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SCIENTIFIC INVESTIGATIONS

Outdoor Artificial Nighttime Light and Use of Hypnotic Medications in Older Adults: A Population-Based Cohort Study

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Study Objectives: Outdoor artificial nighttime light is increasingly recognized as a form of environmental pollution. Excessive nighttime light exposure, whether from indoor or outdoor sources, has been associated with a number of deleterious effects on human health. We performed a population-based cohort study in South Korea to assess the possible association between outdoor nocturnal lighting and insomnia in older adults, as measured by prescriptions for hypnotic drugs.

Methods: This study used data from the 2002–2013 National Health Insurance Service-National Sample Cohort (NHIS-NSC), and a total of 52,027 adults who were age 60 years or older were included in the study. Light data were based on satellite mapping of artificial light. The usage data of two hypnotic drugs, zolpidem (N05CF02) and triazolam (N05CD05), were extracted from the NHIS-NSC records.

Results: Of the 52,027 patients in this cohort, 11,738 (22%) had prescriptions for hypnotic drugs. Increasing outdoor artificial nighttime light exposure (stratified by quartile) was associated with an increased prevalence of hypnotic prescriptions and daily dose intake. Compared with individuals in the lowest quartile 1, the regression coefficients for prescription days and daily defined doses of all hypnotic drugs and certain hypotonic drugs were significantly higher among those living in areas with higher outdoor artificial nighttime light (quartiles 2 through 4).

Conclusions: Outdoor artificial nighttime light exposure was significantly associated with prescription of hypnotic drugs in older adults. These findings are consistent with the hypothesis that outdoor artificial nighttime light may cause sleep disturbances.

Keywords: cohort study, medication use, older adults, outdoor lightening, sleep

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Few studies suggest that excessive nighttime light exposure, whether from indoor or outdoor sources, has deleterious effects on sleep. Whether nighttime light pollution exposure seriously affects sleep health remains unclear.

Study Impact: Prescription days and daily defined doses of all hypnotic drugs and certain hypotonic drugs were significantly higher in individuals living in areas with higher outdoor artificial nighttime light than those living in areas with lower artificial nighttime light. Efforts to define and minimize the adverse effects of light pollution on human health are important.

INTRODUCTION

Other than obscuring a view of the Milky Way for one-third of humanity, the widespread use of artificial lighting at night is changing the biological ecosystem.[1,2] The inappropriate or excessive use of outdoor artificial nighttime light, referred to as light pollution, has emerged as a novel environmental issue linked to human health.[3] Research has shown that artificial nighttime lighting, whether indoor or outdoor, induces disruption of circadian rhythms, potentially leading to metabolic and chronic diseases, including cancer, diabetes, obesity, and depression.[4–8]

An intuitive concern is that nighttime light exposure may lead to sleep deprivation. The clearest example of this is the strong links among light exposure, circadian misalignment, and disturbed sleep habits observed with jetlag or in shift workers who work at night.[9–11] Moreover, experimental studies in both animals and humans have demonstrated the potential role of light manipulation in modifying sleep patterns.[6,9–14] Animals exposed to artificial light during sleep were more likely to fall asleep later, wake up earlier, and sleep less than animals kept in the dark at night.[15–17] In humans, aberrant nighttime light exposure in the bedroom is associated with increased insomnia, delayed sleep onset, and poor sleep quality in terms of sleep depth and arousal frequency.[6,12–14] Of note, a recent cross-sectional telephone study among the general United States population provided insights on the possible effects of outdoor artificial nighttime light on sleep, particularly delayed bedtime, delayed wakeup time, reduced nighttime sleep, and reduced sleep quality.[18]

Light pollution is one of the fastest-growing environmental pollutions, but the health effects remain somewhat less well understood because of the lack of data. Whether long-term light pollution exposure seriously affects sleep health remains debatable. The aim of this study is to determine whether outdoor

artificial nighttime light is associated with insomnia in older adults in South Korea. We conducted a population-based cohort study to assess the association between residential outdoor artificial nighttime light and prescriptions for hypnotic drugs during a 12-year period: a 4-year baseline period (2002–2005) and then assessment during an 8-year period (2006–2013).

