany, while in Korea supporting greater emphasis on early SDB recognition and management given cardiometabolic associations that may not be fully explained by central adiposity.

First, the relationship between body mass and SDB severity highlights population-specific susceptibility. In our study, BMI was more strongly associated with SDB severity in the Korean than in the German cohort, consistent with previous evidence that East Asian populations may develop SDB and other obesity-related health risks at lower levels of adiposity than European populations [12,25,26]. In other words, identical BMI values may not represent equivalent levels of risk [21]. One potential explanation of the stronger relationship between obesity and SDB severity in the Korean population may be population-specific upper airway anatomy. East Asian patients with SDB often have greater skeletal restriction than European patients with comparable disease severity [24,26,27]. A smaller craniofacial enclosure may leave less space for surrounding soft tissue, allowing modest upper-airway fat deposition at lower BMI to more significantly increase airway collapsibility [28,29]. Continued weight gain therefore produces a particularly marked increase in SDB burden in the Korean population. This is particularly impactful in the context of rising adiposity-related health risks in both countries and evidence that East Asian populations may develop obesity-related cardiometabolic consequences at lower BMI levels than European populations [21,25,26,30,31]. Rather than relying on uniform BMI thresholds, population-appropriate obesity definitions, stronger prevention strategies, and earlier SDB recognition will be increasingly important to limit the accompanying cardiometabolic and healthcare burden.

In addition to the impact of obesity, the stronger relationship between AHI and hypertension risk suggests different SDB-related cardiovascular risk profiles across populations. In the German cohort, SDB occurred against an already high background burden of hypertension, consistent with the historically high prevalence reported in Germany, particularly in eastern regions [32,33]. The attenuation of the AHI–hypertension association after adjustment for central adiposity indicates that obesity may be a major shared pathway linking SDB and hypertension in this population, and highlights the importance of weight management. In the Korean cohort, hypertension increased more sharply with AHI even after accounting for central adiposity. This may indicate greater susceptibility to the established effects of SDB-related intermittent hypoxia, persistent sympathetic activation, and oxidative stress on hypertension [34]. This distinction is clinically important, as obesity-based risk assessment alone may fail to identify Korean individuals in whom SDB contributes to hypertension. Public-health strategies may therefore need to differ between populations, with greater emphasis on integrated obesity and cardiovascular prevention in Germany and earlier SDB detection alongside blood-pressure monitoring in Korea. These findings reinforce that AHI should not be interpreted as carrying a uniform cardiovascular impact across populations.

The observed relationships between SDB and diabetes raise a different population-level challenge. Diabetes probability was consistently higher in the Korean cohort, indicating that SDB occurred against a greater underlying disease burden in Korea. This aligns with evidence that East Asian populations develop type 2 diabetes at younger ages and lower BMI levels than European populations [35–37]. This greater metabolic vulnerability may partly reflect higher insulin resistance and reduced pancreatic β -cell reserve at relatively low levels of adiposity [36,38]. Genetic susceptibility, early-life influences, and dietary transitions may further shape diabetes risk across the life course [39,40]. In particular, rapid dietary westernisation across East Asia, including increased consumption of animal products, fats, oils, and processed foods, alongside urbanisation and globalisation, may compound existing metabolic susceptibility in populations already at elevated diabetes risk

[40,41]. In contrast to results for hypertension, the relationship between AHI and diabetes was similar in both the German and Korean cohorts, including attenuation after accounting for central adiposity. These findings suggest that SDB may add to the metabolic burden in both populations. However, this increase in burden may be particularly impactful in Korean populations, among whom diabetes risk is already elevated. Thus, while useful in both populations, earlier metabolic screening and preventive management alongside SDB assessment may be especially valuable in Korea.

Analyses of lipid profiles showed broadly comparable associations with AHI in both populations. More severe SDB was related to higher triglycerides and lower HDL cholesterol, while LDL cholesterol showed no clear association with AHI. Adjustment for central adiposity attenuated these associations, suggesting that SDB and dyslipidaemia coexist within a broader adiposity-related cardiometabolic phenotype. This is consistent with evidence that visceral adiposity contributes to higher triglycerides and lower HDL cholesterol [42]. Overall, these findings support assessing lipid health alongside SDB and adiposity in both populations.

The cardiovascular risk findings further suggest that the implications of SDB depend partly on the background health profile of the population. Estimated 10-year cardiovascular risk was higher in the German cohort, reflecting its greater burden of hypertension and adiposity, while the Korean cohort showed lower absolute risk despite a broadly similar relationship with AHI. The attenuation observed after adjustment for WHtR indicates that central adiposity is an important shared pathway linking SDB with wider cardiovascular risk in both populations. These findings highlight the importance of considering SDB alongside adiposity and blood-pressure status, rather than as an isolated risk marker, and support integrated cardiovascular risk assessment in people with SDB in both populations.

