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Artificial light at night and risk of mental disorders: A systematic review

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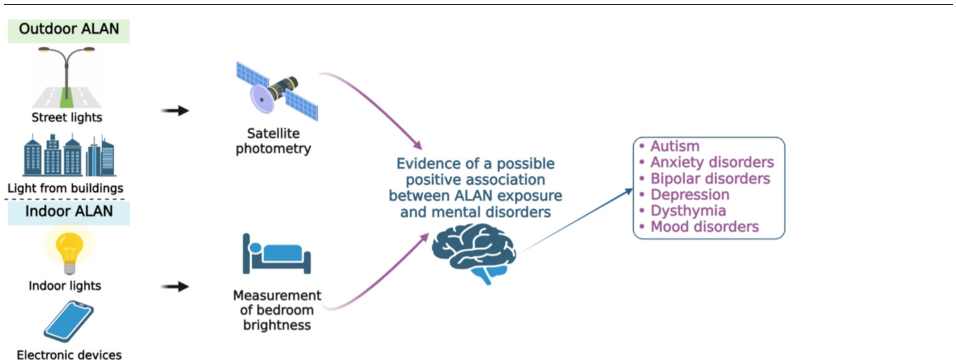
HIGHLIGHTS

- Exposure to artificial light at night (LAN) is increasing worldwide.
- Animal and laboratory studies suggest detrimental effects on behavior and mood.
- Epidemiological evidence suggests that LAN may increase risk of depression.
- Number of epidemiological studies is limited, more robust evidence is needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Emerging evidence suggests a possible association between artificial light at night (LAN) exposure and physiological and behavioral changes, with implications on mood and mental health. Due to the increased amount of individuals' LAN exposure, concerns have been raised regarding harmful impact of light pollution on mental health at the population level.
Aim: To perform a systematic review of observational studies to investigate if light at night, assessed both indoor and outdoor, may be associated with an increased risk of mental diseases in humans.
Methods: We reviewed the epidemiological evidence on the association between LAN exposure, assessed either via satellite photometry or via measurements of bedroom brightness, and mental disorders. We systematically searched the PubMed, Embase and Web of Science databases up to April 1, 2022. Studies were included if they assessed the link between indoor or outdoor artificial light at night and one or more mental disorders in human populations.
Results: Nine eligible studies were included in this review: six studies had a cross-sectional design, two had a longitudinal design with a median follow-up of 24 months, and one was a case-cohort study. Overall, we found moderate evidence of a positive association between LAN exposure and depressive symptoms and to a lesser extent other mental disorders, though the number of studies was limited and potential residual confounding such as socioeconomic factors, noise, or air pollution may have influenced the results.
Conclusions: Although more robust evidence is needed, the epidemiological evidence produced so far seems to support an association between LAN and risk of depressive disorders.

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Contents

Abbreviations

CES-D	Center for Epidemiologic Studies Depression Scale
GDS	Geriatric Depression Scale
LAN	Light at night
PHQ	Patient Health Questionnaire
PRISMA	Preferred Reporting Items for Systematic review and Meta-Analysis

1. Introduction

Mental disorders include a wide range of different illnesses, with depression being the most relevant. Several data have demonstrated the increased burden of mental disorders in the last decades (World Health Organization, 2017) and various risk factors have been investigated, including environmental determinants (Attademo et al., 2017; Bakolis et al., 2021; Kim et al., 2021; Liu et al., 2021). Nevertheless, the etiology of many mental disorders is still uncertain.

In modern society, individuals are increasingly exposed to artificial light at night (LAN) i.e., different sources of light altering the natural day-night cycle. The New World Atlas of Artificial Sky Brightness reports that "more than 80% of the world and more than 99% of the US and European populations live under light-polluted skies" (Falchi et al., 2016). Outdoor LAN (e.g., urban artificial light) can presumably reach indoor environments, although the relationship between outdoor and indoor LAN exposure has not been fully elucidated (Rea et al., 2011). Further, indoor light exposure has increased during the last decades, mainly because of home lights turned on during night, as well as new sources of exposure (e.g., electronic devices such as monitors, smartphones, etc.), polluting the natural nighttime darkness and exerting potential risks to human health.

High LAN exposure has already been linked to detrimental effects in humans, including increased risk of breast cancer (Lai et al., 2021; Urbano et al., 2021) and obesity (Lai et al., 2020). Moreover, emerging evidence suggests that LAN exposure might be associated with physiological and behavioral changes, with implications on mood and mental health (Bedrosian and Nelson, 2013). Hence, increased light pollution and over-illuminated nightlife raise concerns regarding their potentially harmful impact on mental health at a population level (Bedrosian and Nelson, 2013).

Evidence on animal models shows that LAN has a negative influence on mood. Several studies show that nighttime light exposure can induce depressive behaviors in both diurnal (Fonken et al., 2012; Taufique et al., 2018) and nocturnal animals (Bedrosian et al., 2011). The mechanisms underlying these effects are still unclear, as some studies suggest that they may depend on a direct influence in mood regulation (An et al., 2020) whereas others on the disruption of circadian rhythm (Bedrosian and Nelson, 2013; Tam et al., 2021). With regard to the role of LAN on other types of mental disorders, studies suggest that LAN exposure during early development increases adult anxiety-like responses in mice (Borniger et al., 2014; Cissé et al., 2016) and can have a different impact on anxiety levels in aged mice depending on sex and estrous cycle. Other studies show a decreased anxiety-like response in Swiss-Webster mice exposed to lighting conditions for three weeks (Fonken et al., 2009). Further, behavioral detrimental effects due to LAN exposure have been reported in other animal studies carried out in both terrestrial and aquatic organisms (Dickerson et al., 2022; Lynn et al., 2021) and an additional laboratory study suggests that artificial LAN may have negative consequences on cell proliferation and brain plasticity of zebra finches (Moaraf et al., 2021). However, despite the evidence in animal studies produced so far, the link between LAN and mental disorders in humans remains unclear and more information is needed in order to better assess possible risks. Therefore, in this paper, we systematically reviewed and assessed the epidemiological evidence relating to the association between LAN exposure and mental disorders in humans.