METHODS

Data Source and Study Population

The National Health Insurance Service (NHIS) in South Korea is a compulsory social insurance program covering the entire population through government subsidies. NHIS is a comprehensive source of all medical claims data generated in health care facilities, including patient information, medical examination and treatment, prescriptions, medical care costs, and diagnostic codes, as per the International Classification of Diseases, Tenth Revision (ICD-10).

This study used data from the 2002–2013 NHIS-National Sample Cohort (NHIS-NSC), a population-based cohort, which were extracted from the NHIS database (serial number: NHIS-2016-2-081). To ensure that the data were representative of the South Korean population, the NHIS-NSC was constructed using stratified random sampling based on age, sex, residential area, income, and annual medical expenses. A total of 1,025,340 individuals (approximately 2.2% of the total eligible population) were included in the cohort in 2002 and were followed up until 2013.[19]

Of a total of 122,809 adults age 60 years or older in 2002 who were identified, 60,359 who had not undergone at least one medical examination or completed a health behavior questionnaire (including questions regarding smoking status, alcohol intake, and exercise) or in whom a sleep disorder had been diagnosed (ICD-10 code: F51) were excluded during the baseline period (2002–2005). An additional 10,423 individuals who died before the end of the study were also excluded; thus, the final study sample included 52,027 older adults. The study protocol was approved by the Institutional Review Board of Seoul National University Hospital. The requirement for informed consent was exempted by the ethics committee.

Assessment of Hypnotic Medication Use

The Anatomical Therapeutic Chemical (ATC) classification system, established by the World Health Organization, classifies drugs according to the organ or system on which they act and their chemical, pharmacological, and therapeutic properties. Drug consumption statistics can be collected based on the ATC codes.[20] Defined daily dose is the assumed average maintenance dose per day for a drug prescribed for its main indication in adults.[20]

For the current study, data were extracted from the NHIS-NSC records of study individuals on prescriptions for hypnotic drugs (ATC code: N05C), including the following subcategories of sleep medications: barbiturates (N05CA), benzodiazepine derivatives (N05CD), benzodiazepine-related drugs (N05CF), and other hypnotic drugs and sedatives (N05CM). Two drugs, zolpidem (N05CF02) and triazolam (N05CD05), were most commonly prescribed, accounting for 63.2% and for 30.4% of prescriptions. The proportion of these two drugs accounted for more than 93.6% of the total hypnotic drugs prescribed.

Estimation of Outdoor Artificial Nighttime Light Exposure

Satellite data pertaining to outdoor artificial nighttime light in South Korea was provided by the National Centers for Environmental Information.[21] These data were based on visible light intensity data, ranging from 0 to 63 nanowatts/cm^2/sr.

The artificial light map comprised the average digital numbers in the visible bands of cloud-free light composites collected by satellite of towns, cities, and other sites with persistent artificial lighting, including gas flares. Temporary events, such as fires, were discarded. Background noise was detected and changed with values of zero.

For the current study, artificial light maps from 2002 to 2013 were obtained and ArcMap 10.4 (ESRI, Redlands, California, United States) was used to calculate nighttime light levels in 232 administrative districts (**Figure 1**). The estimated light pollution level in each administrative district was matched with individuals' residential districts and then assigned an individual exposure level. Light pollution levels (nanowatts/cm^2/sr) were converted into quartiles: quartile 1 (≤ 22.05), quartile 2 (22.06–45.37), quartile 3 (45.38–61.60), and quartile 4 (≥ 61.61).

