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Heightened sleep propensity: a novel and high-risk sleep health phenotype in older adults

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ABSTRACT

Objectives: To reveal sleep health phenotypes in older adults and examine their associations with time to 5-year all-cause and cardiovascular mortality.
Design: Prospective longitudinal cohorts.
Setting: The Study of Osteoporotic Fractures and Outcomes of Sleep Disorders in Older Men Study.
Participants: N = 1722 men and women aged ≥65 years matched 1:1 on sociodemographic and clinical measures.
Measurements: Self-reported habitual sleep health characteristics (satisfaction, daytime sleepiness, timing, efficiency, and duration) measured at an initial visit and longitudinal follow-up for mortality.
Results: Latent class analysis revealed 3 sleep health phenotypes: (1) heightened sleep propensity (HSP; medium to long duration, high sleepiness, high efficiency/satisfaction; n = 322), (2) average sleep (AS; medium duration, average efficiency, high satisfaction, low sleepiness; n = 1,109), and (3) insomnia with short sleep (ISS; short to medium duration, low efficiency/satisfaction, moderate sleepiness; n = 291). Phenotype predicted time to all-cause mortality ($\chi^2 = 9.4$, $P = .01$), with HSP conferring greater risk than AS (hazard ratio [95% confidence interval] = 1.48 [1.15-1.92]) or ISS (1.52 [1.07-2.17]), despite ISS reporting the poorest mental and physical health. Although sex did not formally moderate the relationship between phenotype and mortality, subgroup analyses indicated that these findings were driven primarily by women. Phenotype did not predict cardiovascular mortality.
Conclusions: These analyses support the utility of examining multidimensional sleep health profiles by suggesting that the combination of long sleep, high efficiency/satisfaction, and daytime sleepiness—previously identified as independent risk factors—may be components of a single high-risk sleep phenotype, HSP. Further investigation of sex differences and the mechanisms underlying mortality risk associated with HSP is warranted.

Introduction

Sleep health is a "multidimensional pattern of sleep/wakefulness"[1] with domains including satisfaction, sleepiness/alertness, timing, efficiency, and duration. Individual sleep characteristics representing each domain are predictive of health outcomes, regardless of the presence or absence of a sleep disorder.[1] However, these

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characteristics do not occur separately from one another, as they are often studied, but simultaneously in the context of one another. This leads us to question whether there are common combinations of sleep health characteristics (ie, phenotypes) that can be observed in older adults and whether they predict mortality. Prior studies indicate that older adults' sleep experiences are heterogeneous and that phenotypes can be identified.[2–5] However, as this research focused on people with insomnia and/or sleep difficulties, sleep health phenotypes in community-dwelling older adults remain to be defined.

Focusing on sleep health phenotypes presents several benefits. First, defining common phenotypes could clarify our understanding of sleep challenges faced by older adults and motivate the development of novel sleep treatments. Second, phenotypes may prove to be stronger and more meaningful predictors than individual characteristics. This is because individual sleep characteristics (eg, long sleep duration) likely reflect heterogeneous traits that are not as informative without consideration of additional sleep characteristics (eg, quality and sleepiness). Third, linking phenotypes to health outcomes could suggest hypotheses for disease pathways, leading to novel treatments that improve health.

We applied latent class analysis (LCA)[6] to reveal sleep health phenotypes in older adults, focusing on habitual self-reported sleep because of the potential for scalability, availability of measures, and growing recognition of the importance of patient-centered outcomes. The sample was aggregated from the Study of Osteoporotic Fractures (SOF)[7,8] and the Outcomes of Sleep Disorders in Older Men Study (MrOS Sleep).[9,10] Propensity score matching was used to develop a sample of men and women with similar sociodemographic and clinical characteristics, thereby reducing unwanted confounding. The 5 selected habitual sleep health measures were directly motivated by the SATED sleep health scale,[1] which measures overall sleep health based Satisfaction, Alertness/Sleepiness, Timing, Efficiency, and Duration.

After revealing sleep health phenotypes, we examined whether they predicted time to 5-year mortality. We also compared the utility of sleep health phenotypes to that of other commonly used multidimensional sleep health approaches. Secondarily, based on prior research on sex differences in sleep and health outcomes,[2,11,12] we examined sleep health phenotypes in matched men and women separately to determine whether sleep health phenotypes or their associations with mortality differed by sex. Finally, we established generalizability by examining sleep health phenotypes and associations with mortality within each of the original parent cohorts.

Participants and methods

Sample

Our study includes data from the SOF and MrOS Sleep studies. The SOF study was designed to determine risk factors for osteoporotic fractures in community-dwelling older women.[7,8] The MrOS Sleep study was a sleep-focused study within the larger Osteoporotic Fractures in Men (MrOS) Study,[13,14] originally designed to assess risk factors for osteoporotic fractures in community-dwelling older men (http://mrosdata.sfcc-cpmc.net). Participants in both studies provided written informed consent to participate in longitudinal studies of sleep health. The SOF and MrOS studies had similarities that facilitated data harmonization, including overlapping scientific teams, study procedures, and measures. However, SOF women were generally older than MrOS men at the time of the sleep study because the SOF sleep questionnaires[15,16] were administered after 16 years of follow-up in SOF but only 3 years in the more recent MrOS. SOF women were also more likely to be African American than MrOS men because of the addition of an African American ancillary study. In contrast, MrOS recruited more individuals who identified as races other than White or Black.

Because of these study design differences, MrOS men and SOF women could not be directly combined without concern regarding unbalanced confounders. Therefore, we used propensity score matching to develop a sample of men and women with similar sociodemographic and clinical characteristics (Table 1). This matched sample allows for a direct comparison of sleep health phenotypes between men and women without confounding from these observed measures.

To develop the matched sample, we first identified a sample of 6162 Black and White participants from MrOS (N = 2907) and SOF (N = 3255) with complete self-reported sleep health and matching characteristics and longitudinal follow-up. Only Black or White participants were included to enhance similarities, excluding n = 206 of the available sample (195 men; 11 women). Propensity score matching was performed in this sample using nearest neighbor matching with a caliper of 0.20,[17] implemented with the matchit package in R version 3.5.1.[18,19] Supplemental Figure S1 illustrates the sample derivation.