2. Methods

2.1. Literature search

For this study, we followed the modified Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) guidelines (Page et al., 2021), including the PRISMA checklist (Supplemental Table S1). We formulated the research question according to PECOS statement (Population, Exposure, Comparators, Outcomes, and Study design): "Is exposure to light at night, assessed both indoor and outdoor, associated with an increased risk of mental diseases in humans in non-experimental studies?" (Morgan et al., 2018). We systematically searched the literature in online databases up to April 1, 2022, using different search terms linked to "mental disorders" and "light at night", with no language restrictions. The studies were searched in Medical Literature Analysis and Retrieval System Online (MEDLINE) using PubMed, Excerpta Medica database (Embase) and Web of Science Core Collections. Details of the search strategies are reported in Supplemental Table S2. We searched the reference lists of all included articles in order to find other relevant articles. Two authors (TF and ST) independently selected the studies and extracted the relevant information following a two-steps process, with a first screening based on each article's title and abstract and a second independent screening of the full texts of the potentially relevant articles. Discrepancies were solved through discussion with a third author (TU). Studies were included if they could meet the following criteria: they were performed in human populations using observational study design (e.g. cross-sectional, case-control, cohort); the exposure variable was artificial light at night, assessed either as indoor or outdoor lighting; the outcome variable was any kind of mental disorders.

2.2. Risk of bias assessment

We assessed the quality of the studies using the National Institute of Health (NIH) Quality assessment tool for Observational Cohort and Cross-Sectional studies (NHLBI, 2013). We assessed potential bias for each study using 14 criteria: (1) research question (2–3) study population (4) groups recruited from the same population and uniform eligibility criteria (5) sample size justification (6) exposure assessment prior to outcome measurement (7) sufficient timeframe to see an effect (8) different levels of exposure of interest (9) exposure measures and assessment (10) repeated exposure assessment (11) outcome measures (12) blinding of outcome assessor (13) follow-up rate (14) statistical analyses. Two authors independently assessed the studies (ST and TU). A "good", "fair" or "poor" quality rating was given to each study. Disagreements were resolved through discussion. Where discrepancies remained, studies were assessed by a third reviewer (TF).

2.3. Data extraction

For each included study we extracted the following data: first author name, year of publication, study country, population characteristics, study design, recruitment period, type of LAN exposure, method of LAN exposure assessment, outcome, method of outcome assessment, adjustment factors and results.

3. Results

Fig. 1 shows the PRISMA flow-chart of the search results. We identified 653 citations and removed 54 duplicate publications. After excluding 584 studies following abstract and title screening, 15 articles were considered to be potentially eligible for this review and retrieved in full text. Eight studies eventually met inclusion criteria (Esaki et al., 2020; Esaki et al., 2022; Helbich et al., 2020; Min and Min, 2018; Obayashi et al., 2013; Obayashi et al., 2018; Paksarian et al., 2020; Xie et al., 2022). One further study was identified through citation chasing, by checking the reference lists of included articles (Wallace-Guy et al., 2002). Main reasons for exclusion were the study being a letter, a commentary or a review, having a different exposure (e.g., exposure to light during daytime) or a different outcome.

Table 1 shows the characteristics of the eligible studies. Among the nine studies included, two were carried out in the US, four in Japan, one in South Korea, one in China, and one in The Netherlands. Six studies had a cross-sectional design (Esaki et al., 2020; Helbich et al., 2020; Min and Min, 2018; Obayashi et al., 2013; Paksarian et al., 2020; Wallace-Guy et al., 2002), two had a longitudinal design with a 24 months median follow-up time (Esaki et al., 2022; Obayashi et al., 2018), and one was a case-cohort study (Xie et al., 2022). Two studies (Esaki et al., 2022; Obayashi et al., 2018) were performed on same cohorts of two previous ones (Esaki et al., 2020; Obayashi et al., 2013), respectively, but we included all of them and assessed them separately because they included different participants (one study excluded participants with diagnosed depression or with a score of the Geriatric Depression Scale (GDS-15) above the cut-off and the other included participants having a GDS-15 score above the cut off, self-reported history of depression or undergoing antidepressant therapy) (Obayashi et al., 2013; Obayashi et al., 2018) or assessed different outcomes (Esaki et al., 2020; Esaki et al., 2022). The studies were published between 2002 and 2022. Seven studies were conducted in adult populations, one among adolescents, and one among children. Sample size ranged from 154 to 152,159 individuals.

In five studies LAN exposure was assessed indoor (Esaki et al., 2020; Esaki et al., 2022; Obayashi et al., 2013; Obayashi et al., 2018; Wallace-

