SYSTEMATIC REVIEW

The impact of environmental risk factors on delirium and benefits of noise and light modifications: a scoping review [version 1; peer review: awaiting peer review]

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Abstract

Background: To explore existing literature on the association between environmental risk factors and delirium, and to investigate the effectiveness of environmental modifications on prevention or management of delirium.
Methods: This is a scoping review of peer-reviewed studies in PubMed and the reference lists of reviewed articles. Observational studies reporting the effect of noise, light, and circadian rhythm on delirium and interventional studies assessing delirium in modified environments were reviewed.
Results: 37 studies were included, 21 of which evaluated the impact of environment on delirium and 16 studied possible solutions to mitigate those impacts. Mixed findings of the reviewed studies yielded inconclusive results; a clearly delineated association between high noise levels, abnormal amounts of light exposure, and sleep disruption with delirium could not be established. The environmental interventions targeted reducing noise exposure, improving daytime and mitigating night-time light exposure to follow circadian rhythm, and promoting sleep. The overall evidence supporting effectiveness of environmental interventions was also of a low confidence; however, quiet-time protocols, earplugs, and bright light therapy showed a benefit for prevention or management of delirium.
Conclusions: Environmental modifications are non-invasive, risk-free, and low-cost strategies that may be beneficial in preventing and managing delirium, especially when used as part of a multi-component plan. However, given the limited evidence-based conclusions, further high-quality and larger studies focusing on environmental modifications and delirium outcomes are strongly

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Any reports and responses or comments on the article can be found at the end of the article.

recommended.

Keywords
delirium, environmental intervention, noise, light, circadian, scoping review

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Introduction

Delirium is a multifactorial, acute, confusional state characterized by disturbance of consciousness and cognition; it is particularly common in the intensive care unit (ICU) with incidence of 19 to 87% with higher rates in mechanically ventilated patients[1–3]. ICU delirium is associated with adverse outcomes, including prolonged mechanical ventilation, increased risk of long-term cognitive dysfunction, prolonged hospitalization, higher cost of care, and increased mortality[4–7]. While the pathophysiology of delirium is poorly understood, there are multiple factors associated with increased risk of delirium including age, education, pre-existing conditions such as hypertension, neurological or psychological disorders, illness severity, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, sensory impairment, and use of analgesics, sedatives, and polypharmacy[8–12]. The ICU environment may be a modifiable risk factor for delirium. Decreased natural daylight, night-time light exposure, excessive noise, immobilization, and isolation are potential delirium risk factors in ICU[13–15].

ICU noise levels are above the World Health Organization's (WHO) recommendations, which suggest 30 A-weighted decibels (dBA) for background noise, a maximum of 35 dBA for treatment and observation areas, and a maximum of 40 dBA at night[16–18]. Patients interviewed post-ICU discharge report noise as an overall stressor and contributor to loss of sleep[19,20]. Another common environmental disturbance for ICUs is non-cycling light sources. Disruptions in normal amounts of blue light (460–480 nm) hitting the retina affect neurological processes responsible for melatonin release[15]. Constant delivery of these wavelengths may cause abnormal suppression of melatonin, altering circadian cycles[15]. Although the ICU does not lend itself to quietude, it is feasible to employ noise-reducing techniques and light modifications that synchronize circadian rhythm, facilitating recovery.

The prevalence of delirium-associated adverse health effects and the multitude of risk factors in the ICU make delirium prevention and management essential. Current strategies include pharmacological, non-pharmacological, and multi-component interventions geared towards decreasing delirium incidence and duration. Pharmacological interventions focus on haloperidol and dexmedetomidine, with limited research into ramelteon, melatonin, and ziprasidone[21–24]. The largest clinical trial to date on haloperidol or ziprasidone in delirious patients failed to show significant clinical benefit[23], and current literature does not support use of anti-psychotic agents, benzodiazepines, or melatonin in delirium management[21–25]. Given the lack of evidence supporting pharmacological measures, research into efficacy of non-pharmacological techniques is crucial. Implementing effective delirium management strategies shows promise in decreasing morbidity, mortality, length of stay, and resource burden in the ICU[2]. The purpose of this scoping review is to examine the extent and nature of available literature, and highlight areas requiring further inquiry regarding these questions: "How do environmental noise, light, and disrupted circadian rhythms affect delirium?" and "How do existing environmental interventions such as noise reduction, light modifications, and sleep promotion help prevent or manage delirium?"

Methods

This review was conducted according to the methods of Arksey and O'Malley[26] and Levac *et al*.[27], and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Extension for Scoping Reviews (*extended data*)[28,29]. The aim of this review is to map existing literature identifying modifiable environmental risk factors for delirium, and assess the role of non-pharmacological noise, light, and circadian rhythm interventions for delirium prevention and management.

Search strategy and data charting

Studies were identified by searching PubMed for articles relating to our questions. Search results were restricted to the English language and peer-reviewed studies, with no restriction on year of publication. The search was last executed on November 20, 2019 in order to cover recent publications. Search queries were generated using the following combination of keywords: ["delirium" AND "noise OR sound OR light OR circadian"]. The search was applied with no field tags to maximize results.

After compiling research results and removing duplicates, HH and JL screened titles and abstracts to retrieve articles for eligibility. Articles on pediatric populations, animal subjects, case reports, or where the full-text was unavailable were excluded. Additional studies were identified through hand-searches and searching the reference list of reviewed articles. Disagreements on study eligibility were resolved by involving a third reviewer and a discussion between the reviewers. HH, JC, and JL reviewed the full text of eligible articles and extracted data using a pre-designed worksheet reviewed and tested by the team before data charting (Table 1). Elements of the data charting worksheet included study design, setting, sample size, aim, detailed methodology, characteristics of intervention and control groups, measured outcomes, diagnostic tools, main conclusions, and study strengths and limitations. Disagreements were resolved by discussion.

We included observational studies analyzing the association between noise levels, light exposure or disrupted circadian rhythm and delirium, and interventional studies assessing the effectiveness of modified noise or light exposure or improved circadian rhythm on delirium. Articles were excluded if environmental intervention was an element of a multi-component non-pharmacological bundle, not the main focus. In the initial full text review and data charting, we reviewed all interventional articles reporting results on delirium or the environmental risk factors of delirium, including noise or light levels, and quality/quantity of sleep. We acknowledge these outcomes are modifiable risk factors linked to delirium prevention or management; however, we excluded articles without results linked to delirium.

Table 1. Data extraction sheet.

Study details	Author/Year:
	Country:
	Study Title:
Study characteristics	Study design:
	Study setting:
	Study period:
Participants	Number of subjects: Include Number of subject per study vs control groups if available)
	Inclusion & exclusion criteria:
	Age/gender/Mechanically ventilation status:
	Was a history of any cognitive disorders or presence of delirium considered? (Please add details if yes)
Study aim	Study aim
Method details (observational and interventional studies)	Details of study method, main assessed factors, and outcome
	Delirium diagnostic tools & criteria: (note if not validated)
	Sleep quality measurement tools: (note if not validated)
	Noise levels measurement details:
	Light levels measurement details:
	Follow up length/timing:
Method details (interventional studies)	Number of study groups:
	Control Group Characteristics:
	Interventional Group Characteristics:
	Intervention details: (Protocol development, Time of intervention, duration of intervention)
Outcomes	List of measured outcomes:
	Significant outcomes and statistics:
	Non-significant outcomes:
	Adherence rates:
Study features	Strengths/limitations:
Review list of references	Added studies for further review:

Results

Literature search results & outcome

The electronic database search retrieved 457 articles, which were screened by title and abstract, resulting in 166 studies for full-text review. Hand-search and the searching of reference lists added 28 additional articles. During the full-text review of these 194 articles, 157 were excluded. In total 37 studies were included: 21 assessed association between environmental risk factors and delirium[13,19,20,30–47], and 16 reported on delirium after an environmental intervention[7,14,15,18,48–59] (Figure 1).

