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Authors
Xiao, Qian
Gee, Gilbert
Jones, Rena
et al.

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Cross-sectional association between outdoor artificial light at night and sleep duration in middle-to-older aged adults: the NIH-AARP Diet and Health Study

Qian Xiao[1,2], **Gilbert Gee**[3], **Rena R. Jones**[4], **Peng Jia**[5], **Peter James**[6], **Lauren Hale**[7]

[1]Department of Health and Human physiology, College of Liberal Arts and Sciences, University of Iowa, Iowa City, IA, USA [2]Department of Epidemiology, College of Public Health, University of Iowa, Iowa City, IA, USA [3]Department of Community Health Sciences, Fielding School of Public Health, University of California, Los Angeles, Los Angeles, CA, USA [4]Occupational and Environmental Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Rockville, MD, USA [5]Department of Earth Observation Science, Faculty of Geo-information Science and Earth Observation, University of Twente, Netherlands [6]Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, MA, USA [7]Program in Public Health, Department of Family, Population, and Preventive Medicine, Stony Brook Medicine, Stony Brook, NY

Abstract

Introduction—Artificial light at night (ALAN) can disrupt circadian rhythms and cause sleep disturbances. Several previous epidemiological studies have reported an association between higher levels of outdoor ALAN and shorter sleep duration. However, it remains unclear how this association may differ by individual- and neighborhood-level socioeconomic status, and whether ALAN may also be associated with longer sleep duration.

Methods—We assessed the cross-sectional relationship between outdoor ALAN and self-reported sleep duration in 333,365 middle- to older-aged men and women in the NIH-AARP Diet and Health Study. Study participants reported baseline addresses, which were geocoded and linked with outdoor ALAN exposure measured by satellite imagery data obtained from the U.S. Defense Meteorological Satellite Program's Operational Linescan System. We used multinomial logistic regression to estimate the multinomial odds ratio (MOR) and 95% confidence intervals (CI) for the likelihood of reporting very short (<5 hours), short (<7 hours) and long (≥9 hours) sleep relative to reporting 7-8 hours of sleep across quintiles of LAN. We also conducted subgroup analyses by individual-level education and census tract-level poverty levels.

Corresponding authors: Qian Xiao, 225 South Grand, Field House E118, Iowa City, Iowa 52242, USA, qian-xiao@uiowa.edu.

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Conflict of Interest
The authors declare no conflict of interest.

Results—We found that higher levels of ALAN were associated with both very short and short sleep. When compared to the lowest quintile, the highest quintile of ALAN was associated with 16% and 25% increases in the likelihood of reporting short sleep in women ($MOR_{Q1\ vs\ Q5}$, (95% CI), 1.16 (1.10, 1.22)) and men (1.25 (1.19, 1.31)), respectively. Moreover, we found that higher ALAN was associated with a decrease in the likelihood of reporting long sleep in men (0.79 (0.71, 0.89)). We also found that the associations between ALAN and short sleep were larger in neighborhoods with higher levels of poverty.

Conclusions—The burden of short sleep may be higher among residents in areas with higher levels of outdoor LAN, and this association is likely stronger in poorer neighborhoods. Future studies should investigate the potential benefits of reducing light intensity in high ALAN areas in improve sleep health.

Keywords

artificial light at night; sleep; circadian disruption; neighborhood; socioeconomic disadvantage

Introduction

Nighttime outdoor lighting has permeated modern societies since the introduction of electric light. Hölker et al. estimated that outdoor artificial light at night (LAN) increased by 5-20% per year in many urban places throughout the second half of the 20th century.[1] A 2016 study reported that in the United States, nearly 80% of the population lived in areas where the natural appearance of the night sky could not be observed and nearly 40% lived in areas where night adaption of human eyes was inhibited by light.[2] Growing evidence suggests that the steady rise in the use of ALAN may have unintended health consequences, as multiple studies have linked ALAN with various diseases, including cancer, [3,4] obesity, [5] cardiovascular disease, [6] and depression. [7] ALAN may suppress melatonin, a key hormone in circadian regulation, and enable nighttime activities that are misaligned with the internal circadian clock, while both melatonin suppression and misaligned nighttime activities may lead to sleep deficiency, an important risk factor for a wide range of health outcomes. [8]

Several epidemiological studies have reported a relationship between higher exposure to outdoor ALAN and sleep deficiency. In a study of more than 8,000 Korean adults, higher residential outdoor ALAN measured by satellite images was significantly associated with shorter sleep duration. [5] Similarly, in another study using data from a representative sample of more than 19,000 American adults, outdoor ALAN was associated with higher likelihood of reporting <6 hours of sleep. [9] However, neither study examined whether ALAN is associated with long sleep duration, a distinct risk factor for morbidity and mortality, especially in older adults. A recent systematic review and meta-analysis study found that long sleep duration was significantly associated with higher risks for all-cause mortality, mental disorders, type 2 diabetes, heart disease, stroke and obesity.[10] Given the high prevalence of ALAN and myriad health problems associated with both short and long sleep, it is important to further evaluate the burden of short and long sleep associated with LAN.