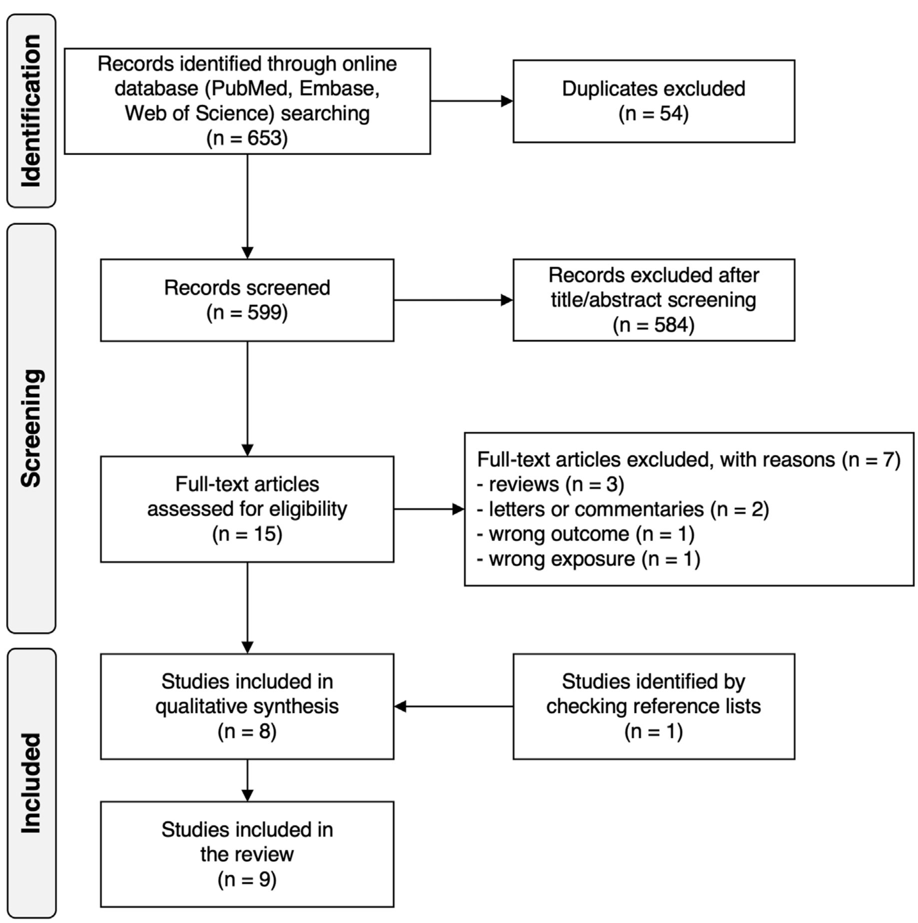

Fig. 1. Flowchart summarizing the literature search.

Table 1
Characteristics of the included studies.

Reference	Country	Study design	Population, N (age range)	Recruitment period	Type of LAN exposure	LAN exposure assessment	Outcome	Outcome assessment	Adjustment factors	Main findings
(Esaki et al., 2020)	Japan	Cross-sectional analysis of the Association between the Pathology of Bipolar Disorder and Light Exposure in Daily Life (APPLE) cohort study	184 (aged 18–75 years)	2017–2019	Bedroom light exposure at night	Bedroom light exposure from bedtime to rising time assessed for 7 consecutive days using a portable photometer	Manic symptoms in BD patients	Young Mania Rating Scale (YMRS)	Type of BD, MADRS (Montgomery–Åsberg Depression Rating Scale) score, sleep duration, and daytime physical activity	Hypomanic state: OR 2.15 (95% CI 1.09–4.22)
(Esaki et al., 2022)	Japan	Longitudinal analysis of the Association between the Pathology of Bipolar Disorder and Light Exposure in Daily Life (APPLE) cohort study	184 (aged 18–75 years)	2017–2019	Bedroom light exposure at night	Bedroom light exposure from bedtime to rising time assessed for 7 consecutive days using a portable photometer	Mood episode relapses in BD patients	Events were diagnosed as manic or hypomanic episodes (with or without mixed features) or depressive episodes according to the DSM-5 criteria	Age, sex, employment status, type of bipolar disorder, anxiety disorder, substance use disorder, depressive and manic symptoms, multiple mood episodes during the year before the baseline assessment, body mass index, bedtime, rising time, total sleep time, sleep efficiency, physical activity, daytime illuminance, and day length	Manic/hypomanic episode relapses: HR 2.173 (1.044–4.522) Manic episode relapses: HR 1.435 (95% CI 0.287–7.182); Hypomanic episode relapses: HR 2.030 (95% CI 0.841–4.902); Manic/hypomanic episode with mixed features relapses: HR 5.763 (95% CI 0.522–63.679)
(Helbich et al., 2020)	The Netherlands	NEEDS project, online cross-sectional survey	10,482 (aged 18–65 years)	2018	Outdoor ALAN	Satellite-measured annual ALAN	Depressive symptoms	Self- administered Patient Health Questionnaire (PHQ–9)	Sex, ethnicity, age, marital and family status, educational background, household income, ethnicity, Shannon index of building usage, air pollution ($PM_{2.5}$, NO_2), noise, urbanicity, greenness, population density, deprivation, and social fragmentation	100 m buffer, crude model: βQ2 0.503 (95% CI 0.207–0.798), βQ3 0.587 (95% CI 0.291–0.884) βQ4 0.921 (95% CI 0.623–1.218) βQ5 1.322 (95% CI 1.023–1.620) 100 m buffer, model adjusted for individual and area-level confounders: βQ2 0.420 (95% CI 0.125–0.715), βQ3 0.383 (95% CI 0.071–0.696), βQ4 0.513 (95% CI 0.177–0.850), βQ5 0.541 (95% CI 0.141–0.941)
(Min and Min, 2018)	South Korea	Korean Community Health Survey (KCHS), cross-sectional study	113,119 (aged 20–59 years) for the assessment of depressive symptoms and 152,159 (aged 20–59 years) for the assessment of suicidal behavior	2009	Outdoor LAN	Outdoor LAN estimated by satellite data	Depressive symptoms and suicidal behavior	Korean version of the CES-D Scale	Age, sex, marital status, education, monthly, job types. Smoking status, alcohol consumption, moderate- intensity physical activities hypertension, diabetes mellitus, and dyslipidemia., nighttime noise, ambient pollutants, and lack of parks and green spaces	Depressive symptoms: OR 1.29 (95% CI 1.15–1.46) Suicidal behaviors: OR 1.27 (95% CI 1.16–1.39)
(Obayashi et al., 2013)	Japan	Cross-sectional analysis of the HEIJO-KYO cohort	516 (aged ≥ 60 years)	2010–2012	Nighttime bedroom light	Light meter (LX-28SD; Sato Shouji Inc., Kanagawa, Japan). Two LAN exposure parameters: average light intensity during the in- bed period (NLavg); and duration of light exposure ≥10 lx during the in-bed period (NL10).	Depressive symptoms	Short version of the Geriatric Depression Scale (GDS-15 ≥5), self-reported medical history or current anti depressive therapy	Daytime light exposure, insomnia, hypertension, habitual sleep duration, and habitual physical activity	NLavg ≥5 lx exposure: OR 1.89 (95% CI 1.10–3.25) NL10 ≥30 min exposure: OR 1.71 (95% CI 1.01–2.89)
(Obayashi et al., 2018)	Japan	HEIJO-KYO cohort	863 (aged ≥60 years)	2010–2014	Nighttime bedroom light	Light meter (LX-28SD; Sato Shouji Inc., Kanagawa, Japan). Three LAN parameters: average	Depressive symptoms	Short version of the Geriatric Depression Scale	Model 1: Age and sex Model 2: Age, sex, body mass index, economic status	LAN 5 exposure: Model 1: HR 1.80 (95% CI 1.08–2.98)