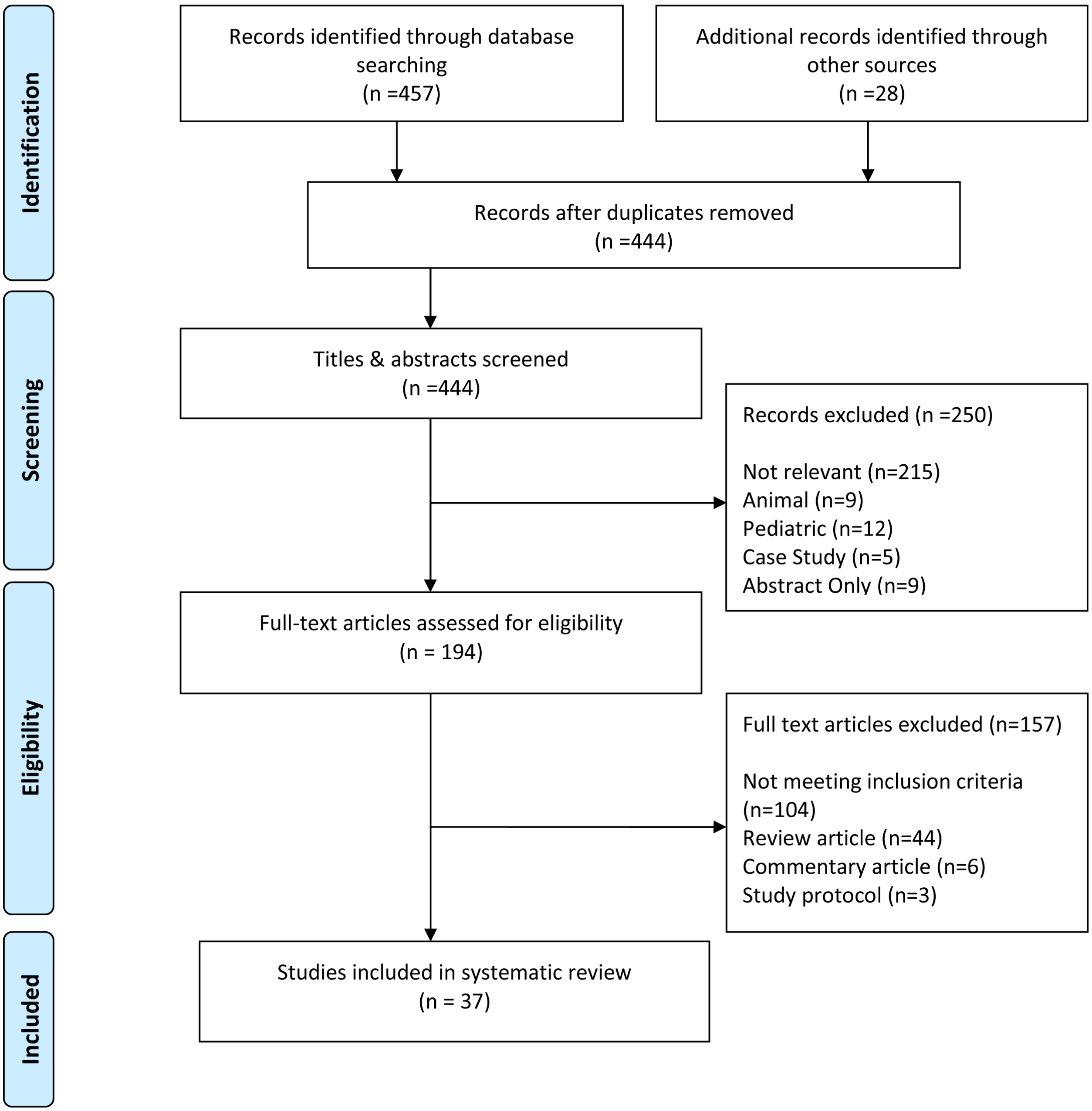

Figure 1. PRISMA record screening flow chart.

Characteristics of the reviewed articles

Included studies were conducted between 1997 to 2019, in the USA[19,31,37,39,43,46,58,59], the Netherlands[14,32,48,50,51], Japan[38,41,52,53], France[33,36,57], Belgium[13,49], Denmark[15,34], Italy[42,47], Sweden[18,20], Canada[35], China[45], India[40], Israel[30], Singapore[55], South Korea[54], Thailand[56], Turkey[44], and the UK[7]. Of these, 31 studies were conducted among critically ill patients while five reviewed general hospital populations[30,35,41,44,54], and one a geriatric monitoring unit for acute delirium care[55]. Among the 37 reviewed articles, all observational association studies and 12 interventional studies reported delirium incidence, while two interventional studies measured delirium prevalence[18,58]. Delirium severity was assessed in three interventional studies[48,54,55]. Three articles reviewed delirium duration[7,48,51].

Most studies assessed delirium using the Confusion Assessment Method for the ICU (CAM-ICU)[7,15,18,19,34,36,37,39,40,42,45–48,51,56–59]; other identification methods included the validated Dutch CAM-ICU[32], Confusion Assessment Method (CAM)[41,50,55], Intensive Care Delirium Screening Checklist (ICDSC)[14,33,43], Neelon and Champagne Confusion Scale (NEECHAM)[13,49], non-validated[52] and validated[53] Japanese NEECHAM, Delirium Observation Screening Scale (DOSS)[50], behavioral observations based on the Diagnostic and Statistical Manual of Mental Disorders, 3rd edition (DSM-III)[35], 3rd edition-revised (DSM-III-R)[38], and 4th Edition (DSM-IV)[20,41,44], and behavioral observations based on International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) criteria[30]. One study used both retrospective chart review and site-specific pre-specified criteria based on new and rapid onset of disturbed consciousness and/or perceptual disturbances[31]. Studies assessed delirium severity by non-validated Delirium Severity Index (DSI)[48], Delirium Rating Scale (DRS)[54], Delirium Rating Scale-Revised-98 (DRS-R-98)[55], and Memorial Delirium Assessment Scale (MDAS)[54]. Details, including study design, setting, sample size, methodology, outcomes, and findings with statistics are summarized in Table 2 to Table 4 for observational studies reporting on environmental risk factors, and Table 5 to Table 7 for environmental intervention studies.

Effect of environmental risk factors on delirium

Of the observational studies, two analyzed for an association between delirium and noise[19,20], five for light[13,30–33], 12 for sleep[34–45], and two evaluated multiple factors[46,47]. Study populations ranged from 7 to 6660 participants, and the majority were done in an ICU (17 of 21)[13,19,31–34,36–40,42,43,45–47]. The remaining studies did not specify a ward[30,35,41,44]. Study details and statistical results are in Table 2–Table 4.

Noise. Although ICU noise is a suggested predictor for delirium development, two of the three investigating studies found no significant association between ICU noise levels and delirium development[19,20] (Table 2). One study assessed A-weighted sound levels with subjective patient reports on ICU noise[20]. They found no correlation between A-weighted equivalent continuous (LAeq) or maximum (LAmax) noise pressure levels and delirium, while patients' responses about ICU sounds spread evenly over a spectrum from scary to non-disturbing[20]. In comparison, Knauert *et al.*[19] evaluated equivalent continuous

Table 2. Summary of characteristics and findings of observational studies on association between delirium and noise.

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Noise						
Johansson 2012 Sweden[20]	Observational, pre-study	ICU (general medical-surgical) n=13 ICU patients excluding head injury, hearing impairment, dementia	A-weighted decibel measurements Post-ICU survey on memories of ICU environment	Delirium: hourly behavioral observations by nurse based on Granberg-Axell protocol (2001) and DSM-IV Noise: Bruel & Kjaer 2260 sound level meter placed close to patient bed, one-minute average interval of A-weighted sound levels analyzed with B&K Evaluator software Memory survey: open-ended, unstructured interview after ICU discharge focusing on memories of ICU environment and sounds	No association between high number of early signs of ICU delirium and high sound levels Interview responses: mixed, some sound memories were scary/ irritating, others were comforting, unnoticed, or incorporated into dreams	$p > 0.05$ for all noise and delirium analyses No statistics reported for interviews.

