Predictors of Sleep-Disordered Breathing in Community-Dwelling Adults

The Sleep Heart Health Study

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Background: Sleep-disordered breathing (SDB) is common, but largely undiagnosed in the general population. Information on demographic patterns of SDB occurrence and its predictive factors in the general population is needed to target high-risk groups that may benefit from diagnosis.

Methods: The sample comprised 5615 community-dwelling men and women aged between 40 and 98 years who were enrolled in the Sleep Heart Health Study. Data were collected by questionnaire, clinical examinations, and in-home polysomnography. Sleep-disordered breathing status was based on the average number of apnea and hypopnea episodes per hour of sleep (apnea-hypopnea index [AHI]). We used multiple logistic regression modeling to estimate cross-sectional associations of selected participant characteristics with SDB defined by an AHI of 15 or greater.

Results: Male sex, age, body mass index, neck girth, snoring, and repeated breathing pause frequency were independent, significant correlates of an AHI of 15 or greater. People reporting habitual snoring, loud snoring, and frequent breathing pauses were 3 to 4 times more likely to have an AHI of 15 or greater vs an AHI less than 15, but there were weaker associations for other factors with an AHI of 15 or greater. The odds ratios (95% confidence interval) for an AHI of 15 or greater vs an AHI less than 15 were 1.6 and 1.5, respectively, for 1-SD increments in body mass index and neck girth. As age increased, the magnitude of associations for SDB and body habitus, snoring, and breathing pauses decreased.

Conclusions: A significant proportion of occult SDB in the general population would be missed if screening or case finding were based solely on increased body habitus or male sex. Breathing pauses and obesity may be particularly insensitive for identifying SDB in older people. A better understanding of predictive factors for SDB, particularly in older adults, is needed.

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Epidemiologic research has shown that sleep-disordered breathing (SDB) is common but largely undiagnosed in the general adult population. Although uncertainty remains as to the level of SDB that should prompt therapy, there is a clear need for evidence-based strategies to target persons with SDB who might benefit from diagnosis and treatment. For this purpose, a deeper understanding of the patterns of SDB occurrence and of its predictive factors is needed. At present, most of our understanding of SDB correlates comes from observations of patients diagnosed as having sleep apnea syndrome, the clinical entity of SDB. Clinical reports have consistently shown that SDB tends to occur predominantly in men during middle age, and that habitual snoring, obesity, and large neck girth are strong predictors of SDB. However, because only a small fraction of SDB is diagnosed, patients with SDB ascertained through sleep clinics are probably not representative of affected persons in the community.

Findings from several population-based studies have confirmed that snoring and obesity are predictors of SDB. However, data from these studies cast doubt on the generalizability of other clinic-based observations to the large proportion of undiagnosed SDB cases in the population. Population-based studies, for example, have shown that although the prevalence of SDB is higher in men compared with women, the excess male prevalence is less than would be expected from early reports that most patients with sleep apnea were men. Furthermore, population-based studies suggest that SDB prevalence in older adults may be considerably higher than in middle-aged adults, the predominant age group in SDB patient populations.

Author affiliations are listed at the end of this article.
Participating institutions and Sleep Heart Health Study investigators are listed in a box on page 899.
In the present study, we investigated the association of sex, age, race, snoring, and obesity with SDB in community-dwelling adults, using data from 6119 participants in the Sleep Heart Health Study (SHHS), a multicenter cohort study of SDB and cardiovascular disease. The large, uniformly studied cohort of men and women in the SHHS is well suited for investigating patterns of SDB occurrence as it extends from early middle age to old age and is ethnically and geographically diverse.

A total of 5615 participants had complete data on all demographic, body habitus, self-reported snoring and...
breathing pause variables, and AHI. Regarding the study sample, 53% were women, 77% were white, and the mean ± SD age was 63.5 ± 10.7 years. The mean ± SD AHI was 8.8 ± 12.2; the median was 4.5 with a range from 0 to 149. Of the sample, 18% had an AHI of 15 or greater and were therefore categorized as having SDB.