						intensity of nighttime light exposure (LAN average), total time of nighttime light intensity of ≥ 5 lx (LAN 5), and total time of nighttime light intensity of ≥ 10 lx (LAN 10)		(GDS-15; cut-off: 6)	Model 3: Age, sex hypertension, diabetes, and sleep parameters	Model 2: HR 1.89 (95% CI 1.13–3.14) Model 3: HR 1.72 (95% CI 1.03–2.89)
(Paksarian et al., 2020)	US	National Comorbidity Survey-Adolescent Supplement (NCS-A), cross-sectional study	10,123 (aged 13–18 years)	2001–2004	Outdoor artificial light at night (ALAN)	Satellite imagery data	Past-year mood, anxiety, behavior, and substance use disorders	In person diagnostic interview with modified version of the World Health Organization Composite International Diagnostic Interview version 3.0	Age, sex, race/ethnicity, parental education, number of siblings, number of biological parents, family income-to-poverty ratio, and immigrant generation	Classes of mental disorders. Mood disorders: OR 1.07 (95% CI 1.00–1.14) Anxiety disorders: OR 1.10 (95% CI 1.05–1.16) Substance disorders: OR 1.00 (95% CI 0.90–1.11) Behavior disorders: OR 1.04 (95% CI 0.93–1.17) Specific disorders. Bipolar disorder: OR 1.19 (95% CI 1.05–1.35) Major depressive disorder or dysthymia: OR 1.07 (95% CI 1.00–1.15) Agoraphobia without panic: OR 1.05 (95% CI 0.89–1.24) Generalized anxiety: OR: 0.93 (95% CI 0.68–1.26) Social Phobia: OR 1.06 (95% CI 0.96–1.18) Specific phobia: OR 1.18 (95% CI 1.11–1.26) Panic disorder: OR 1.07 (95% CI 0.85–1.33) Post-traumatic stress disorder: OR 0.93 (95% CI 0.80–1.08) Separation anxiety OR 1.06 (95% CI 0.88–1.28)
(Wallace-Guy et al., 2002)	US	Women's Health Initiative (WHI) observational Study, cross-sectional study	154 (aged 51–81 years)	1992–2002	Dim illumination (24 lx) in the evening (4 h before bedtime and over 24 h)	Actillume monitor on the wrist	Depression	Eight-items questionnaire	Age and season	Light during the 4 h before bedtime was not significantly related to depressed mood
(Xie et al., 2022)	China	Case-control study, part of a governmental population survey of autism spectrum disorder	157 autism spectrum disorder cases and 1570 controls (aged 3–12 years)	2014	Outdoor LAN	Outdoor LAN estimated by satellite data	Autism spectrum disorder	Chinese version of Social Communication Questionnaire filled by children's parents and teachers; final diagnosis by professional pediatricians	Birth weight, gestational weeks, history of diseases, history of traumatic events, maternal age, family history of mental diseases, single-parent family, parental relationship, parental upbringing style, parental educational attainment, parental smoking status, and annual household income	Continuous LAN and risk of autism spectrum disorder 1) During 3 years after birth: OR 1.060 (95% CI 1.033–1.089) 2) During the 1 year before birth: OR 1.046 (95% CI 1.018–1.075) Categorical LAN and risk of autism spectrum disorder per increasing quartiles Q1: Ref. Q2: OR 1.976 (95% CI 0.913–4.276) Q3: OR 3.825 (95% CI 1.840–7.950) Q4: OR 5.081 (95% CI 2.445–10.563)

Abbreviations: ALAN, artificial light at night; BD, bipolar disorder; CI, confidence interval; HR, hazard ratio; LAN, light at night; OR, odds ratio.

Guy et al., 2002), whereas four studies assessed outdoor LAN via satellite-derived data, using data from the National Oceanic and Atmospheric Administration (Helbich et al., 2020; Min and Min, 2018; Paksarian et al., 2020; Xie et al., 2022). Among the five studies which assessed indoor LAN, four made use of bedroom photometers fixed near the head of the bed (Esaki et al., 2020; Esaki et al., 2022; Obayashi et al., 2013; Obayashi et al., 2018) and one, assessing light exposure in the 4 h before bedtime and over 24 h, made use of photometers placed on the participants' wrist (Wallace-Guy et al., 2002).

The included studies examined several outcomes, with depression being the most frequently investigated. Depressive symptoms were measured using different scales: the short version of the GDS-15 (Obayashi et al., 2013; Obayashi et al., 2018), the World Health Organization Composite International Diagnostic Interview version 3.0 (Paksarian et al., 2020), the Korean version of Center for Epidemiologic Studies Depression Scale (CES-D) (Min and Min, 2018), the Patient Health Questionnaire-9 (PHQ-9) (Helbich et al., 2020), and a brief screening questionnaire developed for detecting depressive disorders (Wallace-Guy et al., 2002). Five out of the six studies investigating depression (Helbich et al., 2020; Min and Min, 2018; Obayashi et al., 2013; Obayashi et al., 2018; Paksarian et al., 2020) found an association between LAN exposure and depressive symptoms. Among the studies assessing other outcomes, one study found an association between LAN exposure and past-year mood and anxiety disorders (e.g., bipolar disorders, dysthymia, specific phobia) and a slight one with some behavior disorders (Paksarian et al., 2020), two between LAN exposure and manic symptoms (Esaki et al., 2020) or manic/hypomanic symptoms relapses (Esaki et al., 2022) in patients suffering from bipolar disorders, one between LAN exposure and suicidal behaviors (Min and Min, 2018). Finally, one study carried out in China found an association between long-term LAN exposure and risk of autism spectrum disorder (Xie et al., 2022).