The final propensity-matched sample included 1722 men and women (50% female) aged 67-96 (median age 82) years, further described in Table 1. Matching was successful, as standardized differences (Cohen *d* [continuous] or *h* [categorical]) between men and women on matching characteristics differed by no more than a magnitude of $d = 0.12$ or $h = 0.11$.[17] Supplemental Figure S2 provides additional details on differences between men and women before vs after matching. As expected, participants who were included vs excluded in the matched sample differed on most matching characteristics (Supplemental Table S1); thus, the men and women in the matched sample are not directly generalizable to their respective parent cohorts.

Measures

Sleep health characteristics for LCA

We selected self-reported habitual sleep characteristics and a priori cut points that mapped onto the SATED scale.[1]

1. Satisfaction was represented by the sleep quality item ("Rate your usual sleep quality the past month") from the Pittsburgh Sleep Quality Index (PSQI).[13] This single item—as opposed to the full PSQI score—was used because the full PSQI score includes information about sleep dimensions in addition to satisfaction. The PSQI sleep quality item is rated as 0 ("very good"), 1 ("fairly good"), 2 ("fairly bad"), or 3 ("very bad"). *Low Satisfaction* was defined as a rating ≥ 2.
2. Alertness/Sleepiness was represented by the Epworth Sleepiness Scale. The scale asks about one's likelihood of dozing off in various daytime situations and ranges from 0 to 24, with higher values reflecting more sleepiness. *High Sleepiness* was defined as a score > 10.[17]
3. Timing was represented by usual sleep midpoint in the past month, computed as the midpoint of the time an individual reported they usually went to bed at night and woke up in the morning. The SATED scale suggests that a midpoint between 2:00 and 4:00 AM is typically considered good sleep health, and these cut points were backed by our own empirical distribution and prior research.[20] Because both early and late midpoints may confer risk, we developed 3 categories: "Early Midpoint" (<2:00 AM), "Middle Midpoint" (2:00-4:00 AM), and "Late Midpoint" (>4:00 AM).
4. Efficiency was represented by usual sleep efficiency in the past month (SE; total sleep time [TST]/time in bed × 100). Time in bed was computed as the time between when a person reported

Table 1
Cross-sectional measures

	Full sample (N = 1722)	Women (n = 861)	Men (n = 861)	Effect size (95% CI)[a]
Sociodemographic characteristics, mean (SD) or % (n)				
Age	81.7 (4.4)	82.0 (3.1)	81.44 (5.3)	0.12 (0.02-0.21)
Black (vs White) race	7.4 (128)	7.9 (68)	7.0 (60)	0.04 (−0.06 to 0.13)
≥ College education[b]	35.6 (613)	35.4 (305)	35.8 (308)	−0.01 (−0.1 to 0.09)
HS or some college education	55.8 (960)	55.1 (474)	56.5 (486)	−0.03 (−0.13 to 0.07)
< HS education	8.7 (149)	9.5 (82)	7.8 (67)	0.06 (−0.03 to 0.16)
Married[c]	63.7 (1097)	61.1 (526)	66.3 (571)	−0.11 (−0.2 to −0.01)
Widowed	25.6 (435)	27.4 (236)	23.1 (199)	0.10 (0.01-0.19)
Other marital status	11.0 (190)	11.5 (99)	10.6 (91)	0.03 (−0.07 to 0.12)
Health behaviors, % (n)				
Past or present smoker	47.8 (823)	45.8 (394)	49.8 (429)	−0.08 (−0.18 to 0.01)
Any alcohol use	54.9 (945)	54.9 (473)	54.8 (472)	0.00 (−0.09 to 0.09)
Mental and physical health, mean (SD)				
Anxiety (GADS)	1.2 (2.1)	1.2 (2.0)	1.1 (2.1)	0.03 (−0.06 to 0.13)
Depression (GDS-15)	2.1 (2.3)	2.1 (2.5)	2.1 (2.2)	−0.01 (−0.1 to 0.09)
Cognition (26-item mMMSE)	24.0 (2.31)	24.0 (2.5)	23.9 (2.2)	0.03 (−0.06 to 0.13)
Self-rated health (1 = excellent; 5 = very poor)	1.9 (0.7)	1.9 (0.7)	1.9 (0.7)	0.03 (−0.06 to 0.13)
No. of functional limitations (range 0-5)	0.7 (1.2)	0.8 (1.2)	0.7 (1.1)	0.07 (−0.03 to 0.16)
No. of chronic conditions[d]	1.7 (1.4)	1.8 (1.3)	1.7 (1.4)	0.04 (−0.05 to 0.14)
No. of prescription medications	4.3 (3.1)	4.3 (2.9)	4.2 (3.2)	0.04 (−0.05 to 0.13)

GDS-15, 15-item Geriatric Depression Scale; HS, high school; mMMSE, modified Mini Mental State Examination.
[a] Cohen *h* (for categorical) or Cohen *d* (for continuous).
[b] Education level omnibus test: 1. 7 (0.43).
[c] Marital status omnibus test 5.3 (0.07).
[d] Stroke, angina, heart failure, heart attack, high blood pressure, diabetes, chronic obstructive pulmonary disease, osteoporosis, arthritis.

they usually went to bed and woke up in the past month. TST was the reported hours of usual nighttime sleep in the past month. *Low SE* was defined as SE <85% based on a summary of quantitative criteria for insomnia.[21]

5. Duration was represented by usual TST. The SATED scale indicates that 6-8 hours may be considered good sleep health, and these cut points were backed by our empirical distribution. Although some guidelines recommend 7-9 hours,[22] the National Sleep Foundation indicates that shorter duration is appropriate in older adults.[23] Therefore, we developed 3 categories: "Short TST" (<6 hours), "Medium TST" (6-8 hours), and "Long TST" (>8 hours).