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Knauert, 2016 USA[19]	Observational, prospective	MICU n=59 Adult patients admitted within 48 hrs before next sound recording period, excluding those expected to die within 24 hrs, undergoing comfort care, or expected to be transferred before study completion	Leq & frequency of peak occurrences	Delirium: CAM-ICU daily Noise: two Extech HD600 sound meters placed at foot of patient bed with standardized distance from care equipment, 10-second interval of A- and C-weighted sound levels, decibel range set to 30-130 dB, detector response set to 'fast, 125 milliseconds'	Delirium was not associated with Leq or peak occurrences	$p > 0.05$ for all noise and delirium analyses
Multiple factors including noise						
Davoudi, 2019 USA[46]	Observational, prospective pilot	SICU n=22 All adult patients expected to stay in ICU more than 2 days and able to wear an ActiGraph device	Sound pressure levels Light intensity Sleep quality	Delirium: CAM-ICU daily, defined as being delirious throughout study period Noise: iPod with a sound pressure recording application measured in dB, device placed on wall behind patient bed Light: ActiGraph sensor placed on wall behind patient bed at height of patient head Sleep: Freedman Sleep Questionnaire daily	Significant higher average night-time noise levels in delirious patients Light levels were significantly different between delirious and non-delirious patients No statistical association between overall quality of sleep and delirium, but delirious patients were significantly more likely to report difficulty falling asleep and to find lighting disruptive at night	Noise $p < 0.05$ Light $p < 0.05$ Ability to fall asleep $p = 0.01$ Whether night-time lighting was disruptive $p = 0.04$ $p > 0.05$ for all other sleep and delirium analyses

Abbreviations: CAM-ICU: Confusion Assessment Method for the Intensive Care Unit; CI: confidence interval; dB: decibel; DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, 4th Edition; hrs: Hours; ICU: intensive care unit; Leq: equivalent continuous sound pressure level; MICU: medical intensive care unit; RASS: Richmond Agitation and Sedation Scale; RRR: relative risk ratio; SICU: surgical intensive care unit; X^2: chi-squared test.

sound pressure level (Leq) and peak sound occurrences for both A-weighted and C-weighted measurements, finding no correlation with delirium development. There are no industry-standard recommendations for C-weighted levels, but LAeq and LAmax values from both studies were higher than recommended by the WHO[17,19,20]. In contrast, a study by Davoudi *et al.*[46] assessing the associations between delirium and multiple environmental factors, found average night-time sound pressure levels were significantly higher for patients with delirium[46]. However, they did not provide exact decibel measurements, likely because they were reporting preliminary findings for a larger cohort study unpublished at the time of this review[46].

Light. Abnormal lighting cycles are another suggested contributor to delirium[60]. Seven reviewed studies considered exposure to natural sunlight and relationships with delirium[13,30–33,46,47] (Table 3). There were two approaches to analysis: effects of windows on delirium incidence[13,31,33,46,47] and association with

Table 3. Summary of characteristics and findings of observational studies on association between delirium and light.

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Light						
Balan 2001 Israel[30]	Observational, retrospective	Geriatric hospital n=234 Patients aged ≥65, with no pre-existing delirium or unable to communicate due to cognitive impairment	Season of delirium diagnosis	Delirium: ICD-9-CM criteria, assessed and diagnosed by a psychiatrist after development of any abrupt change in mental or behavioral condition Light: patients compared by season of admission (winter, December-February; summer, June-August)	Significantly higher rates of delirium in winter than summer months	X^2, 2 df = 14.36 $p < 0.001$
Kohn 2013 USA[31]	Observational, retrospective	MICU n=6336 All admitted patients, restricted to the index ICU admission during a hospitalization SICU n=6660 All admitted patients, restricted to the index ICU admission during a hospitalization	Presence of a window Whether view out of the window was a natural or industrial view Presence of a half- or full-sized window for windows facing the same direction	Delirium, MICU: retrospective chart review of random patient sample (7%); diagnosed if specific keywords associated with delirium were documented by physician or nurse on at least 2 separate days Delirium, SICU: screened daily by nurse practitioner for pre-specified criteria based on new and rapid onset of disturbed consciousness and/or perceptual disturbance Windows, both units: whether patient was admitted to room with or without a window; whether window had a natural or industrial view; whether window was half- or full-sized	No association with delirium incidence and the presence of a window, in all analyses No association with delirium incidence and a natural or industrial view, in all analyses No association between delirium incidence and presence of a half- or full-sized window for windows facing the same direction, in all analyses	$p > 0.05$ for all light and delirium analyses
Simons 2014 Netherlands[32]	Observational, retrospective	ICU n=3198 All patients who were admitted to the ICU within 30 days of hospital admission, restricted to the first ICU admission during a hospitalization	7-, 28-, and 60-day prehospital photoperiod Season of admission Subgroup analysis: 28-day photoperiod in patients admitted to ICU within 48 hrs of hospital admission	Delirium: Dutch validated CAM-ICU at least twice daily during complete ICU stay Light: sunlight data was obtained from nearby weather stations of the Royal Dutch Meteorological Institute; cumulative photoperiod was calculated from the total amount of radiation, defined as total number of hours of daylight for 7, 28, and 60 days before hospital admission	No association between delirium incidence and prehospital sunlight exposure for all photoperiods (7-, 28-, 60-day) No association between delirium incidence and season of admission Subgroup analysis: no association between 28-day photoperiod and delirium incidence	$p > 0.05$ for all light, season, and delirium analyses

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Smonig 2019 France[33]	Observational, prospective	MICU n=195 Consecutive adult patients requiring invasive MV in the ICU for at least 2 days, without acute brain injury or conditions interfering with delirium assessment (i.e. dementia, deaf, blind)	Presence of a window	Delirium: RASS followed by ICDSC twice daily, defined as the presence of ICDSC ≥4 for at least 2 consecutive ICU days Light: exposure determined by whether patient was assigned to a room with or without windows	No association between exposure to windows and delirium burden (incidence and duration), even when excluding room transfers	$p > 0.05$ for all light and delirium analyses
van Rompaey 2009 Belgium[13]	Observational, prospective	ICU (mixed) n=523 All consecutive patients aged ≥ 18 years with ICU stay of ≥ 24 hrs; patients were enrolled when GCS reached at least 10.	Absence of visible daylight	Delirium: NEECHAM Confusion Scale (frequency not specified) Light: exposure determined by whether patient was exposed to visible daylight during ICU stay	Patients had a significantly higher risk of developing delirium with the absence of visible daylight	Univariate OR 1.75 95% CI (1.19-2.56) $p = 0.003$ Multivariate OR 2.39 95% CI (1.28-4.45)
Multiple factors including light						
Davoudi 2019 USA[46]	Observational, prospective pilot	SICU n=22 All adult patients expected to stay in ICU more than 2 days and able to wear an ActiGraph device	Sound pressure levels Light intensity Sleep quality	Delirium: CAM-ICU daily, defined as being delirious throughout study period Noise: iPod with a sound pressure recording application measured in dB, device placed on wall behind patient bed Light: ActiGraph sensor placed on wall behind patient bed at height of patient head Sleep: Freedman Sleep Questionnaire daily	Significant higher average night-time noise levels in delirious patients Light levels were significantly different between delirious and non-delirious patients No statistical association between overall quality of sleep and delirium, but delirious patients were significantly more likely to report difficulty falling asleep and to find lighting disruptive at night	Sound $p < 0.05$ Light $p < 0.05$ Ability to fall asleep $p = 0.01$ Whether night-time lighting was disruptive $p = 0.04$ $p > 0.05$ for all other sleep and delirium analyses