Variables of Interest

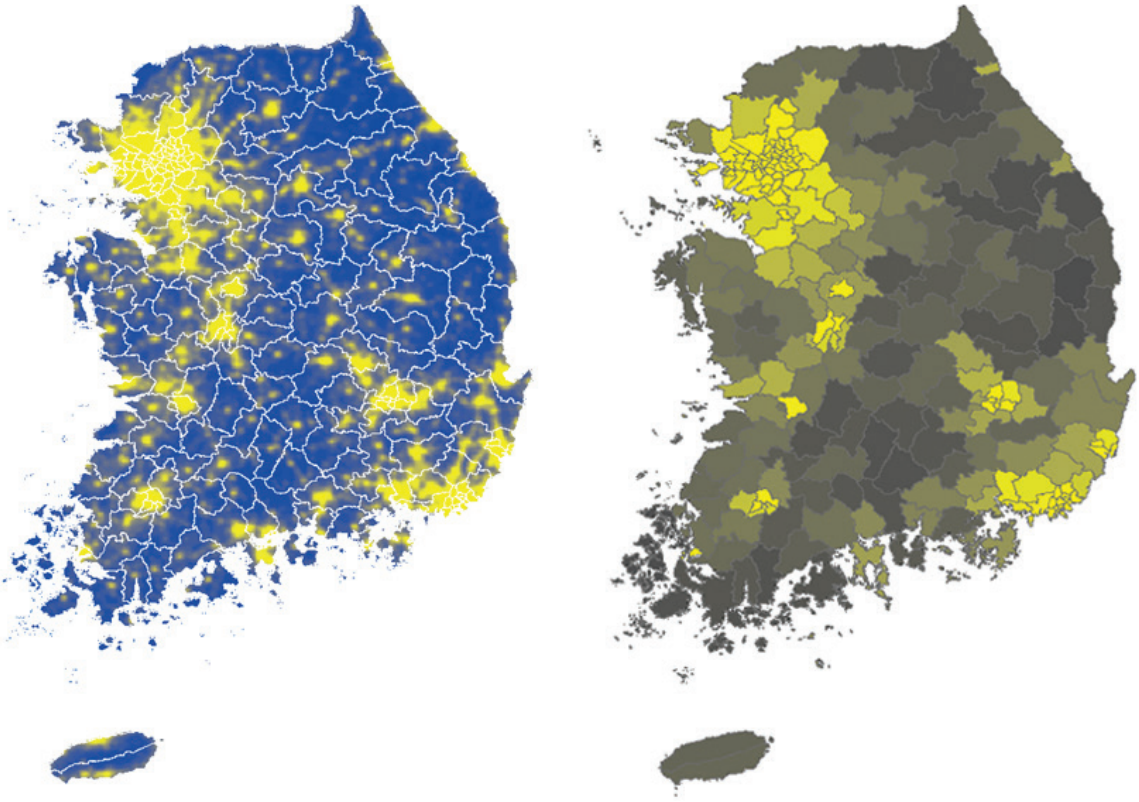
Variables of interest included demographics, health behaviors, and the presence of psychiatric disease as baseline characteristics of the study population in 2002–2005.

Demographic variables included age stratified by 5-year increments (60–64, 65–69, 70–74, 75–79, 80–84, or 85 years or older) and sex (male or female). Residential areas were classified into metropolitan and other area. Household income relative to the median was categorized into four strata: < 25%, 25% to 50%, 50% to 75%, or > 75%. Body mass index (BMI) was calculated as an individual's weight in kilograms divided by height in meters squared, and was categorized as a binary variable, either < 25.0 kg/m^2 or ≥ 25.0 kg/m^2. Variables for health behaviors were exercise (yes or no), cigarette smoking (never smoked, former smoker, or current smoker), and current alcohol consumption (yes or no). The presence of a psychiatric disorder (2002–2005) was defined as a mental health condition affecting hypnotic medication use.