Cross-sectional characteristics

Our strategy for selecting variables for the propensity score model was to use the literature and a priori hypotheses to identify a relatively limited set of characteristics with the clearest associations with mortality or parent cohort. We used this same set of measures for sample characterization and as covariates in our primary regression models. Sociodemographic characteristics were age, sex, education, race, and marital status. Health behaviors were smoking and drinking statuses. Mental health measures were depression symptoms (15-item Geriatric Depression Scale[24]), anxiety symptoms (Goldberg Anxiety and Depression Scale [GADS]; Goldberg et al, 1987[25]), and cognition (26-item modified Mini Mental State Examination[26,27]). Physical health measures were self-reported health status (1 = excellent, 2 = good, 3 = fair, 4 = poor, 5 = very poor) and the numbers of instrumental activities of daily living that could not be performed (range 0-5), prescription medications, and self-reported chronic conditions (considering stroke, heart attack, angina, heart failure, high blood pressure, diabetes, chronic obstructive pulmonary disease, osteoporosis, and arthritis [rheumatoid or osteoarthritis]).

We also considered a set of secondary cross-sectional characteristics that we expected may be relevant for interpreting the sleep health phenotypes and/or predictive of mortality. These were the number of potentially adverse sleep health characteristics (considering poor quality, high sleepiness, low efficiency, early or late midpoint, and short or long timing), self-reported symptoms of sleep disorders (difficulty falling asleep, difficulty staying asleep, frequent snoring, ever stopping breathing during sleep), use of sleep medications, and body mass index (BMI; because of its associations with sleep disordered breathing). These measures were used for sample characterization and as additional covariates in exploratory regression analyses.

Longitudinal outcome

We selected time to all-cause mortality as our primary outcome because of its unequivocal importance and ease of harmonization across studies. In SOF and MrOS, all-cause mortality was adjudicated using either death certificates only or death certificates plus additional medical records when available. As a secondary outcome, we examined time to cardiovascular mortality, which was determined by a physician adjudicator and based on the underlying cause of death (ie, the disease or injury that initiated the train of morbid events leading directly to death).

Because MrOS and SOF had different lengths of follow-up after the sleep measurement, we conservatively focused on 5-year mortality. Five-year all-cause mortality was observed for 19.5% of the sample (189 men, 147 women). Five-year cardiovascular mortality was observed for 6% of the sample (60 men, 43 women).

Data analysis

Latent class analysis

LCA assumes the existence of an unobserved nominal variable (ie, sleep health phenotype) with a fixed number of latent classes, whose distribution is a mixture of observed nominal variables (ie, 5 selected sleep health characteristics). Using LCA model estimates, an individual is assigned to the latent class for which they have the highest probability of belonging. Using the poLCA function and package[28] in R, we fit LCA models with 1 through 6 classes. To select the model (ie, number of classes) that is most representative of the data, we compared relative goodness-of-fit statistics (Akaike Information Criteria [AIC] and Bayesian Information Criteria [BIC]) and also used the Bootstrap Likelihood Ratio Test (BLRT)[29] to determine whether each additional class improved model fit. The final model was

Table 2
Sleep health characteristics

% (n) or mean (SD)	Full sample (N = 1722)	Women (n = 861)	Men (n = 861)	Effect size[a]
Poor quality	14.8 (254)	12.2 (104)	17.4 (150)	−0.15 (−0.25 to −0.06)
High daytime sleepiness	11.4 (196)	8.9 (77)	13.8 (119)	−0.15 (−0.25 to −0.06)
Early midpoint (<2:00 AM)[b]	13.1 (226)	10.0 (86)	16.3 (140)	−0.19 (−0.29 to −0.10)
Middle midpoint (2:00-4:00 AM)	76.8 (1323)	80.4 (692)	73.3 (631)	0.17 (0.07-0.26)
Late midpoint (>4:00 AM)	10.1 (173)	9.6 (83)	10.5 (90)	−0.03 (−0.13 to 0.06)
Low SE (<85%)	46.2 (795)	50.1 (431)	42.3 (364)	0.16 (0.07-0.25)
Short TST (<6 h)[c]	11.8 (203)	12.7 (109)	10.9 (94)	0.05 (−0.04 to 0.15)
Medium TST (6-8 h)	79.4 (1367)	80.3 (691)	78.5 (676)	0.04 (−0.05 to 0.14)
Long TST (>8 h)	8.8 (152)	7.1 (61)	10.6 (91)	−0.12 (−0.22 to −0.03)
No. of potentially adverse sleep characteristics[d]	1.2 (1.1)	1.1 (1.0)	1.2 (1.1)	−0.11 (−0.20 to −0.01)

[a] Cohen *h* (for categorical) or Cohen's *d* (for continuous).
[b] Omnibus test for difference in midpoint: $\chi^2 = 16.0$, $df = 2$, $P < .001$.
[c] Omnibus test for difference in TST: $\chi^2 = 7.2$, $df = 2$, $P = .03$.
[d] Count of the following potentially adverse sleep characteristics: Poor Quality, High Daytime Sleepiness, Early or Late Midpoint, Low Efficiency, and Short or Long TST.

selected to be the most parsimonious model indicated by the BLRT, supplemented by the AIC and BIC.

After selecting a final model, we used the Jaccard coefficient (JC),[30] implemented using the clusterboot function (fpc package) in R,[31] to evaluate the stability of each class through bootstrapping. JC ranges from 0 to 1. A JC ≤ 0.60 indicates that the class may not be present in the sample. A JC > 0.60 indicates that the class is present in the sample, with values closer to 0.60 indicating some uncertainty of who belongs in the class and values closer to 1 indicating high certainty.[31] We also computed the entropy of the final LCA model[32] to summarize the overall degree of separation. Entropy ranges from 0 (low separation) to 1 (high separation).