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Simeone 2018 Italy[47]	Observational, correlational	SICU (cardiac) n=89 All patients aged ≥ 18 years who underwent cardiac surgery with ICU stay longer than 24 hrs, excluding history of psychologic disease or psychogenic drug use, visual disturbances, hearing disorder, RASS ≤ 4	Exposure to natural sunlight Presence of a sleep disorder	Delirium: RASS followed by CAM-ICU Light: whether patient was exposed to natural sunlight Sleep: whether patient has pre-existing sleep disorder	Significantly more patients with delirium were not in a location with sunlight Significantly more patients with delirium had a sleep disorder	Light, univariate $X^2 = 9.737$, $p = 0.32$ Light, multivariate RRR 0.367, 95% CI (0.090-1.494), $p = 0.034$ Sleep, univariate $X^2 = 13.934$, $p < 0.001$ Sleep, multivariate RRR 5.493, 95% CI (1.255-24.047) $p = 0.024$

Abbreviations: CAM-ICU: Confusion Assessment Method for the Intensive Care Unit; CI: confidence interval; dB: decibel; df: degrees of freedom; GCS: Glasgow Coma Scale; hrs: hours; ICD-9-CM: International Classification of Diseases, Ninth Revision, Clinical Modification; ICDSC: Intensive Care Delirium Screening Checklist; ICU: intensive care unit; MICU: medical intensive care unit; MV: mechanical ventilation; NEECHAM: Neelon and Champagne Confusion Scale; OR: odds ratio; RASS: Richmond Agitation and Sedation Scale; RRR: relative risk ratio; SICU: surgical intensive care unit; X^2: chi-squared test.

admission season[46,47]. Findings were mixed, suggesting no easily provable relationship between natural light exposure and delirium occurrence. Two window and one seasonal study found no statistical association between delirium and windows or season of admission/duration of preadmission sunlight exposure, respectively[31–33]. Kohn *et al*.[31] compared windowed versus non-windowed rooms in the medical ICU, and natural versus industrial window views in the surgical ICU.[31]. They also investigated impact of half-sized versus full-sized windows, finding no association between delirium incidence and any of these factors[31]. Similarly, Smonig *et al*. found no difference in delirium incidence between patients admitted to windowed versus non-windowed rooms while proving windowed rooms retained natural circadian light variations and non-windowed rooms did not[33]. In the seasonal study, Simons *et al*. investigated the effect of admission season on delirium incidence and found no correlation[32]. A simultaneous assessment found no correlation between preadmission cumulative sunlight exposure and delirium incidence for three photoperiods (7, 28, and 60 days pre-hospital admission)[32].

In comparison to studies showing no association between natural sunlight exposure and delirium occurrence, three window studies and one seasonal study found a significant correlation[13,30,46,47]. In the window studies, Simeone *et al*.[47] associated the lack of natural sunlight with delirium while Van Rompaey *et al*.[13] found an absence of visible daylight led to higher risk of delirium. Davoudi *et al*.[46] examined the pervasive sensing of ICU patients, finding that the measured light intensity in windowed rooms was significantly different between patients with and without delirium[46]. Additionally, a study on seasonal impact on delirium diagnosis by Balan *et al*. found a higher incidence of delirium among patients admitted in winter compared to summer[30].

Sleep. Disrupted sleep-wake cycles are associated with altered mental states in hospitalized patients, and are connected with delirium[61]. In this review, 14 studies[19,34–38,40–47] assessed sleep and delirium with two main methodologies: objective measurements of physiological sleep phases and subjective reports by staff or patient. Five studies objectively measured sleep quality using overnight polysomnography (PSG) or a Zeo wireless sleep monitor[19,34,36,42,43], while eight assessed staff reports of behavioral observations and/or self-reports by patients[34,35,37,38,41,45–47]. One study compared both methods[33], and two did not specify the measurement method.[40,44] (Table 4).

Similar to the articles on natural light exposure, association studies for sleep and delirium have mixed findings, but lean towards disrupted sleep being a delirium predictor. Six of 14 studies found no relationship between sleep and delirium: two PSG studies[19,34], three using subjective measures[34], and one with an unspecified method[37,40,46]. One study found no difference in the rate of delirium between patients with typical and atypical sleep on PSG[39], while another by Boesen *et al*. also found no difference in atypical PSG results between patients who did or did not develop delirium[34]. They compared PSG results with clinical behavioral observations and were only able to ascertain that the more pathological the patient and electroencephalogram findings, the less association with observed sleep[34]. A study using the Richards-Campbell Sleep Questionnaire (RCSQ) found no significant correlation between perceived sleep quality and delirium, nor any significant relationship when asking how disruptive noise was to sleep[37]. The study by Davoudi *et al*.[46] used the Freedman Sleep Questionnaire and found no correlation between overall sleep quality and delirium, although they noted patients with delirium were more likely to have difficulty falling asleep and find night-time lighting disruptive[46]. The last study did not detail their methodology, but found delirium was not significantly related to sleep deprivation[40].

Of the nine studies showing statistical correlation between sleep and delirium, three used electronic sleep monitoring[36,42,43], five subjective survey measures[35,41,45,47,62] and one did not specify the methodology used[44]. One study found atypical sleep on PSG was significantly tied to increased delirium, while another PSG study found delirium was associated with severe rapid eye movement (REM) reduction[36,42]. A third study used a novel sleep monitoring device and found a relationship between a lack of REM sleep and delirium[43]. Their results must be taken in the context of the device being commercially unavailable (Zeo wireless sleep monitor), and the authors not reporting statistical analyses. Among the remaining positive correlational studies, two had patients self-report sleep satisfaction and quality and both saw significantly poorer responses when comparing patients who developed delirium with those who did not[35,45]. Two studies involved nursing staff observing clinical behaviors and found sleep disturbances were positively linked to higher likelihood of developing delirium[38,41]. Two studies found an association between delirium incidence and sleep deprivation (methodology not specified)[44], and between sleeping disorders and delirium development[47].

Table 4. **Summary of characteristics and findings of observational studies on association between delirium and sleep.**

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Sleep						
Boesen 2016 Denmark[34]	Observational, prospective descriptive	ICU (mixed) n=14 Mechanically ventilated patients aged ≥ 18, without structural neurological illnesses or administration of propofol or benzodiazepines	PSG results Sleep as recorded by CBO	Delirium: SAS & CAM-ICU once/shift Sleep, PSG: 24 hour simplified PSG with a 2-lead-frontal EEG, 2-lead EOG, 1 chin EMG, and 1-lead ECG; recording started at noon; PSGs were scored by an EEG technician in 30 second epochs according to the AASM standards; due to encephalopathy, wakefulness was interpreted using eye-blinking and EEG reactivity Sleep, CBO: registering 24 hour clinical sleep by attending nurses, noted on a case report form as "asleep" or "awake"; measurements included total clinical time awake, or asleep, and number of hours with logged entries	No clear differences in sleep patterns for both PSG and CBO analysis Less correlation with clinically observed sleep in more pathological EEGs and patients Sleep quality and quantity cannot be feasibly assessed with PSG in MV patients, since the vast majority of PSGs were atypical with no objective sleep signs	$p > 0.05$ for all sleep and delirium analyses
Bowman 1997 Canada[35]	Observational, descriptive	Teaching hospital n=43 Elderly (age not specified) undergoing orthopedic hip surgery without dementia or MMSE score ≤ 23	Sleep satisfaction	Delirium: DSM-III diagnosis by RN reports, chart review, interview with RNs, or assessment by researcher in daily rounds; MMSE repeated daily until an score of ≥24 Sleep: 5 days of previous night's sleep satisfaction recorded every AM by a seven-point Likert scale	Patients who developed post-operative delirium had poorer sleep satisfaction than those without post-operative delirium, except postoperative day 5	Day 2, $p = 0.008574$ Day 3, $p = 0.031772$ $p > 0.05$ for all other sleep and delirium analyses
Drouot 2012 France[36]	Observational, retrospective	MICU n=57 Adult, conscious, non-sedated patients with acute respiratory failure treated with NIV for at least 2 days, without GCS < 15, any CNS disorder, delirium, confusion, sleep or EEG interfering drugs in last 48 hrs	PSG results	Delirium: CAM-ICU daily Sleep: Embla S700 digital recorder from 1500 to 0800 on the following day; leads included: three EEG channels, chin EMG, two EOGs, submental EMG, two tibialis anterior EMGs, and ECG; EEG signals amplified and recorded at 200-Hz sampling frequency, filtered (0.5–70 Hz); Rechtschaffen and Kales criteria were used to score sleep stages and awakenings	Significant association between delirium occurrence and atypical sleep on EEG	$p < 0.05$