Few studies examined whether the association between ALAN and sleep differ by other individual and environmental factors. Diez Roux and Mair hypothesized that high stress and lack of economic and psychosocial resources, conditions that are often associated with individual- and neighborhood-level disadvantages, may exacerbate the adverse effects of a harmful physical environment. [11] Indeed, previous studies have consistently documented a higher prevalence of short sleep among people of low socioeconomic status (SES), [12,13] and some studies also reported an association between long sleep and racial/ethnic minority and lower levels of education. [14,15] Moreover, several studies found that residents of low SES neighborhoods are more likely to experience short sleep than their counterparts living in high SES neighborhoods. [16,17] Individual- and neighborhoods-level disadvantage may be important modifiers of the relationship between ALAN on sleep; however, to the best of our knowledge, no study has directly examined this possibility.

These considerations motivate our present research. We studied outdoor ALAN in relation to both short and long sleep duration in more than 300,000 middle-to-older aged men and women in the NIH-AARP Diet and Health Study. We further investigated whether education (as an indicator of individual-level SES) and neighborhood poverty (as an indicator of neighborhood SES) modify the relationship between ALAN and sleep duration.

Methods

Study population

The NIH-AARP Diet and Health Study participants were recruited in 1995-1996 from members of the American Association of Retired Persons (AARP) (age 50-71) who resided in six states (California, Florida, Louisiana, New Jersey, North Carolina, and Pennsylvania) and two metropolitan areas (Atlanta, Georgia, and Detroit, Michigan). Details of the study have been previously reported.[18] Briefly, 566,399 participants completed the baseline questionnaire, which included questions about sociodemographic factors, health, and health behaviors. They also provided residential addresses which were geocoded into latitude/longitude coordinates. A subset of participants who did not report a prior diagnosis of cancer completed an additional questionnaire within 6 months of baseline which included questions about sleep duration and other factors. A total of 334,905 participants completed both questionnaires and met the quality control criteria for inclusion, which has been published. [18] Of these, we excluded those with no information on sleep (N=1,540). Our analytic cohort included 137,360 women and 196,005 men. The study was approved by the National Cancer Institute Special Studies Institutional Review Board.

Assessment of Outdoor LAN

Outdoor ALAN was measured using satellite imagery data obtained from the U.S. Defense Meteorological Satellite Program's (DMSP's) Operational Linescan System (OLS), maintained by the National Oceanic and Atmospheric Administration's Earth Observation Group. [19] The DMSP OLS provides continuous visual and infrared imagery with a swath of 3000 km, and is able to provide daily global coverage. The OLS detector sweeps back and forth in a pendulum-style motion and provides continuous sampling of the earth surface at a constant rate. This database contains annual composites made after excluding the outer quarters of the satellite swath, sun and moon luminance, glare, clouds, atmospheric lightning, and ephemeral events such as fires. While these images capture only a fraction of the light originating from the earth's surface, they represent the relative levels of nighttime illumination at the ground level. [20] The processed imagery data are georectified to a 30 arc-second grid (equivalent to approximately one square kilometer). Because earlier studies have shown that the low-dynamic range 6-bit DMSP data do not provide sufficient variability in urban areas with high ALAN levels, [21] we used the DMSP Global Radiance Calibrated Nighttime Lights high-dynamic range data, which were generated by combing data from three different gain settings of the OLS and the highest gain had a lowest detection limit of 10-10 nW/cm^2/sr. We transformed the values into units of radiance (nanowatts/cm^2/sterradian (sr)). To measure baseline outdoor ALAN exposure for each study participant, their geocoded addresses at baseline were linked with high-dynamic ALAN data in 1996 using ArcGIS (ESRI, Redlands, CA).