Cross-sectional and survival associations

We characterized the latent classes on cross-sectional characteristics and used Cohen *d* or *h* effect sizes to evaluate differences between classes (considering *d* or $h > |0.20|$ as clinically meaningful).[33] In primary analyses, we fit Cox proportional hazards (PH) models adjusted for matching/primary characteristics to test whether class predicted time to all-cause or cardiovascular mortality. We then fit 2 additional adjusted Cox PH models for all-cause mortality: one including all 5

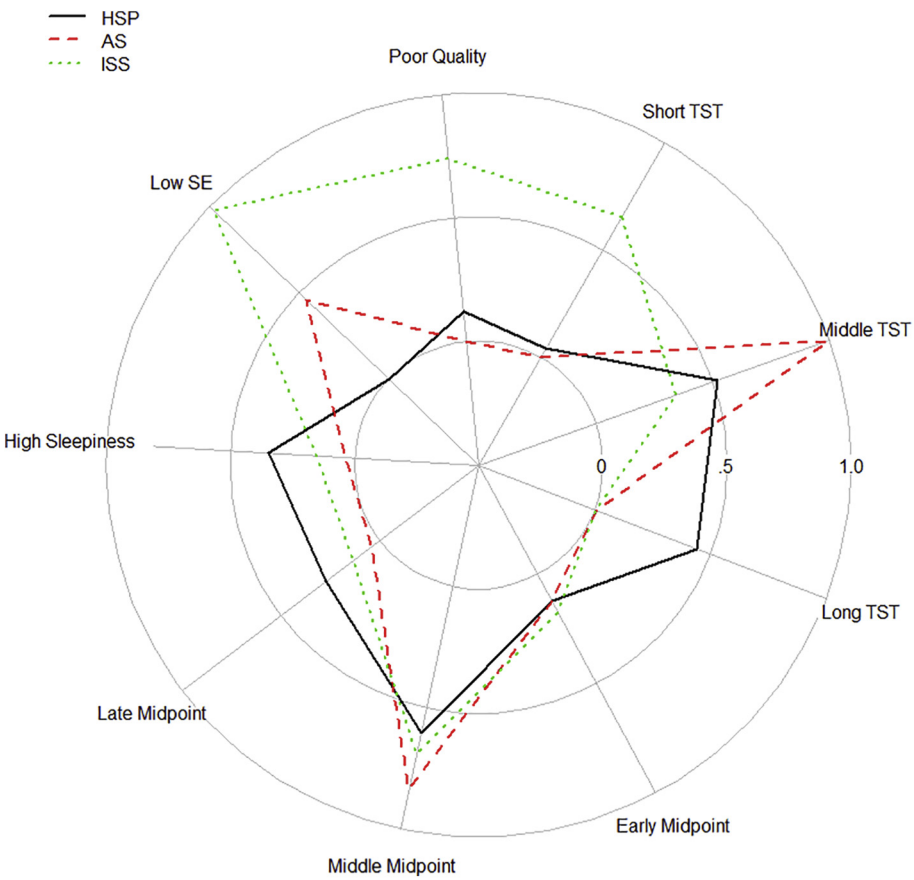

Fig. 1. Probabilities of each sleep health characteristic by latent class membership derived in the full, matched sample (N = 1722). HSP: n = 322 (18.7%), AS: n = 1109 (64.4%), ISS, n = 291 (16.9%).

individual sleep health characteristics (using likelihood ratio tests to determine whether their simultaneous inclusion in the model improved fit) and one including the number of potentially adverse sleep characteristics as a predictor. *P* values were adjusted for multiple comparisons within sets of Cox PH analyses using BH-FDR correction ($\alpha = .05$).[34]

In exploratory analyses, we examined the strength of associations between sleep health phenotype and all-cause mortality after (1) also adjusting for symptoms of sleep disorders, use of medications with known effects on sleep, and BMI and (2) omitting individuals who died in the first 12 months (to decrease the potential effects of preterminal disease).

Sex differences

To determine whether the sleep health characterizations of the classes differed by sex, we used a multinomial or logistic model to regress each of the 5 categorical sleep health characteristics on class, sex, and their interaction. To determine whether associations between sleep health class and mortality differed by sex, we tested a class-by-sex interaction in the adjusted Cox PH models.

Secondarily, we performed sex-stratified analyses among the matched men (n = 861) and women (n = 861) as well as in the MrOS (N = 2907) and SOF (N = 3255) parent cohorts to establish generalizability. This included fitting new LCA models and examining associations between sleep health measures and time to all-cause mortality. Benjamini-Hochberg false discovery rate (BH-FDR) corrections were performed within each sex-stratified sample.

Results

Sleep health characteristics

Table 2 describes the sleep health characteristics of the matched sample. All sex differences were small (*d* or $h < |0.20|$). However, men were more likely to report poor sleep quality, high daytime sleepiness, early midpoint, high sleep efficiency, and long TST. Men also reported more potentially adverse sleep characteristics.

Supplemental Table S2 describes the matched sample based on BMI, sleep medications, and symptoms of sleep disorders. Men (vs women) were more likely to report frequent snoring (13% vs 6%; $h = 0.27$), ever stopping breathing during sleep (11% vs 2%; $h = 0.43$), and more difficulty staying asleep on a scale from 0 ("never") to 3 ("≥3×/week") (mean [SD] = 2.2 [1.1] vs 1.8 [1.3], $d = 0.40$).

LCA results

Matched sample LCA

BLRTs indicated that a 3-class model was the best fit ($P < .001$ for 2 classes vs 1 class; $P < .001$ for 3 vs 2; $P = .21$ for 4 vs 3), as did BIC and AIC indices (Supplemental Table S3). The JCs for classes 1, 2, and 3 were 0.61, 0.86, and 0.96, respectively. These JC values indicate that the clustering is robust overall and that all 3 classes are present in the sample. Class 1 had more uncertainty surrounding exactly which points belong to it, whereas classes 2 and 3 had high certainty. Entropy was 0.59, indicating moderate class separation.