Results of the quality assessment are presented in Supplemental Table S3. Almost all studies were at moderate risk of bias, translating to a "fair" rating of quality. Three studies (Esaki et al., 2022; Obayashi et al., 2018; Xie et al., 2022) had a low risk of bias and were rated "good". All the studies rated "fair" had a cross sectional design which did not allow to assess two criteria of the Quality Assessment Tool ("exposure assessed prior to outcome measurement" and "sufficient timeframe to see an effect") resulting in a higher risk of bias and providing weaker evidence compared to the one case-control and two cohort studies.

4. Discussion

Overall, we found moderate evidence of a positive association between LAN exposure and mental disorders in humans, notably in relation to depressive symptoms. The relation between LAN exposure and some other mood disorders has been previously suggested in both epidemiological and laboratory studies. However, to our knowledge this is the first review aiming at providing a systematic overview of epidemiological evidence on the role of LAN in mental disorders.

In 2012, a policy statement of the American Medical Association summarized the scientific evidence on the association between light pollution and health related effects, including mood and sleep disorders (Stevens et al., 2013) as these conditions may be influenced in their onset and precipitation by circadian disruption (Bedrosian and Nelson, 2017). In this sense, there is biological plausibility for LAN having direct and indirect effects on melatonin secretion, sleep deprivation and/or chronodisruption (Erren et al., 2003; Haus and Smolensky, 2013; Touitou et al., 2017). Several processes involved in depression and mood disorders (i.e., brain plasticity, neurotransmission, alteration of hormone secretion and expression of clock genes) are under circadian control and thus vulnerable to disruption by environmental perturbations of daily rhythms (Bedrosian and Nelson, 2017). In particular, it has been suggested that melatonin suppression may increase risk of depression through interaction with monoamine signalling and alteration of neurotrophic factors levels (Tonon et al., 2021). In addition, melatonin may suppress inflammatory responses through immunological (e.g., influencing neutrophils infiltration and migration, mitigating pro-inflammatory cytokine production) and non-immunological mechanisms (e.g., promoting antioxidant processes), thus influencing neuro-inflammation and subsequent alterations in brain regions implicated in depression (Won et al., 2021).

Evidence from several animal studies supports a role for dim LAN (i.e., 5 lx) in provoking or increasing depressive-like symptoms (Bedrosian et al., 2011; Fonken et al., 2012; Fonken and Nelson, 2013). Exposure to LAN during adolescence has been suggested to promote a modest increase in susceptibility to anxiety-like phenotype in female mice and to induce depressive-like symptoms in both male and female mice (Chen et al., 2021). Moreover, studies suggest that LAN-induced depressive-like behaviors may be mediated not only by the disruption of the endogenous local circadian rhythm but also by direct synaptic inputs from circadian centres in the brain (i.e., neural activities) (An et al., 2020) and that exposure to altered postnatal light may impact the hypothalamic-pituitary-adrenal axis, which is closely related to mood disorders (Coleman et al., 2016). In humans, the association between circadian rhythm disruption and mental health has been widely investigated in epidemiological studies, especially among night-shift workers. A recent meta-analysis of 11 observational studies concluded that night-shift workers are at higher risk of depression compared to day-time workers (Lee et al., 2017). Another longitudinal study conducted among individuals transitioning to rotating shift work, reported increased symptoms of depression and anxiety among these subjects (Kalmbach et al., 2015). In this regards, evidence that night-shift workers had reduced overall melatonin amplitude even in the absence of acute melatonin suppression suggests that circadian disruption, rather than acute melatonin suppression induced by LAN, is associated with adverse health effects (Hunter and Figueiro, 2017). Similarly, data from a systematic review including 42 studies concluded that circadian rhythm disruption and evening chronotype are common in bipolar disorder (Melo et al., 2017).

Among the studies included in this review, the association between LAN exposure and mental disorders was assessed either via measurements of bedroom brightness (indoor LAN) or via satellite photometry (outdoor LAN). Of the five studies assessing indoor LAN exposure in home settings, one (Wallace-Guy et al., 2002) analyzed a sample of postmenopausal women and found no correlation between exposure to low evening light levels and depressed mood. Two studies reported a higher risk of depression among elderly subjects (Obayashi et al., 2013; Obayashi et al., 2018), and two studies (Esaki et al., 2020; Esaki et al., 2022) investigated patients with bipolar disorder, finding out that LAN exposure may be associated with manic symptoms and manic/hypomanic episode relapses. This result corroborates the hypotheses derived from previous studies showing that bipolar affective subjects were supersensitive to melatonin suppression induced by light (Lewy et al., 1985; Nurnberger et al., 1988).

Outdoor LAN was assessed in four studies using satellite-based data. In two of them a positive association with depressive symptoms and depressive symptoms together with suicidal behaviors was found among adult subjects (Helbich et al., 2020; Min and Min, 2018). A third study gave similar results: outdoor LAN was positively associated with mood and anxiety disorders (thus including bipolar disorder, major depressive disorder, dysthymia, specific phobia) and slightly with behavior disorders in US adolescents aged 13–18 years (Paksarian et al., 2020). The only study conducted among children aged 3–12 years similarly reported detrimental effects of outdoor LAN, concluding that a brighter LAN was associated with higher risk of autism spectrum disorder (Xie et al., 2022).

The impact of disruption of circadian rhythm by LAN exposure may differ in late adulthood compared with younger populations. As age increases, blue light (i.e., a major part of the spectrum of visible light) is reduced in its transmission to the retina and may be associated with an increased risk of having sleep disturbances, possibly because of reduced stimulation of the melanopsin containing retinal ganglion cells and hence impaired photoentrainment of circadian rhythm (Kessel et al., 2011). However, the studies included in this review seem to support an association between LAN and some type of mental disorders, independently from age.