Assessment of sleep duration

Participants reported sleep duration in response to the question "how many hours do you spend sleeping at night in a typical 24-hour period over the past 12 months." They were asked to choose from "less than 5 hours", "5 to 6 hours", "7 to 8 hours" and "9 or more hours". We defined 7 to 8 hours as the reference group, less than 5 hours as very short sleep, less than 7 hours (including both "less than 5 hours" and "5 to 6 hours") as short sleep, and 9 or more hours as long sleep, based on the recommendation of the National Sleep Foundation for adults. [22]

Covariates

At baseline, the Study collected information on a broad range of covariates, including basic demographic characteristics such as age, race/ethnicity, education and marital status, and lifestyle factors, such as smoking, alcohol drinking, physical activity and sedentary behaviors. In particular, participants reported the highest grade or level of schooling they completed by choosing one of the following categories: "less than 8 years", "8-11 years", "12 years or completed high school", "post-high school training other than college (e.g. vocational or technical training)", "some college", "post graduate" and "unknown". Baseline addresses were linked to 2000 US Census, from which we derived population density, average median home value, and percent of population below poverty line at census-tract level. We used percent of population below poverty line at census-tract level as the indicator of neighborhood SES. We also defined metropolitan status of counties by the Office of Management and Budget using the 1993 Rural-Urban Continuum Codes.

Statistical analysis

Because the distribution of ALAN is highly right skewed, we categorized ALAN as quintiles, and used the lowest quintile as the reference group. To examine the association between ALAN and sleep duration, we used multinomial logistic regression models to calculate the multinomial odds ratios (MOR) and 95% confidence intervals (CI). We found a significant interaction between ALAN and sex in relation to sleep duration (*p-interaction<.0001*) and therefore conducted sex-specific analysis. For the main analysis, the models contained a four-category outcome variable for sleep duration (< 5 hours, 5-6 hours, 7-8 hours (reference), 9+ hours). For subgroup analyses stratified by education and neighborhood SES, we combined the first two categories of sleep duration to preserve statistical power. We adjusted for multiple covariates collected at enrollment, including sociodemographic factors (age (5-year interval categories), race (black, white, other), education (less than high school, high school grad, some college, college and post graduate), marital status (married, widowed, divorced or separated, never married)), lifestyle factors (smoking (never, former, current), alcohol (non-drinker, <2 drinks/week, 2-6 drinks/week, and 1+ drink/day), vigorous physical activity (never/rarely, 1-3 times/month, 1-2 times/week, 3-4 times/week, 5+times/week), TV viewing (<3, 3-4, 5-6, and 7+ hour/day)), and spatial factors (state of residency (California, Florida, Louisiana, New Jersey, North Carolina, and Pennsylvania, Georgia (Atlanta), and Michigan (Detroit)), and census-tract median home value, population density and poverty level (all in quintiles)). These variables were considered as potential confounders and included in the model because they have been previously linked to sleep duration, [13,17,23–26] and may influence people's choice of residential areas (sociodemographic and lifestyle factors) or are correlated with ALAN (spatial factors).

We also performed subgroup analysis according to education and census tract poverty level. For education, we grouped participants according to whether or not one had a high school diploma; and for census-tract poverty, we grouped census tracts based on the cutoff point of the upper quartile (≥11% of total population were below the 2000 US poverty line). Participants with missing information on education or census-tract poverty were excluded from stratified analysis. All analyses were performed using SAS 9.3 (SAS Institute, Cary, North Carolina).

Results

In Table 1 we present distributions of study characteristics according to ALAN quintiles. When compared with those in the lower ALAN quintiles, participants in the higher quintiles were more likely to be women but less likely to be white or married, or report engaging in vigorous physical activity for ≥5 times/week. In addition, areas with higher levels of ALAN were more likely to be metropolitan areas and had higher home values and a larger population density. The distribution of sleep duration across ALAN quintiles in men and women is presented in Table 2. Overall, the unadjusted results showed that when compared to subjects in lower ALAN quintiles, those in higher quintiles had a higher prevalence of short and very short sleep but a lower prevalence of long sleep for both genders.

Next we examined the relationship between ALAN and sleep duration after adjustment for multiple covariates (Table 3, Figure 1). Overall, we found that higher levels of ALAN were associated with short sleep (<7 hours, including both <5 and 5-6 hours categories) and very short sleep (<5 hours) in both men and women. Specifically, when compared to the lowest quintile of LAN, the highest quintile was associated with 16% and 25% increases in the likelihood of reporting less than 7 hours of sleep relative to 7-8 hours of sleep in women and men, respectively ($MOR_{Q1\ vs\ Q5}$ (95% CI), 1.16 (1.10, 1.22) for women and 1.25 (1.19, 1.31) for men, Figure 1). Moreover, we found that higher ALAN was associated with a decrease in the likelihood of reporting long sleep (≥ 9 hours) in men (0.79 (0.71, 0.89)). In contrast, ALAN was not associated with long sleep in women.