Figure 1 displays the sleep health characteristics by class (also see numeric details in Supplemental Table S4). Class 1 included 322

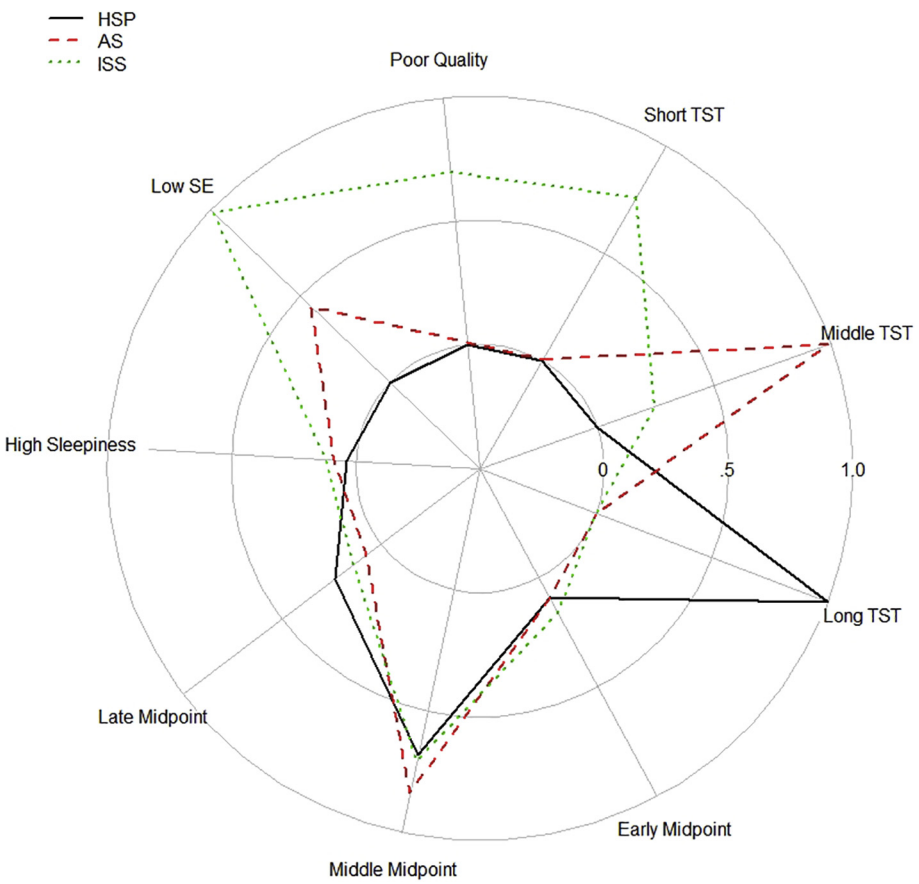

Fig. 2. Probabilities of each sleep health characteristic by latent class membership derived in matched women (n = 861). HSP: n = 56 (6.5%), AS: n = 666 (77.4%), ISS: n = 139 (16.1%).

individuals (18.7% of the sample). Based on their higher probabilities of long sleep time, high sleep efficiency, and high sleepiness, we labeled class 1 as "heightened sleep propensity" (HSP). Class 2 included 1109 individuals (64.4% of the sample). Based on their higher probabilities of normal sleep duration and timing, low sleepiness, average efficiency, and good quality, we labeled class 2 as "average sleep" (AS). Class 3 included 291 individuals (16.9% of the sample). Based on their higher probabilities of short duration, low efficiency, and poor sleep quality, we labeled class 3 as "insomnia with short sleep" (ISS). None of the 5 sleep health characteristics exhibited sex-by-class interactions; thus, the men and women within each class reported similar sleep health characteristics.

Sex-stratified LCAs

LCAs applied to matched men and women separately also indicated 3 classes each. Female-only (Fig. 2) and male-only (Fig. 3) classes had similar interpretations to the full matched sample classes; thus, we retained the HSP, AS, and ISS labels. However, a key difference was that the female-only HSP class had good efficiency/quality and long TST *without* daytime sleepiness, whereas the male-only HSP class had good efficiency/quality and long TST *with* daytime sleepiness (like the matched sample HSP class). Only 75 women (8.7%) and 27 men (3.1%) were not assigned to the same class in the matched vs sex-stratified LCAs, indicating stability between clustering solutions.

These sex-stratified findings from matched men and women were largely generalizable to their respective MrOS and SOF parent cohorts. LCAs fit to each parent cohort also revealed HSP, AS, and ISS classes (Supplemental Figs. S3 and S4). Of note, the MrOS and SOF HSP classes were characterized by higher probabilities of good efficiency/quality and long TST *without* daytime sleepiness.

Cross-sectional class comparisons

Table 3 and Supplemental Table S5 describe the classes on cross-sectional measures. ISS reported the poorest mental health, with greater anxiety and depressive symptoms compared to HSP or AS. ISS reported more prescription medications and worse self-rated health than AS, and more chronic conditions than either HSP or AS. ISS was most likely to report taking sleep-related medications and reported the greatest difficulties falling asleep and staying asleep. HSP had higher measured BMI than AS. Both HSP and ISS were more likely to report ever stopping breathing during sleep compared to AS.

Sleep health and mortality

Matched sample

Sleep health class predicted time to all-cause mortality ($\chi^2 = 9.4$, $P = .01$), with HSP conferring an increased risk of mortality relative to AS and ISS (hazard ratio [95% confidence interval {CI}] = 1.48 [1.15-1.92] for HSP vs AS; 1.52 [1.07-2.17] for HSP vs ISS; 0.97 [0.71-1.33] for ISS vs AS). Class did not predict time to cardiovascular mortality ($\chi^2 = 1.2$; $df = 2$, $P = .54$). Sex did not moderate the effect of class on time to all-cause ($\chi^2 = 0.9$, $P = .64$) or cardiovascular ($\chi^2 = 1.8$, $P = .42$) mortality.