When interpreting the results of this study, several limitations should be considered. First, the number of studies investigating the effect of artificial light at night and metal disorders is still limited and further evidence is needed. Secondly, the relatively limited number of studies reporting risk estimates for each outcome and the high heterogeneity of the included studies did not allow us to quantitatively and meaningfully pool them in meta-analysis. Moreover, although the included studies adjusted for several factors, there may be unmeasured variables with potential residual confounding. In particular, we cannot entirely rule out that LAN exposure may be confounded by factors such as socioeconomic factors, noise or air pollution and more research is needed to rule out the role of confounders in outdoor assessments. Only one study indeed adjusted for air pollutants levels (Helbich et al., 2020) and only two for greenness, both considered as potential effect modifiers in the relation between LAN exposure and adverse health effects (Gascon et al., 2018; Hogan et al., 2015; Kasdagli et al., 2022; McIsaac et al., 2021; Palanivel et al., 2020; Stanhope et al., 2021). Finally, among the studies included in this systematic review, only two had a cohort design, and more longitudinal evidence is needed to assess a possible causal relationship.

In conclusion, by using rigorous methods and transparent reporting, we were able to provide a complete overview of the state of knowledge in this field, which supports an association between LAN and risk of depressive disorders.

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CRediT authorship contribution statement

ST and TF conceived and designed the original study. ST, TU, and TF extracted data and with MV interpreted the data. ST and TU drafted the original manuscript. MV and TF reviewed and edited the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.155185.

References

An, K., Zhao, H., Miao, Y., Xu, Q., Li, Y.F., Ma, Y.Q., et al., 2020. A circadian rhythm-gated subcortical pathway for nighttime-light-induced depressive-like behaviors in mice. Nat. Neurosci. 23, 869–880. https://doi.org/10.1038/s41593-020-0640-8.

Attademo, L., Bernardini, F., Garinella, R., Compton, M.T., 2017. Environmental pollution and risk of psychotic disorders: a review of the science to date. Schizophr. Res. 181, 55–59. https://doi.org/10.1016/j.schres.2016.10.003.

Bakolis, I., Hammoud, R., Stewart, R., Beevers, S., Dajnak, D., MacCrimmon, S., et al., 2021. Mental health consequences of urban air pollution: prospective population-based longitudinal survey. Soc. Psychiatry Psychiatr. Epidemiol. 56, 1587–1599. https://doi.org/10.1007/s00127-020-01966-x.

Bedrosian, T.A., Nelson, R.J., 2013. Influence of the modern light environment on mood. Mol. Psychiatry 18, 751–757. https://doi.org/10.1038/mp.2013.70.

Bedrosian, T.A., Nelson, R.J., 2017. Timing of light exposure affects mood and brain circuits. Transl. Psychiatry 7, e1017. https://doi.org/10.1038/tp.2016.262.

Bedrosian, T.A., Fonken, L.K., Walton, J.C., Haim, A., Nelson, R.J., 2011. Dim light at night provokes depression-like behaviors and reduces CA1 dendritic spine density in female hamsters. Psychoneuroendocrinology 36, 1062–1069. https://doi.org/10.1016/j.psyneuen.2011.01.004.

Borniger, J.C., McHenry, Z.D., Abi Salloum, B.A., Nelson, R.J., 2014. Exposure to dim light at night during early development increases adult anxiety-like responses. Physiol. Behav. 133, 99–106. https://doi.org/10.1016/j.physbeh.2014.05.012.

Chen, R., Weitzner, A.S., McKennon, L.A., Fonken, L.K., 2021. Light at night during development in mice has modest effects on adulthood behavior and neuroimmune activation. Behav. Brain Res. 405, 113171. https://doi.org/10.1016/j.bbr.2021.113171.

Cissé, Y.M., Peng, J., Nelson, R.J., 2016. Dim light at night prior to adolescence increases adult anxiety-like behaviors. Chronobiol. Int. 33, 1473–1480. https://doi.org/10.1080/07420528.2016.1221418.

Coleman, G., Gigg, J., Canal, M.M., 2016. Postnatal light alters hypothalamic-pituitary-adrenal axis function and induces a depressive-like phenotype in adult mice. Eur. J. Neurosci. 44, 2807–2817. https://doi.org/10.1111/ejn.13388.

Dickerson, A.L., Hall, M.L., Jones, T.M., 2022. The effect of natural and artificial light at night on nocturnal song in the diurnal willie wagtail. Sci. Total Environ. 808, 151986. https://doi.org/10.1016/j.scitotenv.2021.151986.

Erren, T.C., Reiter, R.J., Piekarski, C., 2003. Light, timing of biological rhythms, and chronodisruption in man. Naturwissenschaften 90, 485–494. https://doi.org/10.1007/s00114-003-0468-6.

Esaki, Y., Obayashi, K., Saeki, K., Fujita, K., Iwata, N., Kitajima, T., 2020. Association between light exposure at night and manic symptoms in bipolar disorder: cross-sectional analysis of the APPLE cohort. Chronobiol. Int. 37, 887–896. https://doi.org/10.1080/07420528.2020.1746799.

Esaki, Y., Obayashi, K., Saeki, K., Fujita, K., Iwata, N., Kitajima, T., 2022. Effect of nighttime bedroom light exposure on mood episode relapses in bipolar disorder. Acta Psychiatr. Scand. https://doi.org/10.1111/acps.13422.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C.C., Elvidge, C.D., Baugh, K., et al., 2016. The new world atlas of artificial night sky brightness. Sci. Adv. 2, e1600377. https://doi.org/10.1126/sciadv.1600377.

Fonken, L.K., Nelson, R.J., 2013. Dim light at night increases depressive-like responses in male C3H/HeNHsd mice. Behav. Brain Res. 243, 74–78. https://doi.org/10.1016/j.bbr.2012.12.046.