Table 1 gives the proportions of the sample in 3 categories of AHI (<5, 5-15, and ≥15) by demographic and other factors. The AHI category was significantly associated with each factor, but the proportions are not adjusted. Consequently, the distributions should be viewed as descriptive only.

Defined as an AHI of 15 or greater, SDB was approximately twice as prevalent in men compared with women. A small increase in SDB prevalence was observed with increasing 10-year age groups. To investigate the age trend further, we plotted the average prevalence of an AHI of 15 or greater for 5-year age intervals, moving by 1-year increments over the entire age range. The resulting unadjusted smoothed plot (Figure 1) shows a plateau effect for prevalence in our sample beginning at approximately age 60 years. The pattern after age 85 years is not clear owing to the small number of participants in this oldest age group. All body habitus measures were strongly associated with an AHI of 15 or greater.

As expected, SDB was associated with self-reported snoring and breathing pauses. The prevalence of an AHI of 15 or greater increased with increasing categories of snoring frequency, loudness of snoring, and breathing pauses. Cross tabulations of these variables showed that although the variables are correlated, snoring frequency, loudness, and reported pauses each conveyed some different information. Nearly all of the extremely loud snorers and those with reported breathing pauses of 3 or more nights per week were also habitual snorers (92% and 88%, respectively). Most habitual snorers, however, did not report extremely loud snoring or breathing pauses: 79% and 92% of the habitual snorers reported lesser categories of snoring loudness and breathing pause frequency, respectively.

Of all the categories of demographic or predictor factors investigated, self-reported frequent breathing pauses (>3 nights per week) had the highest prevalence (49%) of an AHI of 15 or greater. However, the sensitivity of this symptom was low: of all participants with an AHI of 15 or greater, only 89 (9%) of 1006 had reported frequent breathing pauses.

The results of modeling an AHI of 15 or greater using multiple logistic regression are given in Table 2.
Model 1 includes only the demographic factors of sex, age, and race. Compared with women, men had 2.7 times the odds of having an AHI of 15 or greater. Based on a model with age in years as a continuous variable, a 10-year age increment was associated with an increase in the odds of having an AHI of 15 or greater by 24%. Consistent with Figure 1, the addition of an age-squared term indicated that the excess risk of SDB for American Indian heritage observed in model 1 was explained by increased measures of body habitus.

Table 2. Odds Ratios (95% CIs) for Variables and an AHI of 15 or Greater Estimated by Multiple Logistic Regression Models With Cumulative Addition of Independent Variables