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Kamdar 2015 USA[37]	Secondary analysis of prospective observational study	MICU n=223 Patients with ≥1 MICU night in between 2 days of delirium assessment	Perceived sleep quality	Delirium: CAM-ICU twice daily at 0800 and 2000 Sleep: RCSQ daily with an additional item to evaluate perceived night-time noise	No association between transition to delirium and perceived sleep quality	$p > 0.05$ for all sleep and delirium analyses
Kaneko 1997 Japan[38]	Observational	HCU n=36 Patients aged>70 undergoing gastrointestinal surgery	Sleep-cycle disturbance	Delirium: DSM-III-R (frequency not specified) Sleep: clinical behavioral observations on sleep & wakefulness recorded in 2 blocks (0600-1800, 1800-0600)	Postoperative abnormal sleep patterns are significantly associated with development of delirium	$p < 0.05$
Knauert 2014 USA[39]	Observational, cross-section pilot	MICU n=29 Adults admitted to the MICU for less than 72 hrs without terminal illness, coma, deep sedation, severe agitation, or anatomic contraindications to PSG evaluation	Atypical sleep on PSG	Delirium: CAM-ICU on day of enrollment and during PSG (frequency not specified) Sleep: unattended PSG for up to 24 hrs via Compumedics' Safiro Portable Data Acquisition System; initiated in the evening; leads included: 6 EEG channels, chin EMG, right and left EOG; ECG; 200 Hz sampling frequency and filtered (0.5 - 70 Hz); Compumedics' Profusion 2 software	No significant relationship between delirium incidence and atypical sleep	$p > 0.05$ for all sleep and delirium analyses
Kumar 2017 India[40]	Observational, pilot prospective derivation cohort	SICU (cardiac) n=120 consecutive cardiac surgical adult patients without delirium or deafness	Sleep deprivation	Delirium: assessed once daily with RASS followed by CAM-ICU starting on day of extubation Sleep: method of measurement not specified	Sleep deprivation was not significantly related to delirium	$p > 0.05$ for all sleep and delirium analyses
Shigeta 2001 Japan[41]	Observational	General hospital n=29 Patients undergoing laparotomy for digestive disease	Sleep disturbances	Delirium: CAM followed by DSM-IV diagnosis Sleep: subjects' sleep was monitored every 2 hrs for 5 days after surgery	All delirious patients had sleep disturbances with a reversal of the diurnal sleep cycle, including delayed sleep onset, frequent waking, and increased daytime sleep	No statistics reported.
Trompeo 2011 Italy[42]	Observational	ICU n=29 Patients aged 18-75 with ≥2 days of MV for surgery-related respiratory failure, with no psychosis, mental retardation, stroke, central sleep apnea, drug or alcohol abuse, dementia, Alzheimer, or Parkinson	PSG results	Delirium: CAM-ICU twice daily Sleep: NPB-Mallinckrodt Sandman PSG done from 2200-0800, scored using Rechtschaffen and Kales criteria	Delirium is independently associated with severe REM sleep reduction	$p = 0.002$

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Whitcomb 2013 USA[43]	Observational, pilot	MICU (pulmonary) n=7 65 years or older, intubated & sedated, without a diagnosis preventing mental awareness assessment	Sleep stages	Delirium: ICDSC once daily Sleep: Zeo wireless sleep monitor, dry silver-coated fabric headband sensor with single bipolar channel, signal includes EEG/ EOG/ EMG, captured at 128 samples/second and filtered to a frequency of 2- 47 Hz, microprocessor reports the sleep stage every 30 seconds in real time via artificial neural network using a reduced set of sleep stages including wakefulness, REM, light sleep (stages 1 & 2), and deep sleep (stages 3 & 4)	Preliminary results suggest a relationship between lack of REM sleep and delirium	No statistics reported.
Yildizeli 2005 Turkey[44]	Observational, retrospective	General hospital n=432 Patients >18 years old admitted for thoracotomy or sternotomy with an expected stay of 2 or more days	Sleep deprivation	Delirium: once delirium symptoms were first noted, a psychiatric consult determined diagnosis based on DSM-IV criteria Sleep: method of measurement not specified	Univariate and multivariate analyses showed a significant association between delirium incidence and sleep deprivation	Univariate, p = 0.008 Multivariate, OR 5.642, p = 0.05
Zhang 2015 China[45]	Observational, prospective cohort	ICU (cardiovascular) n=249 adult, post-CABG patients without preoperative diagnoses of delirium, mental disease, or dementia	Quality of sleep	Delirium: assessed three times daily (0800, 1600, 2400) with RASS followed by CAM-ICU, and if patient developed change in mental status Sleep quality: assessed via patient self-report, poor quality was defined by symptoms of sleep disorder or deprivation	Poor sleep quality was the strongest independent predictor of delirium	Univariate, p < 0.001 Multivariate, OR 5.001, 95% CI (2.476-10.101), p < 0.0001
Multiple factors including sleep						
Davoudi 2019 USA[46]	Observational, prospective pilot	SICU n=22 All adult patients expected to stay in ICU more than 2 days and able to wear an ActiGraph device	Sound pressure levels Light intensity Sleep quality	Delirium: CAM-ICU daily, defined as being delirious throughout study period Noise: iPod with a sound pressure recording application measured in dB, device placed on wall behind patient bed Light: ActiGraph sensor placed on wall behind patient bed at height of patient head Sleep: Freedman Sleep Questionnaire daily	Significant higher average of night-time noise levels in delirious patients Significant different light levels in delirious group No statistical association between overall quality of sleep and delirium, but delirious patients were significantly more likely to report difficulty falling asleep and to find lighting disruptive at night	Noise, $p < 0.05$ Light, $p < 0.05$ Ability to fall asleep, $p = 0.01$ Whether night-time lighting was disruptive, $p = 0.04$ $p > 0.05$ for all other sleep and delirium analyses

Study (author, year, country)	Study design	Study setting Population Subjects characteristics	Examined risk factors	Method details	Findings	Statistics
Simeone 2018 Italy[47]	Observational, correlational	SICU (cardiac) n=89 All patients aged ≥ 18 years who underwent cardiac surgery with ICU stay longer than 24 hrs, excluding history of psychologic disease or psychogenic drug use, visual disturbances, hearing disorder, RASS ≤ 4	Exposure to natural sunlight Presence of a sleep disorder	Delirium: RASS followed by CAM-ICU Light: whether patient was exposed to natural sunlight Sleep: whether patient has pre-existing sleep disorder	Significantly more patients with delirium were not in a location with sunlight Significantly more patients with delirium had a sleep disorder	Light, univariate $X^2 = 9.737$, $p = 0.32$ Light, multivariate RRR 0.367, 95% CI (0.090-1.494), $p = 0.034$ Sleep, univariate $X^2 = 13.934$, $p < 0.001$ Sleep, multivariate RRR 5.493, 95% CI (1.255-24.047) $p = 0.024$