Finally, we studied ALAN in relation to both short and long sleep according to education and census tract poverty rate as a measure of neighborhood SES. For short sleep, we found a statistically significant interaction between ALAN and census tract poverty rate in relation in women (Table 4; *p-interaction=0.001*). Specifically, the association between higher ALAN and short sleep was larger in magnitude among women living in census tracts with higher poverty (1.22 (1.10, 1.36)) than among those living in lower poverty areas (1.15 (1.08, 1.23)). A similar trend was observed among men (1.31 (1.18, 1.45) and 1.25 (1.18, 1.32), respectively), although the p-value for interaction was not statistically significant in men (*p-interaction=0.15*). We did not detect a statistically significant interaction between ALAN and education in relation to short sleep in either men or women. For long sleep duration, we did not observe any meaningful interaction for any of the subgroup analyses (Table 5).

Discussion

In this sample of over 300,000 American adults who were 50-71 years old, we found that men and women living in areas with higher outdoor ALAN were more likely to report short sleep, and this finding appeared to be stronger among residents of neighborhoods with higher poverty rates. In addition, we also found an association between higher ALAN and lower likelihood of long sleep in men.

Our findings are consistent with those from several previous population-based studies, which also reported that higher outdoor ALAN was associated with short sleep duration. Koo et al. examined outdoor ALAN measured by satellite imagery and sleep in the Korea Genome and Epidemiology Study and found that people in the high ALAN group on average slept 0.5 hours less and were 20% more likely to report <6 hours of sleep compared to their counterparts in the low ALAN group. [5] In a cross-sectional analysis using data from the Sleep-EVAL general population survey, which included a representative sample of the general US population age 18 or older, Ohayon and Milesi reported a significant association between higher levels of satellite-measured outdoor ALAN and a higher likelihood of reporting <6 hours of sleep ($p<0.01$).[9] The association persisted after adjusting for not only individual-level characteristics, but also environmental factors such as population density and noise. In addition, a study of 857 Japanese elderly participants found that photometer-measured ALAN in the bedroom was associated with shorter total sleep time derived from actigraphy data. [27] Moreover, these studies and others also linked ALAN with higher prevalence of hypnotic prescriptions, higher sleep disturbances, longer sleep onset latency and later sleep timing. [5,9,27–29] Taken together, these findings suggest that the prevalence of sleep deficiency is higher in places with higher levels of LAN.

It is worth noting that multiple studies, including our own, used satellite-measured outdoor ALAN as the main exposure variable, although it is unclear how well outdoor ALAN reflects actual ALAN exposure experienced by individuals. Two earlier studies examined outdoor ALAN in relation to ALAN level in bedrooms and personal ALAN exposure, and found no associations between the two. [30,31] Given the lack of associations between outdoor ALAN levels and indoor and personal ALAN exposures reported by these studies, the relationship between high levels of outdoor ALAN and short sleep needs to be interpreted with caution. On one hand, the observed associations between outdoor ALAN and sleep may be explained by potential confounding by other factors that are known risk factors for sleep deficiency, including environmental factors such as noise and pollution, and individual factors such as nighttime social activities, and stress. [32–37] On the other hand, it is also possible that the observed associations in our study population represent a true relationship, but primarily driven by individuals whose ALAN exposure was more heavily influenced by outdoor ALAN (e.g. individuals living in rooms facing bright streets and/or with insufficient window treatments to block out light, or individuals with a high amount of nighttime activities outside home). Unfortunately, we did not collect information on room location and position, window treatment, and nighttime lifestyle and weren't able to examine their influence on the ALAN and sleep associations. However, it is worth pointing out that failing to account for these individual differences in exposure to outdoor ALAN is likely to result in nondifferential misclassification and thus would attenuate the findings and lead to underestimating the true effects.

Although the aforementioned challenges in ALAN measurement and the observational nature of our study makes it difficult to draw causal inference, a causal relationship between high ALAN and sleep deficiency is plausible and can be explained by several mechanisms. The pineal hormone melatonin is a critical regulator of the circadian rhythms and has sleep-promoting effects. It is well established that nocturnal light exposures, even at moderate intensities, can directly suppress melatonin production, which may in turn lead to delayed sleep onset, impaired sleep maintenance and compromised sleep quality. [38] Moreover, electric light also allows people to work, socialize, and engage in leisure time activities at night, all of which have a significant impact on people's sleep schedule and may curtail sleep duration. [8] In order to establish a causal relationship between outdoor ALAN and sleep will require randomized intervention studies that manipulate outdoor ALAN levels in different populations, which is likely to be challenging, costly and likely unethical. Alternatively, studying changes in outdoor ALAN that "naturally" occur in different areas may provide a unique opportunity to further evaluate to what degree ALAN may cause sleep deficiency. In particular, over the past several decades, light pollution legislations were enacted in many parts of the world, including in 18 states in the US and several European and Asian countries, such as Slovenia, Italy, France, UK and South Korea. [39–41] However, few studies have examined the effectiveness of these laws in reducing individual ALAN exposure, and to the best of our knowledge, no study has examined their effects on human sleep or health in general. The current investigation provides support for future studies to evaluate the potential sleep and health benefits of reducing light pollution in areas with high levels of LAN.