<table>
<thead>
<tr>
<th>Model Term</th>
<th>Model 1 (Age, Sex, Race)</th>
<th>Model 2 (Model 1 + Body Habitus)</th>
<th>Model 3 (Model 2 + Snore)</th>
<th>Model 4 (Model 2 + Breathing Pauses)</th>
<th>Model 5 (Model 2 + Breathing Pauses)</th>
<th>Model 6 (Model 2 + Snore, Breathing Pauses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (male vs female)</td>
<td>2.70 (2.24-3.12)</td>
<td>1.71 (1.37-2.15)</td>
<td>1.60 (1.27-2.01)</td>
<td>1.60 (1.27-2.01)</td>
<td>1.59 (1.27-2.00)</td>
<td>1.51 (1.29-1.90)</td>
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<tr>
<td>Age (10-y increment)</td>
<td>1.24 (1.15-1.32)</td>
<td>1.36 (1.26-1.47)</td>
<td>1.47 (1.35-1.60)</td>
<td>1.49 (1.37-1.62)</td>
<td>1.40 (1.30-1.52)</td>
<td>1.52 (1.40-1.65)</td>
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<tr>
<td>Race (vs white)</td>
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<tr>
<td>African American</td>
<td>1.23 (0.96-1.60)</td>
<td>1.13 (0.86-1.49)</td>
<td>1.12 (0.85-1.48)</td>
<td>1.19 (0.91-1.57)</td>
<td>1.16 (0.89-1.53)</td>
<td>1.17 (0.89-1.55)</td>
</tr>
<tr>
<td>American Indian</td>
<td>1.70 (1.37-2.11)</td>
<td>1.09 (0.87-1.37)</td>
<td>1.21 (0.95-1.53)</td>
<td>1.26 (1.00-1.60)</td>
<td>1.10 (0.87-1.40)</td>
<td>1.23 (0.97-1.57)</td>
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<tr>
<td>Other</td>
<td>0.94 (0.65-1.37)</td>
<td>1.13 (0.77-1.66)</td>
<td>1.12 (0.78-1.67)</td>
<td>1.19 (0.80-1.77)</td>
<td>1.18 (0.79-1.74)</td>
<td>1.17 (0.78-1.74)</td>
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<tr>
<td>BMI (5.3 kg/m² increment)</td>
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<td>...</td>
<td>1.60 (1.45-1.76)</td>
<td>1.55 (1.40-1.70)</td>
<td>1.57 (1.43-1.73)</td>
<td>1.59 (1.44-1.75)</td>
<td>1.55 (1.41-1.71)</td>
<td>1.55 (1.41-1.71)</td>
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<tr>
<td>Neck girth (1.7-in increment)†</td>
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<td>...</td>
<td>1.48 (1.31-1.67)</td>
<td>1.46 (1.29-1.65)</td>
<td>1.42 (1.25-1.61)</td>
<td>1.45 (1.28-1.65)</td>
<td>1.42 (1.25-1.61)</td>
<td>1.42 (1.25-1.61)</td>
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<td>Waist-to-hip ratio (0.09-unit increment)†</td>
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<td>...</td>
<td>1.12 (1.01-1.23)</td>
<td>1.09 (0.99-1.21)</td>
<td>1.10 (1.00-1.22)</td>
<td>1.12 (1.02-1.24)</td>
<td>1.11 (1.00-1.22)</td>
<td>1.11 (1.00-1.22)</td>
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<tr>
<td>Snoring frequency (vs none)</td>
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<td>Moderate (&lt;3 nights/wk)</td>
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<td>...</td>
<td>1.28 (0.92-1.78)</td>
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<td>...</td>
<td>1.02 (0.70-1.49)</td>
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<tr>
<td>Habitual (3-7 nights/wk)</td>
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<td>...</td>
<td>2.87 (2.10-3.91)</td>
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<td>...</td>
<td>1.75 (1.18-2.62)</td>
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<tr>
<td>Do not know</td>
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<td>...</td>
<td>1.63 (1.19-2.25)</td>
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<td>1.28 (0.83-1.97)</td>
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<td>Snoring loudness (vs none or audible breathing)</td>
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<td>Somewhat loud</td>
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<td>...</td>
<td>...</td>
<td>1.95 (1.57-2.42)</td>
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<td>1.42 (1.08-1.86)</td>
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<tr>
<td>Extremely loud</td>
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<td>...</td>
<td>...</td>
<td>3.96 (2.98-5.27)</td>
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<td>2.21 (1.56-3.14)</td>
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<tr>
<td>Do not know</td>
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<td>...</td>
<td>...</td>
<td>1.47 (1.18-1.85)</td>
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<td>1.27 (0.92-1.75)</td>
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<td>Reported breathing pauses (vs none)</td>
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<tr>
<td>Sometimes (&lt;3 nights/wk)</td>
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<td>...</td>
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<td>...</td>
<td>1.78 (1.34-2.37)</td>
<td>1.43 (1.07-1.92)</td>
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<tr>
<td>Often (3-7 nights/wk)</td>
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<td>...</td>
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<td>...</td>
<td>4.03 (2.87-5.67)</td>
<td>2.47 (1.72-3.53)</td>
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<tr>
<td>Do not know</td>
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<td>...</td>
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<td>...</td>
<td>1.16 (0.98-1.36)</td>
<td>0.99 (0.84-1.18)</td>
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</table>

*CI indicates confidence interval; AHI, apnea-hypopnea index; BMI, body mass index; and ellipses, term not included in the model. †1 SD.