Abbreviations: AASM: American Academy of Sleep Medicine; CABG: coronary artery bypass graft; CAM: Confusion Assessment Method; CAM-ICU: Confusion Assessment Method for the Intensive Care Unit; CBO: clinical behavioral observation; CI: confidence interval; CNS: central nervous system; dB: decibel; DSM-III: Diagnostic and Statistical Manual of Mental Disorders, 3rd Edition; DSM-III-R: Diagnostic and Statistical Manual of Mental Disorders, 3rd Edition, Revised; DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, 4th Edition; ECG: electrocardiography; EEG: electroencephalography; EMG: electromyography; EOG: electrooculography; GCS: Glasgow Coma Scale; HCU: high intensive care unit; hrs: hours; Hz: Hertz; ICDSC: Intensive Care Delirium Screening Checklist; ICU: intensive care unit; MICU: medical intensive care unit; MMSE: Mini-Mental State Examination; MV: mechanical ventilation; NIV: non-invasive ventilation; OR: odds ratio; PSG: polysomnography; RASS: Richmond Agitation and Sedation Scale; RCSQ: Richards-Campbell Sleep Questionnaire; REM: rapid eye movement; RN: registered nurse; RRR: relative risk ratio; SAS: Riker Sedation-Agitation Scale; SICU: surgical intensive care unit X^2: chi-squared test.

Effect of environmental interventions on delirium prevention and treatment

In total, 16 studies evaluated the effects of a modified environment on delirium prevention or management[7,14,15,18,48–59] (Table 5–Table 7). Half were randomized control trials (RCT)[18,49,51–54,56,57], while half used different study designs including: before-after[7,14,48,59], retrospective cohort[15,50], and prospective cohort[55,58]. Sample sizes varied from 11 to 748. Interventions focused on controlling environmental risk factors, including noise and light exposure, disrupted circadian rhythm, and sleep (Figure 2). We categorized these interventions into four modification types: architectural design[18,48], environmental noise[14,49], environmental light[15,50–57], and environmental modification bundles with noise and light components[7,57–59]. A summary of environmental interventions on delirium and reported statistical results are presented in Table 8. The interventional articles with results on delirium modifiable risk factors such as noise, light, and sleep were excluded if they did not assess delirium as an outcome. Table 9 represents list of these excluded studies.

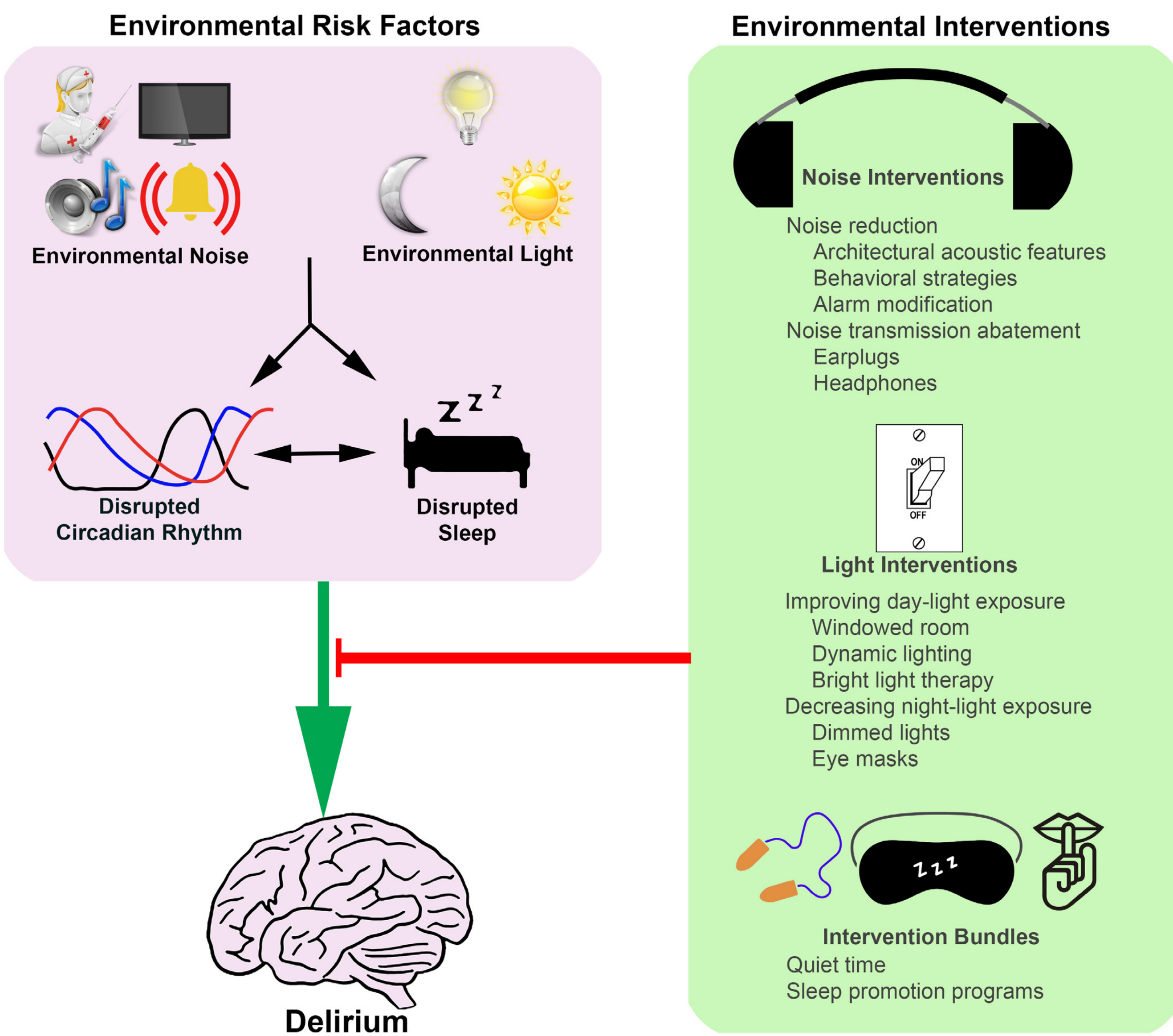

Figure 2. Environmental risk factors for delirium, and the mitigation strategies.

Architectural design. Two studies[18,47] explored a modified ICU design. One study altered the acoustics of the ICU[18], whereas the other used a multi-aspect architectural design intervention[48]. Results were mixed, but subtly suggest the benefit of architectural designs that consider acoustic features (Table 5). Zaal *et al.*[48] assessed patient outcomes in a multi-bed ICU room with less natural light and more noise exposure versus a private room with improved daylight and reduced noise

Table 5. Summary of characteristics and findings of interventional studies modifying architectural design.

Study (Author, Year, Country)	Study Purpose	Study Design	Study setting Population Subjects characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Architectural design modification						
Johansson 2018 Sweden[18]	To assess feasibility and effect of a modified ICU room on noise and delirium	Quasi RCT (feasibility study)	ICU (General) n=31: 25 control, 6 intervention Adult, ICU stay ≥48 hrs	Modified ICU room to control noise: Installed drop ceilings with low frequency noise absorber, plain room design, kept mobile medical equipment in room only if required Control group: same ICU room with no modification	Delirium prevalence (CAM-ICU) Level of noise (Microphone located 10cm below ceiling, and 130-160 cm from wall, attached to a sound-card, recorded 30s intervals of A, C, and Z weighted noise levels)	Reported study as feasible with required improvement in randomization, noise measurement process, and delirium assessment No statistical analysis performed due to small sample size; however intervention resulted in slight lower reverberation time and higher speech clarity
Zaal 2013 Netherlands[48]	To explore effect of ICU environment on incidence, and course of delirium	Pre- post Intervention	ICU (Mixed) n=130: 55 control, 75 intervention Adult, ICU stay ≥24 hrs, excluded unresponsive patients (RASS <-3 or GCS ≤ 8) in ICU	Single-bed room ICU with more daylight and less noise exposure: use of sound absorbers, glass sliding doors, optimized alarm system sending filtered alarms to staff cell phones, remotely controlled monitors, sufficient daylight with view, warm colored room design Control group: multi-bed room, beds separated by curtains	Delirium incidence, and duration (CAM-ICU) Delirium severity (non-validated DSI) Level of light (Light-sensor placed 1m from bed's head, recorded 30s intervals of light intensity in Volts)	No significant effect on incidence of delirium, however decreased number of days with delirium No effect on severity of delirium Increased daylight exposure, but no effect on night-time light exposure

Abbreviations: CAM-ICU: Confusion Assessment Method for the ICU, DSI: Delirium Severity Index, GCS: Glasgow Coma Scale/Score, hrs: hours, ICU: intensive care unit, RASS: Richmond Agitation and Sedation Scale, RCT: Randomized control trial.