Neither the number of potentially adverse sleep characteristics nor the 5 sleep health characteristics considered simultaneously predicted time to all-cause or cardiovascular mortality (Table 4; Supplemental Table S6). Long TST (vs medium) had the largest effect size for

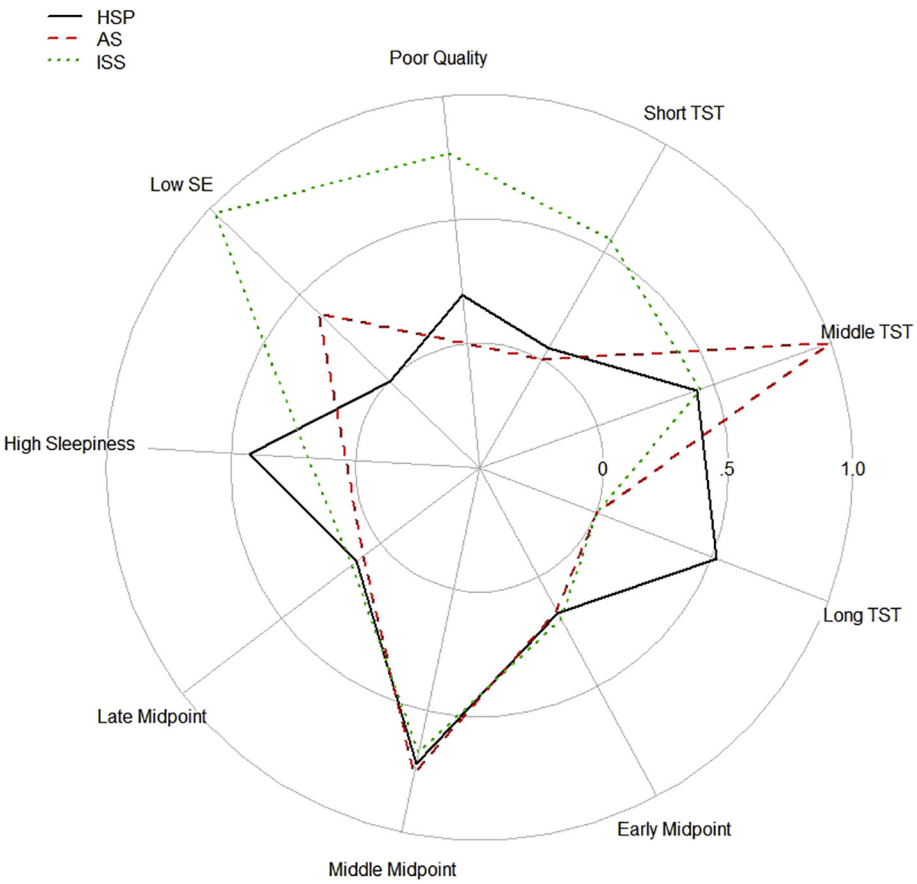

Fig. 3. Probabilities of each sleep health characteristic by latent class membership derived in matched men (n = 861). HSP: n = 166 (19.3%), AS: n = 541 (62.8%), ISS: n = 154 (17.9%).

all-cause mortality risk (1.44 [1.03-2.02]), although this effect was not significant after multiple comparison adjustment.

In exploratory analyses, the associations between sleep health class and all-cause mortality were consistent after also adjusting for BMI category, self-reported symptoms of sleep disorders, and sleep-related medication use (1.48 [1.15-1.92] for HSP vs AS; 1.52 [1.07-2.17] for HSP vs ISS; 0.97 [0.71-1.33] for ISS vs AS). Associations were also consistent after omitting n = 37 individuals (8 HSP, 19 AS, 10 ISS) who died in the first year (1.71 [1.17-2.51] for HSP vs ISS; 1.50 [1.15-1.97] for HSP vs AS; 0.88 [0.62-1.24] for ISS vs AS).

Sex-stratified samples

In stratified analyses, sleep health class membership derived in the full matched sample did not predict time to all-cause mortality in matched women ($\chi^2 = 4.9$, $P = .09$) or men ($\chi^2 = 3.7$, $P = .16$). Class memberships derived in women-only samples predicted time to all-cause mortality ($\chi^2 = 6.5$, $P = .04$ in matched women; $\chi^2 = 7.8$, $P = .02$ in SOF). However, class memberships derived in male-only samples did not predict time to all-cause mortality ($\chi^2 = 1.9$, $P = .39$ for matched men; $\chi^2 = 0.6$, $P = .75$ in MrOS). Overall, the HSP class consistently conferred the most risk for mortality across sex-stratified analyses; however, there were notably larger effect sizes among women vs men and within the sex-stratified matched samples vs their respective parent cohorts (Table 5; Supplemental Table S7).

The number of potentially adverse sleep characteristics did not predict all-cause mortality in any of the sex-stratified samples. The 5 sleep health characteristics considered simultaneously predicted time to all-cause mortality within MrOS only ($\chi^2 = 15.1$, $P = .04$). In an investigation of individual sleep health characteristics, long TST (vs medium) increased all-cause mortality risk in the full matched sample (1.44 [1.03-2.02]), among matched women (1.82 [1.08-3.08]), and in SOF (1.39 [1.09-1.76]). However, the effect survived multiple comparison adjustment only within SOF. Late midpoint (vs middle) increased all-cause mortality risk among matched men (2.00 [1.32-3.05]) and in MrOS (1.59 [1.15-2.21]) (Table 5; Supplemental Table S7).