Statistical Analysis

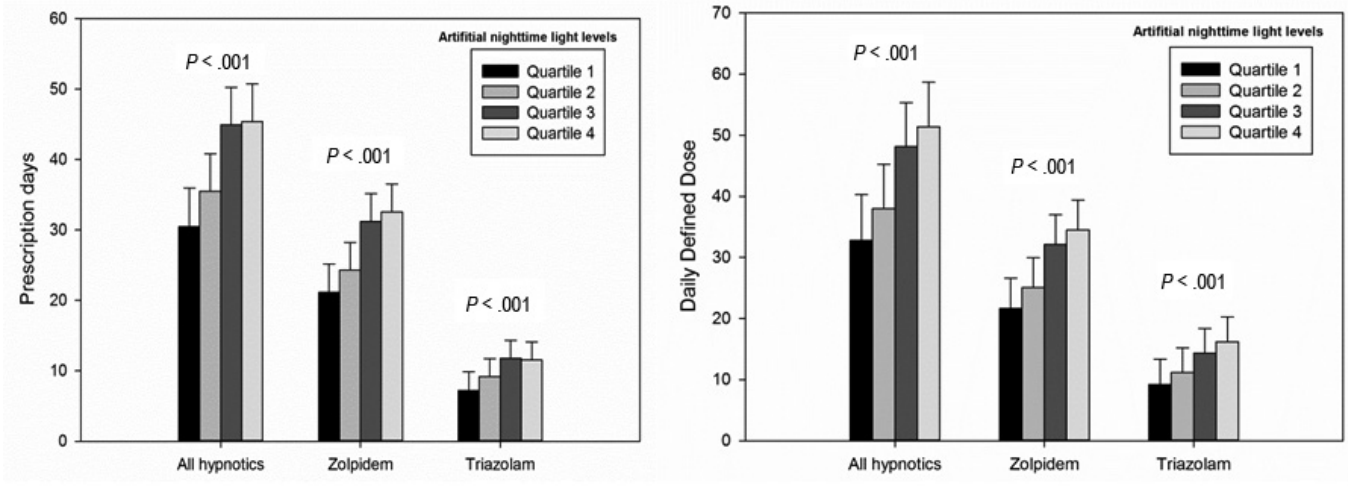
Statistical differences in demographic variables (ie, age, sex, residential area, and income), BMI, health behaviors (ie, exercise, cigarette smoking, and current alcohol consumption), and history of psychiatric disorders between participants with and without hypnotic drug use were examined using the chi-square test. Outdoor artificial nighttime light levels (nanowatts/cm^2/sr) were categorized into quartiles: quartile 1 (≤ 22.05), quartile 2 (22.06–45.37), quartile 3 (45.38–61.60), and quartile 4 (≥ 61.61). Summary statistics of the mean and standard error (SE) for the number of prescription days and daily defined dose of hypnotic drugs were calculated by quartiles of artificial

Figure 1—Distribution of artificial nighttime light in South Korea.



Satellite light pollution image (left) and mean light pollution value of each district (right). Lighter colors indicate greater light pollution.

Figure 2—Least square means.



Least square means of the number of prescription days (left) and daily defined dose (right) by quartiles of light pollution exposure. Least square means were calculated by adjustment for the confounding variables of age, sex, residential area, income, body mass index, exercise, smoking, alcohol, and the presence of psychiatric diseases. Bar indicates the mean number of prescription days or daily defined dose according to quartiles of outdoor artificial nighttime lighting. The central line on each bar indicates the standard error.

nighttime light. Least square means (or adjusted mean) were calculated by adjustment for all confounders (age, sex, residential area, income, BMI, exercise, smoking, alcohol, and the presence of psychiatric diseases), as seen in **Figure 2**. Linear regression analysis was performed to identify associations between light pollution exposure and the number of prescription days and daily defined dose of hypnotic drugs. Linear regression analyses provided beta coefficient and standard error (SE) for prescription days and daily defined dose of hypnotic drugs among individuals exposed to higher levels of artificial nighttime light (quartiles 2 through 4), as compared those exposed to the lowest level of nighttime light (quartile 1) as the reference group. The adjusted linear regression model was adjusted for all potential confounders, whereby age

Table 1—Characteristics of individuals who did or did not take hypnotic drugs (2006–2013).