[1] Only outcomes of interest including delirium related outcomes, sleep quality, sound pressure levels, and light intensity levels, has listed in this table.

[2] Details of measured noise and light, such as devices, location, and frequency has not been discussed in detail in this table.

by sound absorbers, glass sliding doors, optimized alarms, and remotely controlled monitors. There was no effect on delirium incidence or severity, but they found a reduction of delirious days in the study group by 0.4 (95% confidence interval (CI) 0.1–0.7, p = 0.005). Another quasi-randomized feasibility study[18] conducted noise reduction by refurbishing an ICU room. They installed a wall-to-wall drop ceiling, low frequency sound absorbers, and used a visually plain design. Implementing the noise reduction strategies was deemed feasible, requiring improvements in noise measurements and delirium assessments. Given the small sample size (n=31) and feasibility nature of the study, no further statistical analysis of outcomes was performed; Delirium developed in 33% (2/6) versus 25% (5/25) of study versus control patients. There was a slight reduction in noise reverberation and increase in speech clarity in the modified room, though sound levels remained higher than the WHO recommendations[17].

Noise modification. In this review, there were two approaches to mitigate patient exposure to excessive sound. One was to reduce source noise by utilizing behavioral strategies and device/alarm optimization. The other was noise abatement by earplugs. No studies investigated the impacts of behavioral modification on delirium as an independent intervention, but this strategy was used as part of an environmental modification bundle in four studies[7,14,58,59]. Earplugs were mostly a component of an environmental bundle[7,14,57,58], though one study evaluated the effect of earplugs as a single-component intervention[49]. One article implemented a combination of behavioral strategies and earplugs to reduce excessive noise[14]. There were mixed findings across studies with noise modification component(s), but results suggest behavioral strategies and earplugs together might help delirium prevention, particularly as part of a multi-disciplinary program targeting environmental risk factors. However, the implementation of sustained behavioral changes and tolerability of earplugs remain challenges[57] (Table 6).

Van de Pol *et al.*[14] analyzed the impact of noise reduction on 421 non-delirious ICU patients in an interrupted time series before-after study. They used earplugs and behavioral strategies, including limited bedside conversations, lowered voices, grouped care activities, optimized alarm settings, and closed doors. Reported noise levels were still higher than the WHO limit post-intervention[17], however there was a significant decrease in delirium incidence by 3.7% per time interval ($p = 0.02$), and reduction in sleep medication usage ($p < 0.0001$) in the study group. Perceived night-time noise was improved, but with no effect on sleep quality or use of delirium medication. Van Rompaey *et al*. show associations between environmental noise, sleep perception, and delirium[49]. They conducted a randomized control trial on 136 non-delirious ICU patients and found use of earplugs (from 2200 to 0600) reduced risk of confusion or delirium by 53% (hazard ratio 0.47, 95% CI 0.27–0.82) and improved sleep perception.

Our full-text review and data extraction appraised articles studying single-component noise control strategies, such as behavioral programs[65–69], earplugs or noise cancelling headphones[71–74], and headphones equipped with an alarm filtering system[70]; however these were not included since they reviewed the impact of interventions on the level of noise or quality of sleep, but delirium was not reported as an outcome (Table 9).

Light modification. Light interventions were implemented in an attempt to realign circadian rhythms by reducing night-time exposure and/or improving natural or artificial daylight exposure (Table 7).

Reduction of nocturnal light exposure

The included articles in this review, studied eye masks[7,57,59] and overnight light dimming[7,58,59] as part of an environmental modification bundle to reduce night-time light exposure. However, the effects of less nocturnal light exposure on delirium, was not evaluated as a single intervention.

Improving natural daylight exposure

Three observational studies[31,33,87] and one before-after study[48] investigated improved natural lighting via windows. They compared patient outcomes in rooms with a window or larger-sized windows versus windowless or smaller-sized windows, respectively. No observational studies suggested association between improved natural lighting and delirium[31,33,87]. Zaal *et al.*[48] demonstrated reduction in delirium duration, comparing patients in private rooms with more natural light versus less bright multi-bed rooms; however, there were no differences in delirium incidence or severity between groups.

Improving artificial daylight exposure

Eight studies examined effect of improved daylight exposure via artificial lighting, of which three used an artificial circadian lighting system[15,50,51], and five used bright light therapy (BLT)[52–56]. No study implementing artificial dynamic or circadian lighting revealed significant effects on delirium. BLT studies had mixed results; three studies significantly improved delirium prevention or management, while the other two showed a non-significant tendency to reduce delirium rates.

A retrospective cohort study of 183 non-sedated ICU patients by Estrup *et al.*[15] used a circadian lighting system from 0700 to 2300 which varied in intensity and color temperature. During the morning, light intensity was greatest, up to 4000 lux (lx), and the amount of blue light strongest. As the day progressed, light intensity decreased and color temperature shifted towards warmer tones until no blue light was present. There was no improvement in delirium incidence, and no association between circadian lighting and delirium incidence (odds ratio (OR) 1.14; 95% CI 0.55, 2.37; $p = 0.73$). Pustjens *et al.*[50] retrospectively studied a cohort of 748 non-sedated patients. They implemented a dynamic lighting system consisting of two ceiling-mounted light-emitting diode (LED) panels which delivered variable intensities of light (peak of 750 lx) with a color temperature between 2700 and 6500 Kelvin (K). There was no effect on delirium incidence. Another RCT by Simons *et al.*[51] measured the effects of a dynamic lighting application (DLA) in 734 ICU patients. DLA was administered through ceiling-mounted

Table 6. Summary of characteristics and findings of interventional studies modifying environmental noise.