Fonken, L.K., Finy, M.S., Walton, J.C., Weil, Z.M., Workman, J.L., Ross, J., et al., 2009. Influence of light at night on murine anxiety- and depressive-like responses. Behav. Brain Res. 205, 349–354. https://doi.org/10.1016/j.bbr.2009.07.001.

Fonken, L.K., Kitsmiller, E., Smale, L., Nelson, R.J., 2012. Dim nighttime light impairs cognition and provokes depressive-like responses in a diurnal rodent. J. Biol. Rhythm. 27, 319–327. https://doi.org/10.1177/0748730412448324.

Gascon, M., Sanchez-Benavides, G., Dadvand, P., Martinez, D., Gramunt, N., Gotsens, X., et al., 2018. Long-term exposure to residential green and blue spaces and anxiety and depression in adults: a cross-sectional study. Environ. Res. 162, 231–239. https://doi.org/10.1016/j.envres.2018.01.012.

Haus, E.L., Smolensky, M.H., 2013. Shift work and cancer risk: potential mechanistic roles of circadian disruption, light at night, and sleep deprivation. Sleep Med. Rev. 17, 273–284. https://doi.org/10.1016/j.smrv.2012.08.003.

Helbich, M., Browning, M., Huss, A., 2020. Outdoor light at night, air pollution and depressive symptoms: a cross-sectional study in the Netherlands. Sci. Total Environ. 744, 140914. https://doi.org/10.1016/j.scitotenv.2020.140914.

Hogan, M.K., Kovalycsik, T., Sun, Q., Rajagopalan, S., Nelson, R.J., 2015. Combined effects of exposure to dim light at night and fine particulate matter on C3H/HeNHsd mice. Behav. Brain Res. 294, 81–88. https://doi.org/10.1016/j.bbr.2015.07.033.

Hunter, C.M., Figueiro, M.G., 2017. Measuring light at night and melatonin levels in shift workers: a review of the literature. Biol. Res. Nurs. 19, 365–374. https://doi.org/10.1177/1099800417714069.

Kalmbach, D.A., Pillai, V., Cheng, P., Arnedt, J.T., Drake, C.L., 2015. Shift work disorder, depression, and anxiety in the transition to rotating shifts: the role of sleep reactivity. Sleep Med. 16, 1532–1538. https://doi.org/10.1016/j.sleep.2015.09.007.

Kasdagli, M.I., Katsouyanni, K., de Hoogh, K., Lagiou, P., Samoli, E., 2022. Investigating the association between long-term exposure to air pollution and greenness with mortality from neurological, cardio-metabolic and chronic obstructive pulmonary diseases in Greece. Environ. Pollut. 292, 118372. https://doi.org/10.1016/j.envpol.2021.118372.

Kessel, L., Siganos, G., Jørgensen, T., Larsen, M., 2011. Sleep disturbances are related to decreased transmission of blue light to the retina caused by lens yellowing. Sleep 34, 1215–1219. https://doi.org/10.5665/sleep.1242.

Kim, S.Y., Bang, M., Wee, J.H., Min, C., Yoo, D.M., Han, S.M., et al., 2021. Short- and long-term exposure to air pollution and lack of sunlight are associated with an increased risk of depression: a nested case-control study using meteorological data and national sample cohort data. Sci. Total Environ. 757, 143960. https://doi.org/10.1016/j.scitotenv.2020.143960.

Lai, K.Y., Sarkar, C., Ni, M.Y., Gallacher, J., Webster, C., 2020. Exposure to light at night (LAN) and risk of obesity: a systematic review and meta-analysis of observational studies. Environ. Res. 187, 109637. https://doi.org/10.1016/j.envres.2020.109637.

Lai, K.Y., Sarkar, C., Ni, M.Y., Cheung, L.W.T., Gallacher, J., Webster, C., 2021. Exposure to light at night (LAN) and risk of breast cancer: a systematic review and meta-analysis. Sci. Total Environ. 762, 143159. https://doi.org/10.1016/j.scitotenv.2020.143159.

Lee, A., Myung, S.K., Cho, J.J., Jung, Y.J., Yoon, J.L., Kim, M.Y., 2017. Night shift work and risk of depression: meta-analysis of observational studies. J. Korean Med. Sci. 32, 1091–1096. https://doi.org/10.3346/jkms.2017.32.7.1091.

Lewy, A.J., Nurnberger Jr., J.I., Wehr, T.A., Pack, D., Becker, L.E., Powell, R.L., et al., 1985. Supersensitivity to light: possible trait marker for manic-depressive illness. Am. J. Psychiatry 142, 725–727. https://doi.org/10.1176/ajp.142.6.725.

Liu, Q., Wang, W., Gu, X., Deng, F., Wang, X., Lin, H., et al., 2021. Association between particulate matter air pollution and risk of depression and suicide: a systematic review and meta-analysis. Environ. Sci. Pollut. Res. Int. 28, 9029–9049. https://doi.org/10.1007/s11356-021-12357-3.

Lynn, K.D., Quintanilla-Ahumada, D., Anguita, C., Widdicombe, S., Pulgar, J., Manriquez, P.H., et al., 2021. Artificial light at night alters the activity and feeding behaviour of sandy beach amphipods and pose a threat to their ecological role in Atlantic Canada. Sci. Total Environ. 780, 146568. https://doi.org/10.1016/j.scitotenv.2021.146568.

McIsaac, M.A., Sanders, E., Kuester, T., Aronson, K.J., Kyba, C.C.M., 2021. The impact of image resolution on power, bias, and confounding: a simulation study of ambient light at night exposure. Environ. Epidemiol. 5, e145. https://doi.org/10.1097/EE9.0000000000000145.

Melo, M.C.A., Abreu, R.L.C., Linhares Neto, V.B., de Bruin, P.F.C., de Bruin, V.M.S., 2017. Chronotype and circadian rhythm in bipolar disorder: a systematic review. Sleep Med. Rev. 34, 46–58. https://doi.org/10.1016/j.smrv.2016.06.007.