	Not Taking Hypnotic Drugs (n = 40,289)	Taking Hypnotic Drugs (n = 11,738)	*P*
Age (years)			
60–64	20,096 (79.3)	5,262 (20.8)	< .0001
65–69	12,109 (76.3)	3,754 (23.7)	
70–74	5,586 (75.0)	1,863 (25.0)	
75–79	1,930 (74.4)	665 (25.6)	
80–84	490 (74.1)	171 (25.9)	
85 or older	78 (77.2)	23 (22.8)	
Sex			
Male	16,692 (81.4)	3,816 (18.6)	< .0001
Female	23,597 (74.9)	7,922 (25.1)	
Residential area			
Metropolitan	15,512 (76.6)	4,742 (23.4)	.0002
Others	24,777 (78.0)	6,996 (22.0)	
Household income relative to the median (%)			
Lowest (< 25%)	12,640 (77.9)	3,595 (22.1)	< .0001
25–50%	6,520 (78.3)	1,807 (21.7)	
50–75%	9,163 (78.2)	2,561 (21.8)	
Highest (≥ 75%)	11,966 (76.0)	3,775 (24.0)	
BMI (kg/m^2)			
< 25	26,049 (77.8)	7,423 (22.2)	.0048
≥ 25	14,240 (76.7)	4,315 (23.3)	
Exercise			
No	26,627 (77.7)	7,650 (22.3)	.0652
Yes	13,662 (77.0)	4,088 (23.0)	
Smoking status			
Never smoker	32,343 (76.8)	9,755 (23.2)	< .0001
Former smoker	1,946 (79.6)	500 (20.4)	
Current smoker	6,000 (80.2)	1,483 (19.8)	
Alcohol consumption			
No	30,429 (76.5)	9,360 (23.5)	< .0001
Yes	9,860 (80.6)	2,378 (19.4)	
Psychiatric disease (2002–2005)			
No	25,951 (82.8)	5,375 (17.2)	< .0001
Yes	14,338 (69.3)	6,363 (30.7)	

Values are presented as n (%). The *P* values are based on the chi-square test. BMI = body mass index.

(60–64, 65–69, 70–74, 75–79, 80–84, or 85 years or older as reference), sex (male or female as reference), residential area (metropolitan or other area as reference), income relative to the median (< 25%, 25% to 50%, 50% to 75%, or > 75% as reference), BMI (< 25.0 kg/m^2 or ≥ 25.0 kg/m^2 as reference), exercise (no or yes as reference), smoking (never smoked, former smoker, or current smoker as reference), drinking alcohol (no or yes as reference), and the presence of psychiatric diseases (no or yes as reference). All analyses were performed using SAS 9.2 software (SAS Institute, Cary, North Carolina, United States), and the statistical significance level was set at $\alpha = .05$.

RESULTS

Among the 52,027 older adults in the study population, 11,738 (22.6%) took hypnotic drugs (**Table 1**). These individuals were more likely to be older than those not taking hypnotic drugs, with the use of hypnotics increasing with each age group up to 85 years and older. Individuals using hypnotic drugs were more likely to be women, to live in metropolitan areas, or to have the highest household income (≥ 75%). Older adults who took hypnotic drugs were also more likely to be overweight or obese (BMI ≥ 25 kg/m^2), to be nonsmokers, or to drink alcohol. There was a higher proportion of psychiatric diagnoses among those taking hypnotic drugs. Differences in all these variables, with the exception of exercise, were statistically significant.

Table 2 shows the summary statistics with the mean (SE) for daily defined doses and prescription days of hypnotic agents. With increased outdoor artificial nighttime light exposure, prescription days of all hypnotic drugs (including zolpidem and triazolam) were significantly increased ($P < .0001$). Similar associations between light pollution and daily defined dose of all and specific hypnotic drugs were observed. The least square

Table 2—Number of prescription days and daily defined dose of hypnotic drugs by quartiles of outdoor artificial light exposure.