Model modified the effects of the body habitus variables with respect to the outcome variable of an AHI of 15 or greater. An attenuated effect with increasing age is shown in Figure 2 with ORs for an AHI of 15 or greater estimated for an increase of 1 SD in BMI, computed for 5 points along the age range. The OR (95% confidence interval) for BMI and an AHI of 15 or greater at age 40 years was 2.0 (1.7-2.4) and dropped to 1.3 (1.1-1.5) by age 80 years. The associations of neck circumference and waist-to-hip ratio with an AHI of 15 or greater also decreased with age and became statistically nonsignificant by age 80 and 70 years, respectively.

Similarly, ORs for an AHI of 15 or greater and breathing pauses decreased with age group (Figure 3); at age...
80 years or older, breathing pauses were not significantly associated with an AHI of 15 or greater. There was also a trend showing decreased associations of snoring frequency and loudness with an AHI of 15 or more as age increased.

For women, the proportions of an AHI of 15 or greater in nonsnorers, moderate snorers, and habitual snorers were 3%, 7%, and 20%, respectively, and for men were 19%, 18%, and 33%, respectively. It is clear that the sensitivity and specificity of habitual snoring as a marker for an AHI of 15 or greater is poor for both men and women. However, there is a stronger trend for SDB in women to increase with severity of snoring; this is reflected by the higher ORs for an AHI of 15 or greater with snoring for women compared with men (Figure 4).

**COMMENT**

Using the SHHS baseline data, we found that the demographic pattern of SDB includes a moderately higher risk for men compared with women and a small increase in risk with age. Additional significant predictors of SDB included increased measures of body habitus and self-reported habitual snoring, very loud snoring, and frequent self-reported breathing pauses. We also found that some of the associations of these predictors and SDB varied by the demographic characteristics.

**DEMOGRAPHIC PATTERNS OF SDB PREVALENCE**

The OR of 2.7 for an AHI of 15 or greater and male sex, adjusted for age and race, is smaller than expected based on previous reports of a strong predominance of men in SDB patient populations, but it is in agreement with every published population-based study of SDB in men and women. The high prevalence of occult SDB in both men and women in the general population is widely acknowledged, but our findings, based on a large sample of women ranging in ages from 39 to 98 years, further underscores the need for more attention to diagnosis of SDB in women.

Our finding that there was little increase in AHI in those older than 60 years is not consistent with a large upswing in incidence or significant worsening of SDB with aging in later life. If correct, this finding supports the need for a new perspective on SDB in later life, but several sources of bias must be addressed. Recruitment strategies varied by study site, depending on the parent cohort characteristics and sample size quotas. Selection was not random, and it is possible that selection and participation were slightly greater for younger snorers. Overrepresentation of younger snorers would tend to reduce an age-related increase in prevalence. However, when the sample was stratified on habitual snoring status, the increase in prevalence with age tended to plateau at age 60 years in both strata. Thus, it is unlikely that selective recruitment explains the age trend in our sample. If the participation rate was higher among the healthiest of the older people, but not among the younger people, the prevalence of SDB in older age groups would be underestimated. However, a “healthy volunteer” bias is well documented for younger as well as older participants in population studies.

Bias could arise if error in PSG-determined SDB status varied by age, but we found no evidence that older age was significantly associated with overall study success or the average duration of the 7 PSG signals. Of greater concern, the sample would be biased toward lower SDB prevalence among the older participants if there is significant mortality associated with SDB. Recent stud-
PREDICTORS OF SDB: OBESITY AND SELF-REPORTED SLEEP-RELATED BREATHING EVENTS

Three measures of body habitus were related to SDB, but less strongly than would be expected based on the high prevalence of obesity and morbid obesity in sleep apnea patient populations. Based on our data, the OR for an AHI of 15 or greater with a BMI difference of 10 kg/m² and an AHI of 15 or greater is only 2.4. This lower than expected association indicates that a significant portion of the general population with SDB would be missed if only obese people were targeted for SDB evaluation.