Table 3
Cross-sectional characteristics by latent class membership

	1. HSP (n = 322)	2. AS (n = 1109)	3. ISS (n = 291)	|ES| > 0.20[a]
Demographics, mean (SD) or % (n)				
Age	81.9 (4.1)	81.8(4.36)	81.2 (4.58)	
Female	40.7 (131)	53.3(591)	47.8 (139)	2 > 1
Black	6.8 (22)	7.2 (80)	8.9 (26)	
≥ College education[b]	40.4 (130)	36.2 (401)	28.2(82)	1 > 3
HS or some college	52.2 (168)	55.2 (612)	61.9 (180)	
< HS education	7.5 (24)	8.7 (96)	10.0 (29)	
Married[c]	63.0 (203)	64.1 (711)	62.9 (183)	
Widowed	21.1 (68)	26.2 (291)	26.1 (76)	
Other marital status	15.8 (51)	9.7 (107)	11.0 (32)	
Health Behaviors, % (n)				
Past or present smoker	50.6 (163)	46.9 (520)	48.1 (140)	
Any alcohol use	51.9 (167)	55.6 (616)	55.7 (162)	
Mental and physical health, mean (SD)				
Anxiety (GADS)	0.9 (1.7)	0.9 (1.8)	2.5 (2.9)	3 > 1, 2
Depression (GDS-15)	2.3 (2.236)	1.9 (2.2)	3.0 (2.7)	3 > 1, 2
Cognition (26-item mMMSE)	23.8 (2.7)	24.0 (2.2)	23.9 (2.2)	
Self-rated health (1 = excellent; 5 = very poor)	2.0 (0.8)	1.9 (0.7)	2.0 (0.7)	3 > 2
No. of functional limitations (range 0-5)	0.8 (1.2)	0.6 (1.1)	1.0 (1.4)	[1,3] > 2
No. of chronic conditions[d]	1.8 (1.5)	1.6 (1.2)	2.1 (1.6)	3 > 1, 2
No. of prescription medications	4.4 (3.1)	4.0 (2.9)	5.1 (3.6)	3 > 2

[a] Cohen *d* for continuous measures; Cohen's *h* for categorical measures.
[b] Omnibus test for education: $\chi^2 = 6.7$, $P = .16$.
[c] Omnibus test for marital status: $\chi^2 = 11.4$, $P = .02$.
[d] Stroke, angina, heart failure, heart attack, high blood pressure, diabetes, chronic obstructive pulmonary disease, osteoporosis, arthritis.

Discussion

In a propensity-matched sample of 1722 community-dwelling older men and women aged ≥65, we used LCA to identify 3 distinct sleep health phenotypes: AS, HSP, and ISS. Phenotype was associated with all-cause mortality, with HSP conferring the greatest risk. Neither the number of potentially adverse sleep health characteristics nor the set of individual sleep characteristics considered simultaneously predicted mortality in this sample, thus highlighting the utility LCA as a key approach in the study of multidimensional sleep health.

Older adults in the matched sample with the HSP phenotype were likely to report long sleep duration and higher daytime sleepiness, with good sleep efficiency and quality. Although this phenotype had the highest risk for mortality, it was characterized by better physical and mental health than the ISS phenotype. Given the higher average BMI of the HSP phenotype, HSP individuals may have suboptimal health behaviors (eg, less exercise, poorer diet) and/or sleep-disordered breathing; these factors are important for mortality but unmeasured in this study.

Our findings linking HSP to mortality are consistent with prior findings indicating that the effects of long duration on mortality are not attenuated by health conditions.[35] The association between long sleep duration and mortality is sometimes cited as a rationale for sleep restriction especially among older adults.[36] However, the underlying mechanisms are not clear. Inflammation is one potential mechanism, although prior research has suggested that inflammation mediates only the association between short sleep and mortality.[37] Other plausible mechanisms include intrinsic changes in sleep-wake control mechanisms that reflect accelerated biological aging[38] or neurological diseases such as Parkinson.[39]

Although older adults with the ISS phenotype generally reported worse mental and physical health, they did not have a greater risk of all-cause mortality relative to either HSP or AS. Whether

Table 4
Cox model results for time to all-cause mortality in full matched sample (N = 1722)

	z (adjusted *P*[a])	Hazard ratio (95% CI[b])
Model 1: latent class (omnibus $\chi^2 = 9.4$; $df = 2$, $P = .01$)		
HSP vs AS	3.0 (.03)	1.48 (1.15-1.92)
HSP vs ISS	2.3 (.10)	1.52 (1.07-2.17)
ISS vs AS	−0.2 (.87)	0.97 (0.71-1.33)
Model 2: no. of potentially adverse sleep characteristics		
No. of potentially adverse sleep characteristics	1.1 (0.54)	1.06 (0.95-1.17)
Model 3: all sleep health characteristics considered simultaneously (omnibus $\chi^2 = 11.5$, $df = 7$, $P = .12$)		
Poor quality	−0.4 (0.81)	0.93 (0.66-1.31)
High sleepiness	1.8 (0.19)	1.33 (0.98-1.82)
Early vs middle midpoint[c]	−0.2 (0.81)	0.97 (0.70-1.35)
Late vs middle midpoint	1.7 (0.19)	1.34 (0.96-1.87)
Low SE (<85%)	0.6 (0.81)	1.07 (0.84-1.38)
Short vs medium TST[c]	−0.5 (0.81)	0.90 (0.61-1.35)
Long vs medium TST	2.1 (0.13)	1.44 (1.03-2.02)

[a] BH-FDR correction across Table 4 (α = .05).
[b] Not adjusted for multiple comparisons.
[c] Omnibus test for sleep midpoint: $\chi^2 = 3.0$, $P = .23$; omnibus test for TST: $\chi^2 = 4.6$, $P = .09$.