Quartiles of Outdoor Artificial Nighttime Light (nanowatts/cm²/sr)	All Hypnotic Drugs	Zolpidem	Triazolam
Prescription days			
Quartile 1 (≤ 22.05)	19.10 (1.00)	13.71 (0.79)	3.81 (0.39)
Quartile 2 (22.06–45.37)	25.22 (1.19)	17.24 (0.83)	6.02 (0.56)
Quartile 3 (45.38–61.60)	33.90 (1.52)	23.41 (1.14)	8.18 (0.67)
Quartile 4 (≥ 61.61)	35.24 (1.66)	24.96 (1.23)	8.81 (0.86)
Daily defined dose			
Quartile 1 (≤ 22.05)	20.18 (1.12)	12.88 (0.77)	4.55 (0.49)
Quartile 2 (22.06–45.37)	26.62 (1.38)	16.42 (0.82)	6.77 (0.64)
Quartile 3 (45.38–61.60)	36.54 (1.75)	22.30 (1.13)	9.82 (0.85)
Quartile 4 (≥ 61.61)	38.84 (2.12)	23.82 (1.22)	10.81 (1.19)

Values are presented as mean (standard error).

Table 3—Number of prescription days and daily defined dose of hypnotic drugs by quartiles of outdoor artificial light exposure in unadjusted and adjusted models.

Quartiles of Outdoor Artificial Nighttime Light (nanowatts/cm²/sr)	All Hypnotic Drugs		Zolpidem		Triazolam	
	Beta (SE)	*P*	Beta (SE)	*P*	Beta (SE)	*P*
Prescription days						
Unadjusted model						
Quartile 1 (≤ 22.05)	Reference		Reference		Reference	
Quartile 2 (22.06–45.37)	6.68 (1.91)	.0005	3.75 (1.42)	.0082	2.33 (0.90)	.0097
Quartile 3 (45.38–61.60)	16.41 (1.94)	< .0001	10.38 (1.44)	< .0001	5.15 (0.91)	< .0001
Quartile 4 (≥ 61.61)	16.19 (1.98)	< .0001	11.40 (1.48)	< .0001	4.99 (0.94)	< .0001
Adjusted model						
Quartile 1 (≤ 22.05)	Reference		Reference		Reference	
Quartile 2 (22.06–45.37)	5.83 (1.57)	.0002	3.44 (1.16)	.0030	2.17 (0.75)	.0038
Quartile 3 (45.38–61.60)	14.89 (1.76)	< .0001	9.77 (1.30)	< .0001	4.75 (0.85)	< .0001
Quartile 4 (≥ 61.61)	14.03 (1.92)	< .0001	10.51 (1.42)	< .0001	4.07 (0.92)	< .0001
Daily defined dose						
Unadjusted model						
Quartile 1 (≤ 22.05)	Reference		Reference		Reference	
Quartile 2 (22.06–45.37)	6.14 (2.10)	.0035	3.54 (1.41)	.0122	2.22 (1.17)	.0573
Quartile 3 (45.38–61.60)	15.59 (2.11)	< .0001	9.41 (1.42)	< .0001	5.27 (1.17)	< .0001
Quartile 4 (≥ 61.61)	17.07 (2.15)	< .0001	10.94 (1.45)	< .0001	6.26 (1.19)	< .0001
Adjusted model						
Quartile 1 (≤ 22.05)	Reference		Reference		Reference	
Quartile 2 (22.06–45.37)	6.43 (2.14)	.0027	3.82 (1.44)	.0079	2.42 (1.19)	.0420
Quartile 3 (45.38–61.60)	16.47 (2.43)	< .0001	10.26 (1.63)	< .0001	5.82 (1.35)	< .0001
Quartile 4 (≥ 61.61)	18.20 (2.65)	< .0001	12.04 (1.78)	< .0001	6.96 (1.47)	< .0001

Adjusted model is adjusted by age, sex, residential area, income, body mass index, exercise, smoking, alcohol, and the presence of psychiatric diseases.
SE = standard error.

means (adjusted means) of daily defined doses and prescription days of hypnotic agents in terms of increased nighttime light exposures were calculated. Values were adjusted for age, sex, residential area, income, BMI, exercise, smoking, alcohol, and the presence of psychiatric diseases. With each quartile increase in outdoor artificial nighttime light exposure, the mean number of prescription days of all hypnotic drugs and specific agents significantly increased, along with the mean daily defined dose.