In a model that included all 3 body habitus variables, the effect size for an AHI of 15 of greater was greatest for BMI and was negligible for waist-to-hip ratio. Recent studies have focused on upper body fat distribution as the critical obesity parameter in SDB, but our findings indicate that excess body mass is an important predictor of SDB.

AGE AND SEX AS MODIFIERS OF THE EFFECTS OF OBESITY AND SELF-REPORTED BREATHING DISTURBANCES ON SDB

We found SDB in older people was poorly predicted by higher BMI, neck circumference, waist-to-hip ratio, and self-reported breathing pauses, suggesting that SDB in older people would be missed if case finding or referral were based on body habitus and reported breathing pauses. The reason for the differences in the SDB risk factors by age is not clear.

The decreased importance of body habitus as a predictor of SDB in older people may be due to age differences in how well current measures reflect the past status of weight and other body habitus measures that would be relevant to the onset of SDB. Although little is known about the natural history of SDB, Lugaresi and Plazzi and others have speculated that progression from the onset of SDB pathogenesis to the condition of frequent apnea and hypopnea episodes takes decades. Current measures of body habitus in older people may either underestimate or overestimate their obesity status of decades past. The recent increase in obesity at all ages in the United States implies that the older SHHS participants would have probably been less obese when they were middle-aged compared with the obesity status of participants who are presently middle-aged. If true, using current obesity measures would lead to an attenuation of the cross-sectionally determined OR for SDB with obesity in older, but not younger, participants.

Our findings are also consistent with the hypothesis that SDB in older people is a condition distinct from that in younger people. This hypothesis has been supported by findings that SDB in older people, in contrast to SDB in younger people, is not related to sleepiness and hypertension and that snoring (a strong marker for obstructive SDB) decreases past middle age. In Table 3, our data show the latter, with a 1.8-fold decrease in prevalence of habitual snoring from age between 50 and 60 to 70 years and older. However, the decline in self-reported snoring with age should be interpreted with caution. Older people may be less able to report their snoring status and other sleep-related breathing disturbances accurately because of the loss of a bed partner, hearing problems, or other age-related changes. We found an increase in the “do not know” response for snoring frequency for ages 70 years and older, and it might be suspected that true snorers who would have been able to report their snoring correctly at a younger age become uncertain in old age. However, if this were the case, the OR for the “do not know” category and an AHI of 15 or greater would tend to increase with age, concomitant with the decrease in the association for habitual snoring and an AHI of 15 or greater. This was not the case: as age increased, the OR for the “do not know” vs non-snorer category also decreased.

Table 3. Frequency of Self-reported Habitual Snoring by Age Group

<table>
<thead>
<tr>
<th>Age Group, y</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Habitual Snorer</td>
<td>Do Not Know</td>
</tr>
<tr>
<td>&lt;50</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>50-59</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>60-69</td>
<td>29</td>
<td>33</td>
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<tr>
<td>70-79</td>
<td>18</td>
<td>48</td>
</tr>
<tr>
<td>80-99</td>
<td>8</td>
<td>55</td>
</tr>
</tbody>
</table>

*Data are percentage of patients.
With the emergence of a distinct SDB condition in older age, a decrease in the prevalence of SDB typical of middle age might be expected. Such a decrease in older age could result from selectively greater mortality among those with the obesity-related SDB characteristics of middle age. Central sleep apnea (a condition of nonobstructive breathing pauses caused by lack of breathing effort) could account for a distinct, older-age onset of SDB. However, we found no evidence in our data that central sleep apnea was associated with age. The proportion of people with any central apnea events defined as a 10-second or longer period of no airflow and no respiratory effort was very low (91% had less than 1 central apnea event per hour), and did not increase with age. Furthermore, central sleep apnea did not explain our finding indicating that the associations of obesity and reported breathing pauses diminished with age. When people with any central apnea events were eliminated from analysis or when a term for the average number of central apnea events per hour of sleep was added to the relevant logistic regression models, the age interactions with body habitus and breathing pauses were not affected. In contrast, Bixler et al reported that the prevalence of central sleep apnea in men was higher for ages ranging from 65 to 100 years compared with 20 to 64 years. Further investigation of the nature of SDB in older age is clearly warranted because identification of a distinctly different older-age onset of SDB would be highly relevant to management of SDB in older people.