We found that the associations between ALAN and short sleep appeared to be stronger among people living in areas with higher poverty rates, suggesting that neighborhood socioeconomic disadvantage may exacerbate the detrimental effects of ALAN on sleep. The interaction between census tract poverty and ALAN in relation to short sleep was statistically significant only in women, however in men we observed a similar trend suggesting larger associations in poorer neighborhoods. More studies are needed to further examine neighborhood SES as a potential modifier of the relationship between ALAN and sleep, and clarify if the impact of neighborhood SES differ by gender. Several factors could potentially explain the moderating effects of neighborhood SES. Residents of poor neighborhoods typically have worse living conditions and experience higher stress levels, both of which have been linked to disturbed sleep.[42,43] The presence of multiple risk factors for sleep deficiency in disadvantaged neighborhoods create an adverse environment that make individual sleep behaviors particularly vulnerable to additional disruptors, such as LAN. Moreover, people who have altered sleep patterns due to stress and poor living conditions may stay up late, which leads to prolonged exposure to ALAN that in turn further disrupts sleep and suppresses sleep duration. As a result, the burden of sleep deficiency may be particularly high among people living in disadvantaged neighborhoods with high level of LAN. Finally, lower income households may not have the resources to take preventive measures (e.g., black out shades) to reduce the adverse effects of light on sleep health. If confirmed, these findings support programs to monitor sleep health, promote sleep hygiene, improve neighborhood conditions and reduce ALAN in these populations. Potential interventions should not merely target individual behaviors, but also the broader environment.

We found that men living in areas with higher ALAN were less likely to report long sleep. Earlier studies have consistently linked long sleep with various health conditions, especially among older populations. However, the underlying mechanisms of the relationships are unclear. Some scholars have suggested that long sleep may be a mere marker of underlying health conditions, fatigue and sleep problems such as sleep fragmentation, sleepiness and apnea, [44] which may be the actual causes of mortality and morbidity. Alternatively, long sleepers are likely to spend extended time in dark and as a result experience shortened photoperiod and circadian alterations, which have been linked with disease risks and mortality. [45] Long sleep is also linked to depression and light and wake therapies that induce sleep deprivation have been shown to be efficacious treatments for depression. [46] Although the causal mechanisms require elaboration, our study provides new evidence that ALAN is inversely related to long sleep.

Our results suggest gender differences in the ALAN and sleep relationship. Higher levels of ALAN were associated with a larger increase in the likelihood of reporting short sleep in men than in women, and the inverse association between ALAN and long sleep was only observed in men. This may be explained by biological differences in light response between men and women. As suggested by an earlier study, men's visual system may more sensitive to light, especially the blue spectrum of light. [47] Moreover, a recent study also found that exposure to very low levels of blue-enriched light at night led to a higher increase in vigilant attention and larger alterations in sleep architecture in men than in women. [48] These biological differences may explain why we found a stronger relationship between ALAN and both short and long sleep in men in our study. Alternatively, gender differences observed in our study could also be explained by differences in lifestyle factors. For example, men are more likely to smoke and drink alcohol, both of which can lead to sleep disturbances, [49,50] and it is possible that the presence of both sleep-disturbing behaviors such as smoking and drinking and exposure to ALAN may result in synergistic interactions and lead to a stronger association between ALAN and sleep duration observed in men. Moreover, men and women may also differ in nighttime activities (e.g. social activities outside home) and sleep hygiene practices (e.g. having a regular nighttime routine), both of which may impact the extent to which outdoor ALAN influence personal ALAN exposures, and thus influence the relationship between outdoor ALAN and sleep. However, little research has examined gender differences in these behaviors and their impact on ALAN exposure levels and sleep patterns, and more studies are needed to identify factors and the mechanisms by which they may modify the relationships between ALAN and sleep.