Min, J.Y., Min, K.B., 2018. Outdoor light at night and the prevalence of depressive symptoms and suicidal behaviors: a cross-sectional study in a nationally representative sample of korean adults. J. Affect. Disord. 227, 199–205. https://doi.org/10.1016/j.jad.2017.10.039.

Moaraf, S., Heiblum, R., Okuliarova, M., Hefetz, A., Scharf, I., Zeman, M., et al., 2021. Evidence that artificial light at night induces structure-specific changes in brain plasticity in a diurnal bird. Biomolecules 11, 1069. https://doi.org/10.3390/biom11081069.

Morgan, R.L., Whaley, P., Thayer, K.A., Schünemann, H.J., 2018. Identifying the PECO: a framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. Environ. Int. 121, 1027–1031. https://doi.org/10.1016/j.envint.2018.07.015.

NHLBI, 2013. National Heart, Lung, and Blood Institute. Study quality assessment tools. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools.

Nurnberger Jr., J.I., Berrettini Jr., W., Tamarkin Jr., L., Hamovit Jr., J., Norton Jr., J., Gershon Jr., E., 1988. Supersensitivity to melatonin suppression by light in young people at high risk for affective disorder. A preliminary report. Neuropsychopharmacology 1, 217–223. https://doi.org/10.1016/0893-133x(88)90020-6.

Obayashi, K., Saeki, K., Iwamoto, J., Ikada, Y., Kurumatani, N., 2013. Exposure to light at night and risk of depression in the elderly. J. Affect. Disord. 151, 331–336. https://doi.org/10.1016/j.jad.2013.06.018.

Obayashi, K., Saeki, K., Kurumatani, N., 2018. Bedroom light exposure at night and the incidence of depressive symptoms: a longitudinal study of the HEIJO-KYO cohort. Am. J. Epidemiol. 187, 427–434. https://doi.org/10.1093/aje/kwx290.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. J. Clin. Epidemiol. 134, 178–189. https://doi.org/10.1016/j.jclinepi.2021.03.001.

Paksarian, D., Rudolph, K.E., Stapp, E.K., Dunster, G.P., He, J., Mennitt, D., et al., 2020. Association of outdoor artificial light at night with mental disorders and sleep patterns among US adolescents. JAMA Psychiatry 77, 1266–1275. https://doi.org/10.1001/jamapsychiatry.2020.1935.

Palanivel, R., Vinayachandran, V., Biswal, S., Deiuliis, J.A., Padmanabhan, R., Park, B., et al., 2020. Exposure to air pollution disrupts circadian rhythm through alterations in chromatin dynamics. iScience 23, 101728. https://doi.org/10.1016/j.isci.2020.101728.

Rea, M.S., Brons, J.A., Figueiro, M.G., 2011. Measurements of light at night (LAN) for a sample of female school teachers. Chronobiol. Int. 28, 673–680. https://doi.org/10.3109/07420528.2011.602198.

Stanhope, J., Liddicoat, C., Weinstein, P., 2021. Outdoor artificial light at night: a forgotten factor in green space and health research. Environ. Res. 197, 111012. https://doi.org/10.1016/j.envres.2021.111012.

Stevens, R.G., Brainard, G.C., Blask, D.E., Lockley, S.W., Motta, M.E., 2013. Adverse health effects of nighttime lighting: comments on American Medical Association policy statement. Am. J. Prev. Med. 45, 343–346. https://doi.org/10.1016/j.amepre.2013.04.011.

Tam, S.K.E., Brown, L.A., Wilson, T.S., Tir, S., Fisk, A.S., Pothecary, C.A., et al., 2021. Dim light in the evening causes coordinated realignment of circadian rhythms, sleep, and short-term memory. Proc. Natl. Acad. Sci. U. S. A. 118, e2101591118. https://doi.org/10.1073/pnas.2101591118.

Taufique, S.K.T., Prabhat, A., Kumar, V., 2018. Illuminated night alters hippocampal gene expressions and induces depressive-like responses in diurnal corvids. Eur. J. Neurosci. 48, 3005–3018. https://doi.org/10.1111/ejn.14157.

Tonon, A.C., Pilz, L.K., Markus, R.P., Hidalgo, M.P., Elisabetsky, E., 2021. Melatonin and depression: a translational perspective from animal models to clinical studies. Front. Psychiatry 12, 638981. https://doi.org/10.3389/fpsyt.2021.638981.

Touitou, Y., Reinberg, A., Touitou, D., 2017. Association between light at night, melatonin secretion, sleep deprivation, and the internal clock: health impacts and mechanisms of circadian disruption. Life Sci. 173, 94–106. https://doi.org/10.1016/j.lfs.2017.02.008.

Urbano, T., Vinceti, M., Wise, L.A., Filippini, T., 2021. Light at night and risk of breast cancer: a systematic review and dose-response meta-analysis. Int. J. Health Geogr. 20, 44. https://doi.org/10.1186/s12942-021-00297-7.

Wallace-Guy, G.M., Kripke, D.F., Jean-Louis, G., Langer, R.D., Elliott, J.A., Tuunainen, A., 2002. Evening light exposure: implications for sleep and depression. J. Am. Geriatr. Soc. 50, 738–739. https://doi.org/10.1046/j.1532-5415.2002.50171.x.

Won, E., Na, K.S., Kim, Y.K., 2021. Associations between melatonin, neuroinflammation, and brain alterations in depression. Int. J. Mol. Sci. 23. https://doi.org/10.3390/ijms23010305.

World Health Organization, 2017. Depression and other common mental disorders: global health estimates. Geneva. https://apps.who.int/iris/handle/10665/254610.

Xie, Y., Jin, Z., Huang, H., Li, S., Dong, G., Liu, Y., et al., 2022. Outdoor light at night and autism spectrum disorder in Shanghai, China: a matched case-control study. Sci. Total Environ. 811, 152340. https://doi.org/10.1016/j.scitotenv.2021.152340.