The SHHS data have limitations that could potentially affect the validity of our findings. Error in measuring SDB may compromise the accuracy of the association estimates. The validity of PSG data, particularly single-night PSG, as a measure of usual SDB has been questioned. Error may result from technical limitations of the unattended PSG technology, interference of the recording procedure on sleep quality, and intrasubject nightly variation. The potential for error from these sources has been considered at the design, implementation, and analysis stages of the SHHS, and steps were taken to minimize error and to assess its magnitude.17,30 The technical quality of the PSG recording and scoring was regularly monitored, and only studies of good quality or better were included in analyses.10 Over 50% of the participants reported that their sleep during the PSG was as good or better compared with their usual sleep, indicating that most studies were not based on a highly irregular night’s sleep. A study of night-to-night variation showed that the AHI recorded by the SHHS methodology was relatively stable; there was no evidence to support a strong “first night effect.”32

We defined SDB by a dichotomous variable based on an AHI cut point of 15, approximately the beginning of the upper quartile for AHI in this sample. Although this is a commonly used cut point indicating SDB of physiological or clinical notability, its validity has not been established. However, this cut point was recommended by an international task force on standardization of definitions for sleep-related breathing disorders to indicate moderate SDB.33

Error in measuring SDB or any of the other study factors is of concern in estimating accurate ORs. Random error in measuring SDB could attenuate the strength of associations, but error with respect to SDB severity that differs by the covariates of interest may introduce bias in the estimates. Of greatest concern is that we have underestimated the association of AHI and age. It is possible that difficulty sleeping with the monitor is related to age or that intrasubject variability increases with age, resulting in less accurate AHI measurement for older people. Therefore, our findings indicating that AHI does not increase appreciably with age must still be interpreted with caution.

The sex difference in ORs for SDB and snoring indicates less of a dose-response association for snoring frequency and SDB in men compared with women. This finding suggests that compared with women, men may tend to overreport their snoring. Little is known about sex differences in the validity of self-reported snoring. It is possible that participation bias could account for this finding, but for such a bias to occur, self-selection of snorers into the SHHS would have to differ by sex.

In summary, the results of this study shed new light on the demographic patterns of SDB. In view of the lack of associations, but error with respect to SDB severity that differs by the covariates of interest may introduce bias in the estimates. Of greatest concern is that we have underestimated the association of AHI and age. It is possible that difficulty sleeping with the monitor is related to age or that intrasubject variability increases with age, resulting in less accurate AHI measurement for older people. Therefore, our findings indicating that AHI does not increase appreciably with age must still be interpreted with caution.

The sex difference in ORs for SDB and snoring indicates less of a dose-response association for snoring frequency and SDB in men compared with women. This finding suggests that compared with women, men may tend to overreport their snoring. Little is known about sex differences in the validity of self-reported snoring. It is possible that participation bias could account for this finding, but for such a bias to occur, self-selection of snorers into the SHHS would have to differ by sex.

In summary, the results of this study shed new light on the demographic patterns of SDB. In view of the lack
of a marked increase of SDB prevalence in older age, the role of late-life aging in SDB needs investigation. Our findings also indicate that case finding should not be restricted to men, middle-aged, or obese persons, and it does not appear that targeting any particular ethnic group is warranted. Although we found a strong association of self-reported snoring and breathing pauses with SDB, sensitivity and specificity of these symptoms for identification of SDB were low. Of particular importance, snoring and obesity may be inappropriate for identifying SDB in older people. These finding could have important implications for targeted case finding and point to the need for further research on SDB in older people.

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