An important strength of our study is the large study population. This has allowed us to examine various individual and environmental characteristics as potential modifiers of the relationship between ALAN and sleep, which has not been investigated before. Moreover, we adjusted a large number of potential confounders, including TV viewing, a factor that may influence indoor lighting. However, our study did not specifically ask about TV viewing before bedtime, and we caution that further adjustment for light exposure from computer screens and other devices is warranted. However, our study also has several limitations. First, as discussed before, satellite-measured ALAN represents outdoor lighting levels that may not accurately reflect ALAN exposure experienced by individuals, especially in an indoor environment. Second, sleep was measured by self-reported information regarding a typical night over the past year, which is prone to error and may lead to misclassification. [51] Moreover, we did not have information on other aspects of sleep, such as sleep timing, quality and regularity, or history of sleep disorders, and therefore were not able to examine their relationships with LAN. Third, our study used data originating mid-1990s, and since then outdoor ALAN has continued to increase across North America, [52]and in particular, the use of light emitting diode technology has become increasingly popular. This has led to a particularly high increase in blue LAN, which has the strongest effect in entraining the circadian system when compared to other light spectrums. [53] Unfortunately, DMSP images in mid-1990s were only able to detect the intensity but not the spectrum of light, and therefore we were not able to specifically measure the exposure to blue wavelengths of light Moreover, there have also been changes in other environmental exposures such as pollution, noise, and climate, all of which may interact with ALAN to influence sleep patterns. Thus there is a need to examine the relationship between ALAN and sleep using more recent data. Finally, although we adjusted for multiple individual- and environmental-level factors, we did not have information on other potentially important confounders. In particular, ALAN is highly correlated with urbanicity, and unmeasured environmental attributes related to urbanicity, such as noise, air pollution, and cultural and psychosocial factors may be a source of residual confounding.

In summary, our study findings support a role of outdoor ALAN in sleep deficiency. Our results also indicate that those living in disadvantaged neighborhoods may be most affected by the adverse effects of ALAN on sleep. Future studies should investigate if reducing light pollution lead to improved sleep and other health benefits.

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- Higher outdoor residential light at night (LAN) was associated with a higher likelihood of reporting short sleep (<7 hours) in middle-to-old aged adults in the US.
- Higher LAN was associated with a decrease in the likelihood of reporting long sleep in men, but not in women.
- The associations between LAN and short sleep were larger in neighborhoods with higher levels of poverty

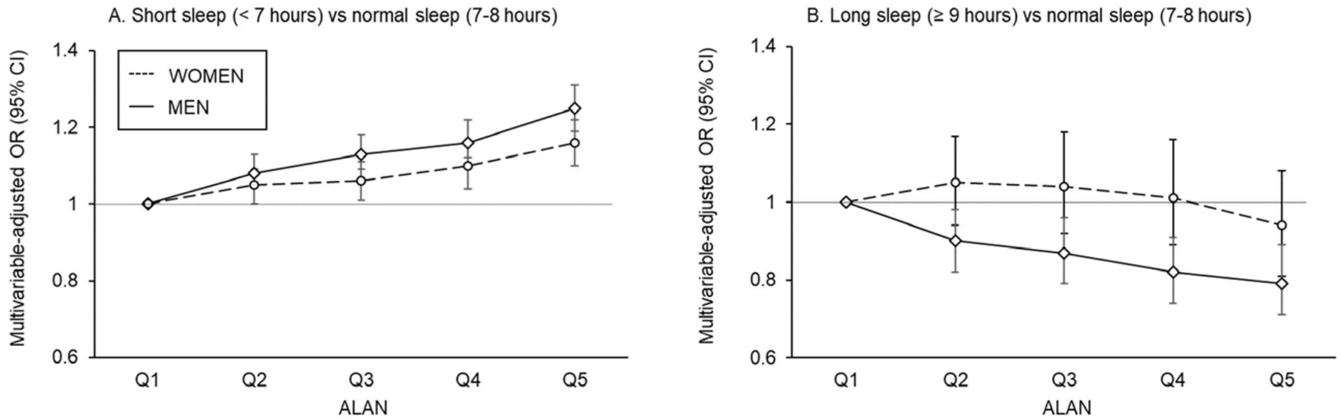

Figure 1.

Multivariable-adjusted association between ALAN and sleep duration in men and women in the NIH-AARP Diet and Health Study.Models were adjusted for age, race, marital status, state of residency, smoking, alcohol, vigorous physical activity, TV viewing, and median home value, population density and poverty rate at census tract level. A) presents results for short sleep (<7 hours, including both the <5 hours and 5-6 hours groups); and B) presents results for long (≥9 hours) sleep. Abbreviations: ALAN, artificial light at night; CI, confidence interval; OR, odds ratio.