Table 5
Cox model results for time to all-cause mortality within sex-stratified matched samples

	Females only		Males only	
	z (*P*[a])	Hazard ratio (95% CI[b])	*z* (*P*[a])	Hazard ratio (95% CI[b])
Model 1a: full-sample LCA[c]				
HSP vs AS	2.0 (.15)	1.52 (1.01-2.28)	1.90 (.336)	1.38 (0.99-1.95)
HSP vs ISS	2.0 (.15)	1.78 (1.00-3.18)	1.30 (.336)	1.35 (0.86-2.13)
ISS vs AS	−0.6 (.67)	0.85 (0.52-1.41)	0.14 (.893)	1.03 (0.68-1.57)
Model 1b: sex-stratified LCAs[d]				
HSP vs AS	2.5 (.11)	1.86 (1.14-3.05)	1.38 (.336)	1.28 (0.90-1.83)
HSP vs ISS	2.4 (.11)	2.23 (1.17-4.29)	0.95 (.434)	1.25 (0.78-1.99)
ISS vs AS	−0.7 (.66)	0.83 (0.51-1.37)	0.12 (.336)	1.02 (0.68-1.55)
Model 2: no. of potentially adverse sleep characteristics				
No. of potentially adverse sleep characteristics	−0.1 (.90)	0.99 (0.83-1.17)	1.41 (.336)	1.10 (0.96-1.26)
Model 3: all sleep health characteristics considered simultaneously[e]				
Poor quality	−0.6 (.67)	0.83 (0.44-1.58)	−0.45 (.760)	0.90 (0.59-1.39)
High sleepiness	1.2 (.52)	1.39 (0.82-2.38)	1.37 (.336)	1.32 (0.89-1.98)
Early vs middle midpoint[f]	−0.4 (.77)	0.90 (0.53-1.55)	−0.23 (.880)	0.95 (0.63-1.45)
Late vs middle midpoint	−1.1 (.54)	0.72 (0.40-1.30)	3.25 (.014)	2.00 (1.32-3.05)
Low SE (<85%)	−0.7 (.66)	0.97 (0.59-1.28)	1.71 (.336)	1.33 (0.96-1.86)
Short vs medium TST[g]	0.9 (.66)	1.30 (0.71-2.40)	−1.81 (.347)	0.72 (0.42-1.24)
Long vs medium TST	2.2 (.12)	1.82 (1.08-3.08)	1.16 (.347)	1.31 (0.83-2.07)

[a] BH-FDR correction within sex for Table 5 ($\alpha = .05$).
[b] Not adjusted for multiple comparisons.
[c] Omnibus $\chi^2 = 4.9$, $P = .09$ for women; omnibus $\chi^2 = 3.7$, $P = .16$ for men.
[d] Omnibus $\chi^2 = 6.5$, $P = .04$ for women; omnibus $\chi^2 = 1.90$, $P = .39$ for men.
[e] Omnibus $\chi^2 = 8.7$, $P = .28$ for women; omnibus $\chi^2 = 16.08$, $P = .02$ for men.
[f] Omnibus test for midpoint: $\chi^2 = 1.4$, $P = .15$ for women; omnibus test for midpoint: $\chi^2 = 9.8$, $P = .01$ for men.
[g] Omnibus test for TST: $\chi^2 = 5.3$, $P = .07$ for women; Omnibus test for TST: $\chi^2 = 2.9$, $P = .22$ for men.

self-reported short sleep and/or insomnia confer risk for mortality independent of other comorbidities in older adults is unclear and may differ by age and sex.[11,39–41] However, evidence is accumulating that self-reported long sleep (eg, as observed in HSP) may be a greater risk factor for poor health outcomes than self-reported short sleep duration, especially in older adults.[11,41]

Our sample of men and women was matched on sociodemographic and clinical characteristics, thus affording a unique opportunity to secondarily investigate sex differences without confounding by several key measures. Three similar phenotypes (HSP, ISS, AS) were revealed across sex-stratified analyses. However, the HSP phenotype derived in matched women reflected a heightened sleep propensity only at night, whereas the HSP phenotype derived in matched men reflected a heightened sleep propensity at any time of day. Additionally, the effect of HSP on mortality was notably stronger among women. This is consistent with our finding that long sleep duration was the individual sleep characteristic that conferred the greatest risk for mortality among women. Among men, late vs middle midpoint conferred the greatest risk. However, none of the sleep health classes were differentiated on midpoint. This finding highlights the utility of considering individual sleep characteristics along with sleep phenotypes. Individual characteristics may be important predictors of an outcome but not relevant for revealing latent classes.

The phenotypes and mortality associations we observed in the sex-stratified samples were largely replicated within their respective parent cohorts (MrOS and SOF), although the samples differed considerably in their demographic and clinical characteristics. However, the MrOS HSP phenotype was characterized by heightened sleep propensity only at night, whereas the matched male HSP phenotype was characterized by heightened sleep propensity at any time of day. These differences are also reflected in the lower JC of the HSP class. Additionally, effect sizes in the parent cohorts were generally smaller than those in the matched samples. Future research should further examine sex differences in sleep health phenotypes (especially HSP) and sex specific mechanisms underlying different sleep health–mortality associations.

Strengths of our study included a large sex-matched sample that facilitated a comparison of male and female sleep health profiles without confounding from several key confounders, an assessment of phenotype stability through bootstrapping, and replication of sex-stratified findings in parent cohorts. Still, our findings should be replicated in other samples, especially with regard to the HSP phenotype. Limitations of the study include a lack of generalizability to nonwhite populations, reliance on retrospective self-reported sleep, absence of self-reported sleep regularity and sleep-disordered breathing assessments, and lower power for testing predictors of cardiovascular mortality. Matched men and women were not representative of their respective MrOS and SOF cohorts; however, this limitation was mitigated by similar findings in these cohorts. Finally, these results are based on older adults that have survived past the current life expectancy in the United States. Therefore, this phenotyping applies to the oldest old and not necessarily across generations.

Conclusions

This is the first study to identify empirically derived self-reported sleep health phenotypes in older community-dwelling adults. Those with HSP (a combination of long nighttime sleep duration, daytime sleepiness, and high efficiency/satisfaction) may be an important future target for health screening, and research should be conducted to investigate mechanisms including inflammation, biological aging, and neurological disease. Given the observation that those with ISS had the most mental and physical health problems, it may be beneficial to develop insomnia treatments for older adults that incorporate pain management, treatment of comorbid conditions, or mental health treatment. Future research should also examine sex-specific sleep health phenotypes and pathways to mortality. Finally, it will be critical to apply LCA to both objectively and subjectively measured sleep health characteristics, as such findings may provide further insight into the associations between our observed self-reported phenotypes and mortality.

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Appendix A. Supplementary data

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