Table 3 shows the beta coefficients (SE) for the number of prescription days and daily doses of hypnotic drugs by quartiles of outdoor artificial nighttime light exposure. Compared with individuals living in the lowest quartile of outdoor artificial nighttime light exposure (quartile 1), the regression coefficients for prescription days of all hypnotic drugs and certain hypotonic drugs were significantly higher among those living in areas with higher outdoor artificial nighttime light (quartiles 2 through 4). After adjustment for age, sex, residential area,

income, BMI, exercise, smoking status, alcohol, and presence of psychiatric disease, the association between outdoor artificial nighttime light and the number of days of hypnotic drug use remained significant. The results were similar for daily defined doses of hypnotic drugs. The adjusted beta coefficient of the daily defined dose was significantly higher with increasing quartiles, of outdoor artificial nighttime light exposure, with the highest beta coefficient observed in individuals in quartile 4 ($\beta = 17.07$, $P < .0001$ for all hypnotic drugs; $\beta = 10.94$, $P < .0001$ for zolpidem; and $\beta = 6.26$, $P < .0001$ for triazolam).

DISCUSSION

The results of the current study showed that outdoor artificial nighttime light exposure was significantly associated with prescription of hypnotic drugs in older adults. In particular, as compared with those with the lowest exposure (quartile 1), older adults exposed to higher levels of residential outdoor artificial nighttime light were more likely to use hypnotic drugs for longer periods or higher daily dosages. These findings support the evidence in the literature of an association between artificial nighttime light and sleep disturbances. In addition, these findings suggest that artificial nighttime light pollution contributes to insomnia, as shown by higher hypnotic use among older adults with higher degrees of light exposure.

In modern society, artificial light at night has become a ubiquitous environmental pollutant.[1,2] Artificial light exposure, unlike other environmental pollutants, is not directly toxic and does not impose a direct physical energy burden on living organisms. Therefore, it is difficult to define a biologically hazardous dose of light. However, the prevalence of certain human health effects continues to increase along with artificial nighttime light exposure.[3,4] Light-induced disruption of circadian rhythms is recognized as a contributor to a host of health problems in humans.[3,7]

Circadian rhythms, which are physiological and behavioral cycles occurring approximately every 24 hours,[22,23] play a central role in the regulation of a variety of biological processes, with sleep being of special concern. Circadian rhythms are generated by the endogenous biological pacemaker in the suprachiasmatic nucleus (SCN) in the anterior hypothalamus, but can also be reset by exogenous stimuli, known as zeitgebers.[22–24] The most potent environmental zeitgeber is light exposure.[24] Light enters the eye and is perceived in the retina containing the photoreceptors: rods, cones, and intrinsically photosensitive retinal ganglion cells (ipRGCs).[25,26] The classic ocular photoreceptors, rods and cones, are responsible for image-forming vision. In contrast, melanopsin-containing ipRGCs are responsible for non-image-forming biological functions, such as circadian rhythms, pupillary light reflexes, and sleep.[25,27] Thus, light exposure on the retina acts as an environmental zeitgeber or cue for the internal central clock in SCN, resulting in the inhibition of melatonin synthesis. Melatonin, a hormone secreted by the pineal gland, is responsible for synchronizing circadian rhythms and the sleep-wake cycle.[28] Artificial nighttime light exposure can, therefore, potentially lead to changes in the SCN clock and melatonin production, which further contribute to sleep problems.