Table 1

Study characteristics by quintiles of ALAN in 333,365 participants in the NIH-AARP Diet and Health Study (1995-1996)

	LAN in 1996				
	Q1	**Q2**	**Q3**	**Q4**	**Q5**
Artificial light at night, nW/cm^2/sr, median (IQR)	4.3 (2.1)	12.6 (2.8)	25.1 (4.3)	43.0 (6.2)	78.2 (21.2)
Age, mean (SD)	62.4 (5.2)	62.4 (5.3)	62.3 (5.3)	62.4 (5.3)	62.2 (5.4)
Female, %	39.3	38.9	40.0	42.1	45.8
White, non-Hispanic, %	96.9	96.1	95.0	93.9	86.4
College and postcollege, %	33.6	40.2	44.7	44.3	39.6
Less than high school, %	10.0	7.4	6.4	6.6	8.4
Married, %	75.8	72.7	69.9	66.2	57.5
Current smoker, %	11.3	10.6	10.7	10.9	12.3
Vigorous physical activity >= 5 times/wk, %	21.2	20.7	20.2	19.6	18.2
TV viewing ≤ 2 hr/d, %	33.8	34.3	36.3	36.2	34.1
Body mass index, kg/m2, mean (SD)	27.1 (5.0)	27.0 (4.9)	26.8 (5.0)	26.9 (5.0)	27.1 (5.3)
Alcohol consumption, ≥ 1 drinks/day, %	22.5	23.4	24.1	23.1	20.8
Self-reported health, excellent, %	16.2	17.7	18.9	18.5	16.6
Census tract median home value, 1000USD, mean (SD)	137 (104)	174 (148)	203 (155)	204 (146)	193 (140)
Census tract poverty rate, percentage, mean (SD)	9.9 (6.5)	7.7 (6.4)	7.0 (6.3)	7.4 (6.4)	10.5 (8.3)
Census tract population density, per km^2, mean (SD)	201 (322)	786 (701)	1343 (1033)	1933 (1373)	3634 (3215)
Metropolitan counties [a], %	68.7	91.2	98.6	99.8	100.0

[a] metro status of counties was determined by the Office of Management and Budget using the 1993 Rural-Urban Continuum Codes

Abbreviations: ALAN, artificial light at night; HEI, health eating index, IQR, interquartile range; SD, standard deviation

Table 2

Distribution (%) of sleep categories by quintiles of ALAN in 333,365 participants in the NIH-AARP Diet and Health Study (1995-1996)

	Sleep duration, hour				
ALAN in 1996	**<5**	**5-6**	**7-8**	**9+**	***p-value*** [a]
		Women			*<.0001*
Q1	3.5	30.9	61.8	3.8	
Q2	3.4	32.0	61.1	3.6	
Q3	3.6	32.0	60.8	3.5	
Q4	3.7	33.2	59.6	3.5	
Q5	4.6	36.8	55.5	3.1	
		Men			*<.0001*
Q1	2.2	27.3	66.1	4.5	
Q2	2.2	29.6	64.6	3.7	
Q3	2.3	30.6	63.6	3.5	
Q4	2.7	31.3	62.7	3.3	
Q5	3.5	34.7	58.5	3.3	

[a] derived from chi-square test

Abbreviations: ALAN, artificial light at night

Table 3

Associations [a] (OR (95% CI)) between ALAN and sleep duration in men and women in the NIH-AARP Diet and Health Study

	Sleep duration, hour		
ALAN in 1996	**<5 vs 7-8**	**5-6 vs 7-8**	**9+ vs 7-8**
Women (N=137,360)			
Q1	ref	ref	ref
Q2	1.06 (0.94, 1.19)	1.05 (1.00, 1.10)	1.05 (0.94, 1.17)
Q3	1.17 (1.02, 1.33)	1.06 (1.00, 1.11)	1.04 (0.92, 1.18)
Q4	1.17 (1.02, 1.34)	1.10 (1.04, 1.16)	1.01 (0.89, 1.16)
Q5	1.20 (1.03, 1.38)	1.18 (1.11, 1.25)	0.94 (0.81, 1.08)
p-trend	*0.03*	*<.0001*	*0.20*
Men (N=196,005)			
Q1	ref	ref	ref
Q2	1.09 (0.98, 1.23)	1.09 (1.05, 1.13)	0.90 (0.82, 0.98)
Q3	1.20 (1.06, 1.36)	1.13 (1.09, 1.18)	0.87 (0.79, 0.96)
Q4	1.32 (1.16, 1.51)	1.16 (1.10, 1.21)	0.82 (0.74, 0.91)
Q5	1.45 (1.26, 1.67)	1.25 (1.19, 1.31)	0.79 (0.71, 0.89)
p-trend	*<.0001*	*<.0001*	*<.0001*

[a] adjusted for age, race, marital status, state of residency, smoking, alcohol, vigorous physical activity, TV viewing, and median home value, population density and poverty rate at census tract level.