This study highlights the risks of generalizing the impact of SDB, emphasizing population differences with implications for prevention and public health. The clinical implications of SDB depend on the anatomical, anthropometric, and cardiometabolic context in which respiratory events occur. Ultimately, risk assessment based on obesity or AHI alone could overlook individuals whose susceptibility is not adequately reflected by conventional thresholds. More broadly, SDB assessment should be combined with evaluation of body composition and prevalent comorbidities. This need for population-specific prevention may become increasingly important given rising obesity prevalence in both countries: from 12.2% in 2003 to 19.7% in 2023 in Germany and from 31.1% in 2014 to 38.4% in 2023 in Korea [30,31].

A major strength of this study is the direct comparison of two well-characterised population-based cohorts using harmonised demographic, anthropometric, cardiometabolic, and polysomnographic measures. The use of common AHI definitions, reciprocal rescoring, IPW, and formal interaction testing further strengthened cross-population comparability. Reciprocal rescoring showed excellent agreement when the SHIP-TREND team rescored KoGES recordings and good-to-excellent agreement in the reverse direction. The modest directional difference may partly reflect scorer and software familiarity, as the SHIP-TREND team had prior experience with the platform used for KoGES scoring, whereas the KoGES team had to adapt to the SHIP-TREND software. This suggests that the observed difference may reflect scorer- and platform-related factors rather than substantive incompatibility between the two sleep assessments.

Several limitations should nevertheless be considered. The largely cross-sectional design limits causal inference, and WHtR does not capture other potentially relevant aspects of adiposity and anatomy, including visceral or upper-airway fat, lifetime obesity exposure, or craniofacial characteristics. Residual confounding by behavioural, socioeconomic, treatment-related, and healthcare-related factors also remains possible. In addition, the unequal cohort sizes resulted in greater statistical power and more precise estimates in KoGES than in SHIP-TREND, particularly for interaction analyses and smaller effect sizes.

Future research should extend these observations through more detailed anatomical and longitudinal comparisons. A previous multi-ethnic study in clinical sleep centers shows that anthropometric and clinical anatomic risk factors relate differently to SDB severity across populations [28]. Building on this, direct imaging-based assessment of craniofacial structure, soft tissues, and regional fat distribution could clarify anatomical contributions to the stronger BMI–AHI association in the Korean population. Longitudinal cross-cohort studies would help to determine how changes in adiposity and SDB severity influence the subsequent development of cardiometabolic disease. A broader physiological characterisation of SDB may also be informative, combining AHI with complementary measures such as oxygen desaturation index, cumulative time spent with oxygen saturation below 90%, hypoxic burden, respiratory-event characteristics, and sleep fragmentation or arousal burden. This could provide a more complete picture of SDB-related physiological stress and help clarify which pathways contribute most strongly to population differences in cardiometabolic risk. Additional consideration of diet, physical activity, working patterns, socioeconomic conditions, healthcare access, and treatment may help explain residual population differences in SDB and its consequences.

5. Conclusion

The clinical meaning of SDB is shaped by the population in which it occurs. In the Korean cohort, increasing body mass was accompanied by a greater rise in SDB severity, while hypertension and diabetes remained important concerns even at comparatively lower levels of adiposity. In the German cohort, SDB was more closely embedded within an established obesity-related cardiovascular-risk profile. AHI should therefore be interpreted alongside population-appropriate measures of adiposity and cardiometabolic health, so that prevention and risk assessment reflect not only how much SDB is present, but what it means for the population affected.

CRedit authorship contribution statement

Matthew Salanitro: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antoine Weihs:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Seung Ku Lee:** Writing – review & editing, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Brendan T. Keenan:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Martin Glos:** Writing – review & editing, Methodology, Investigation. **Anja Seiger:** Writing – review & editing, Methodology, Investigation. **Hanyi Jiang:** Writing – review & editing, Methodology, Investigation. **Beate Stubbe:** Writing – review & editing, Investigation, Data curation. **Ralf Ewert:** Writing – review & editing, Investigation, Data curation. **Ingo Fietze:** Writing – review & editing, Investigation, Data curation. **Henry Völzke:** Writing – review & editing, Investigation, Data curation. **Hans J. Grabe:** Writing – review & editing, Investigation, Data curation. **Nan Hee Kim:** Writing – review & editing, Investigation, Data curation. **Chol Shin:** Writing – review & editing, Supervision, Investigation, Data curation. **Allan Pack:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Thomas Penzel:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

Declaration of generative AI

An artificial intelligence tool was used for grammar checking and to assist with code development for figure design.

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Declaration of competing interest

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All authors have nothing to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.sleep.2026.109273>.

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