This study is the first population-based investigation to report a significant association between outdoor artificial nighttime light exposure and insomnia, as indicated by the use of hypnotic drugs. This is consistent with results from a study by Ohayon and Milesi, showing an association between light pollution and modifications of the sleep-wake cycle and sleep disturbances in the general population.[18] A natural question associated with our findings is how outdoor artificial nighttime light is linked to sleep deprivation among those while inside the house, an issue not addressed in this study. Chepesiuk suggested a scenario whereby outdoor artificial nighttime lighting could affect indoor light exposure,[3] which could occur directly, with outside artificial nighttime lighting reaching people inside the house at levels capable of affecting hormone production. Conversely, it might function indirectly, with bright outside lighting making the inside seem darker. This could lead people to turn on more interior lights, resulting in greater interior light exposure than required if there were not such a great contrast between the outside and inside lights, which in turn would contribute to disturbances of biological rhythms.[3] A growing body of literature has provided evidence on significant associations between outdoor artificial nighttime light intensity and cancer, obesity, and sleep health.[29–32] The findings of the current study may fit this context, drawing attention to the possibility that artificial light-associated sleep disturbances are attributable to outdoor light pollution. However, the current results suggest that these reports may underestimate true differences because, although prescription hypnotic use represents a subgroup of individuals with sleep disturbances, this may be an underrepresentation because many individuals may not seek treatment or may pursue nonprescription or other nonpharmacological solutions. Also, the possible correlation of greater nighttime illumination with areas of increased accessibility to health care and prescription medications cannot be ruled out in regions where residents experience increased stress levels. In the latter case, the sleep problems indicated by the hypnotic medications use might not result entirely from direct photic effects. Future studies are needed to determine the effects of outdoor artificial nighttime light on human health. Our study has several limitations. The most critical issue is the methodology to estimate outdoor light pollution exposure, namely the use of satellite data. Although satellite images provide a real-time direct readout of local environmental data to mobile receiving terminals at key locations throughout the world,[33] there have been concerns about its low spatial resolution, low radiometric resolution, the saturation effect in bright regions, and lack of on-board calibration.[34] These issues might lead to misclassification of outdoor artificial nighttime light exposure. Nevertheless, satellite-based measurements of outdoor artificial nighttime light exposure as a proxy for personal outdoor artificial nighttime light exposure has been widely used.[29–32] The necessity and usefulness of satellite-based data has been supported.[35,36] Second, although we used the NHIS-NSC, a representative population-based cohort in South Korea,[19] it was not designed with any particular study in mind. Our data showed that older individuals were more likely to use hypnotic medications, with the use increasing with each age group, which is consistent with United States data.[37] Nevertheless, the exclusion of individuals

based on personal characteristics from the database may have introduced systematic bias, indicating that our findings may not be generalizable to adults who were not included in the research. Third, we cannot rule out misclassification of data and the presence of confounding variables. The details of the hypnotic drugs prescribed (ie, drug name, daily dose, and duration) might have been incorrect because of misdiagnosis or miscoding in the insurance claims database. Although these results were adjusted for several covariates, the NHIS-NSC cannot include all possible confounders (ie, occupation, mental stress, illumination in the bedroom, and residential environment). Thus, the potential effect of unmeasured confounders could not be ruled out. In future research, such considerations should be addressed to clarify the observed association between outdoor light pollution and hypnotic drug use.

In conclusion, we observed a significant association between the intensity of outdoor light pollution and the prevalence of insomnia as indicated by hypnotic agent prescriptions for older adults in South Korea. This study strengthens the potential link between outdoor artificial nighttime light and adverse health consequences, especially sleep disturbances, suggesting that light pollution may be a novel risk factor for prescribing hypnotic drugs. Although light pollution is very common, it seems to be of less interest than other environmental pollutants. However, the findings of the current study and previous studies imply that efforts to define and minimize the adverse effects of light pollution on human health are important.

ABBREVIATIONS

ATC, Anatomical Therapeutic Chemical
BMI, body mass index
ICD, International Classification of Diseases
ipRGCs, intrinsically photosensitive retinal ganglion cells
NHIS, National Health Insurance Service
NHIS-NSC, NHIS-National Sample Cohort
SCN, suprachiasmatic nucleus
SE, standard error

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