Abbreviations: ALAN, artificial light at night; CI, confidence interval; OR, odds ratio.

Table 4

Associations [a] (OR (95% CI)) between ALAN and short sleep (<7 hour) according to race, education and census tract poverty rate in the NIH-AARP Diet and Health Study

	ALAN in 1996					
	Q1	Q2	Q3	Q4	Q5	*p-interaction*
Women (N=137,360)						
Education						*0.10*
High school graduate	ref	1.03 (0.99, 1.08)	1.06 (1.00, 1.11)	1.09 (1.03, 1.15)	1.15 (1.09, 1.22)	
Less than high school	ref	1.13 (0.95, 1.34)	1.08 (0.89, 1.33)	1.17 (0.94, 1.45)	1.24 (0.98, 1.56)	
Census tract poverty						*0.001*
<11%	ref	1.05 (0.99, 1.10)	1.06 (1.00, 1.12)	1.09 (1.03, 1.16)	1.15 (1.08, 1.23)	
≥11%	ref	1.03 (0.94, 1.12)	1.07 (0.97, 1.19)	1.12 (1.01, 1.24)	1.22 (1.10, 1.36)	
Men (N=196,005)						
Education						*0.12*
High school graduate	ref	1.08 (1.04, 1.12)	1.12 (1.08, 1.17)	1.16 (1.10, 1.21)	1.25 (1.19, 1.31)	
Less than high school	ref	1.07 (0.93, 1.25)	1.12 (0.94, 1.34)	1.13 (0.94, 1.37)	1.13 (0.92, 1.39)	
Census tract poverty						*0.15*
<11%	ref	1.08 (1.04, 1.13)	1.14 (1.09, 1.19)	1.17 (1.11, 1.23)	1.25 (1.18, 1.32)	
≥11%	ref	1.12 (1.03, 1.21)	1.13 (1.03, 1.24)	1.17 (1.06, 1.29)	1.31 (1.18, 1.45)	

[a] adjusted for age, race, marital status, state of residency, smoking, alcohol, vigorous physical activity, TV viewing, and median home value, population density and poverty rate at census tract level. Factors that were stratified by were not included.

Abbreviations: ALAN, artificial light at night; CI, confidence interval; OR, odds ratio.

Table 5

Associations [a] (OR (95% CI)) between ALAN and long sleep (≥9 hour) according to race, education and census tract poverty rate in the NIH-AARP Diet and Health Study

	ALAN in 1996					
	Q1	**Q2**	**Q3**	**Q4**	**Q5**	***p-interaction***
Women (N=137,360)						
Education						*0.76*
High school graduate	ref	1.05 (0.94, 1.18)	1.06 (0.93, 1.21)	1.01 (0.88, 1.16)	0.96 (0.83, 1.12)	
Less than high school	ref	1.03 (0.62, 1.70)	0.96 (0.53, 1.73)	1.11 (0.60, 2.06)	0.61 (0.30, 1.24)	
Census tract poverty						*0.60*
<11%	ref	1.11 (0.93, 1.32)	1.06 (0.88, 1.28)	1.12 (0.92, 1.36)	1.05 (0.84, 1.31)	
≥11%	ref	1.02 (0.88, 1.19)	1.07 (0.90, 1.27)	0.93 (0.77, 1.12)	0.89 (0.73, 1.08)	
Men (N=196,005)						
Education						*0.42*
High school graduate	ref	0.90 (0.82, 0.98)	0.89 (0.80, 0.98)	0.83 (0.74, 0.92)	0.81 (0.72, 0.92)	
Less than high school	ref	0.80 (0.59, 1.09)	0.66 (0.45, 0.97)	0.64 (0.42, 0.97)	0.69 (0.44, 1.09)	
Census tract poverty						*0.97*
<11%	ref	0.89 (0.81, 0.98)	0.87 (0.78, 0.97)	0.80 (0.71, 0.90)	0.78 (0.68, 0.89)	
≥11%	ref	0.91 (0.76, 1.09)	0.85 (0.69, 1.05)	0.87 (0.69, 1.10)	0.85 (0.67, 1.08)	

[a] adjusted for age, race, marital status, state of residency, smoking, alcohol, vigorous physical activity, TV viewing, and median home value, population density and poverty rate at census tract level. Factors that were stratified by were not included.

Abbreviations: ALAN, artificial light at night; CI, confidence interval; OR, odds ratio.