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Single-component noise modification interventions						
van de Pol 2017 Netherlands[14]	To test effect of nocturnal sound-reduction protocol on delirium incidence and sleep quality in ICU	Pre- post Intervention (interrupted time series)	MICU, SICU n=421: 211 control, 210 intervention Adult, non-delirious, RASS<–3 for > 50% of ICU stay, ICU stay≥24 hrs	Nocturnal sound-reduction protocol: Lowered staff and devices noise, clustered care-activities, closed doors and earplugs in non-delirious patients, limited and clustered care activities Control group: usual care	Delirium incidence (ICDSC) Sleep (RCSQ) Level of noise (Perceived noise item of RCSQ, and sound meter with microphone located near bed's head, recorded 1s intervals of A weighted noise levels)	Decreased delirium incidence No improvement in sleep quality Reduced perceived night-time noise. Noise pressure levels not compared between the two groups due to unusable pre-intervention values Reduced use of sleep medication, no effect on delirium medication
Van Rompaey 2012 Belgium[49]	To evaluate effect of sleeping with earplugs on prevention of delirium in ICU	RCT	MICU, SICU, cardiosurgical ICU n=136: 67 control, 69 intervention Non-delirious, non-sedated, non-intubated adults, GCS≥10, no dementia, ICU stay >24 hrs	Earplugs during sleep from 2200 to 0600 Control group: No earplugs	Delirium incidence (NEECHAM) Sleep perception (Non-validated simplified sleep questionnaire with five dichotomous questions)	No effect on incidence of delirium, but reduced risk of confusion, and increased time to cognitive disturbance onset Improved sleep quality
Multi-component environmental interventions including noise reduction components						
Demoule 2017 France[57]	To evaluate effect of earplugs and eye mask on sleep in ICU	RCT	ICU (General) n=43: 28 control, 15 intervention Adult, non-sedated, Ramsay Sedation Scale <3, no history of sleep or neurological disorder, sepsis, encephalopathy, ICU stay >48hr	Earplugs and eye-masks during sleep from 2200 to 0800 Control group: No earplugs or eye mask	Delirium incidence (CAM-ICU) Sleep (PSG on first day of study, Self-reported sleep quality by simplified visual analogue scale (VAS; 10 cm horizontally) at discharge, and by Pittsburgh Sleep Quality Index at day 90)	No effect on delirium No effect on sleep proportion of N3, but improved sleep quality only by increasing duration of N3 stage and reducing long awakenings in compliant subjects.
McAndrew 2016 USA[58]	To evaluate effect of quiet time on delirium, sedation level, and physiologic measures in MV patients	Prospective cohort study	MICU n=72 Mechanically ventilated adults until extubated	Quiet time from 1400 to 1600; Dimmed lights, closed window shades, TVs off, closed doors, clustered care-activities	Presence of delirium (CAM-ICU) Sleep (Nurse perception of patient's sleep by an investigator created tool with uninterrupted sleep time, and overall quality of sleep questions)	No significant effect on delirium; however reported no increase in delirium Improved sleep perception moderately Improved respiratory rates, and nursing satisfaction of quiet time protocol

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Patel 2014 UK[7]	To test a non-pharmacologic bundle with environmental noise and light reduction components on delirium and sleep	Pre- post Intervention	MICU, SICU n=338: 167 control, 171 intervention Non-delirious, non-sedated adults with ≥1 ICU night, and no sleep, or cognitive, or neurologic disorder	Multidisciplinary intervention from 2300 to 0700; Limited bedside conversation, clustered care-activities, minimized devices noise levels, dimmed lights, earplugs and eye mask, patient orientation, early mobilization, and sedation targets. Control group: usual care	Delirium incidence and duration (CAM-ICU) Sleep quality (RCSQ, and the Sleep in Intensive Care Questionnaire) Level of noise Level of light (Two environmental meters placed centrally; mean level of noise reported in dB, illuminance reported in lx)	Decreased delirium incidence and duration Increased sleep quality, decrease daytime sleepiness Decreased level noise Decrease level of light
Kamdar 2013 USA[59]	To determine impact of a multi-faceted quality improvement program on ICU delirium, and sleep	Pre- post Intervention	MICU n=300: 122 control, 178 intervention Adults with ≥1 ICU night, and discharge to an inpatient ward bed or pending discharge directly from ICU; without ≥1 night in another ICU during admission, any cognitive disorder, or alcohol or drug abuse, cardiac arrest during admission, any other ICU discharge>96 hrs prior to assessment	Multi-faceted sleeping promotion protocol; 3 additive stages of 1) quiet time, and realignment of circadian rhythm, 2) earplugs, eye-masks, and soothing music, 3) pharmacological targets to reduce sedatives. Control group: usual care	Delirium incidence (CAM-ICU) Sleep (RCSQ)	Decreased incidence of delirium No effect on quality of sleep ratings

Abbreviations: CAM-ICU: Confusion Assessment Method for the ICU, dB: decibels, GCS: Glasgow Coma Scale/Score, hrs: hours, ICDSC: Intensive Care Delirium Screening Checklist, ICU: intensive care unit, K: Kelvin, lx: Lux, MV: mechanically ventilated, NEECHAM: Neelon and Champagne Confusion Scale, PSG: Polysomnography, RASS: Richmond Agitation and Sedation Scale, RCSQ: Richards-Campbell Sleep Questionnaire, RCT: Randomized control trial.

[1] Only outcomes of interest including delirium related outcomes, sleep quality, sound pressure levels, and light intensity levels, has listed in this table.

[2] Details of measured noise and light, such as devices, location, and frequency has not been discussed in detail in this table.

Table 7. **Summary of characteristics and findings of interventional studies modifying environmental light.**

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Light modification interventions						
Estrup 2018 Denmark[15]	To explore effect of circadian light on delirium	Retrospective cohort study	MICU, SICU n=183 Non-sedated adults with available CAM-ICU scores, without any coma: RASS of -5 or -4, or severe dementia	Circadian Lighting: Supplemental lighting system delivered light with strongest intensity of 4000lx and most blue component from 0700 to 1200, and minimum of 50lx at 2030 Control group: Regular lighting	Delirium Incidence (CAM-ICU, and use of Haloperidole)	No effect on incidence of delirium Reported age and dexedetomidine as risk factors for delirium
Pustjens 2019 Netherlands[50]	To test effect of dynamic lighting on delirium and	Retrospective cohort study	CCU n=748: 379 control, 369 intervention Non-sedated adults with ≥ 24 hrs ICU stay	Circadian Lighting: Ceiling mounted LED panels delivered light with color temperature between 2700 and 6500 K at varying intensities (peak 750lx) Control group: Regular lighting	Delirium incidence (DOSS, and CAM)	No effect on incidence of delirium
Simons 2016 Netherlands[51]	To assess effect of dynamic lighting on incidence and duration of delirium	RCT	MICU, SICU n=714: 360 control, 354 intervention Adult, ICU stay>24 hrs, both intubated and non-intubaed without impairments preventing delirium assessments were included	Artificial high-intensity dynamic lighting application: Ceiling mounted fluorescent tubes delivered light with alteration in color temperature and intensity: blueish-white light up to 4300 K, and 1700 lx from 0900 to 1600, except intensity of 300 lx from 1130 to 1330 Control group: Usual lighting: 300 lx, 3000 K	Delirium incidence, and duration (CAM-ICU) Level of light (Photometer placed at 2m height on wall near bed's head, recorded 15minutes intervals of light intensity in lx)	No significant effect on incidence of delirium, or number of delirium-free days Increased mean cumulative daytime lighting
Taguchi 2007 Japan[52]	To evaluate effect of BLT on post-operative circadian optimization and delirium	RCT (Pilot)	SICU n=11: 5 control, 6 intervention Middle-aged, or aged post-operative esophageal cancer patients, with no mental disorders; randomized after extubation	BLT: 5000lx from 0730 to 0930 for 3 of the post-operative days, by a self-stand or a table-top illuminator Control group: Usual lighting: 600-1000lx	Delirium incidence (non-validated Japanese NEECHAM) Sleep/Circadian rhythm (Activity levels and rhythm recorded by ankle accelerometers and memory heart rate recorder)	Decreased post-operative delirium rate on day 3 of the BLT, but no overall significant effect on delirium incidence Non-significant decrease in activity level during sleep

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Ono 2011 Japan[53]	To evaluate effect of BLT on post-operative circadian optimization and delirium	RCT (Pilot)	SICU n=22: 12 control,10 intervention Adult post-esophagectomy patients, who anticipated to be extubated the day after surgery; randomized after extubation	BLT: 2500 to 5000lx from 0730 to 0930 for 4 days (0730-0745: 2500lx, 0745-0800: 4000lx, 0800-0900: 5000lx, 0900-0915: 4000lx, 0915-0930 2500lx), by a self-standing L-shaped illuminator to maintain lighting in front of patient's face Control group: usual lighting	Delirium incidence (Validated Japanese NEECHAM) Sleep/Circadian rhythm (Activity levels and rhythm recorded by ankle accelerometers and memory heart rate recorder)	Non-significant lower rate of post-operative delirium Decreased amount of activity during sleep on the nights of days 4 and 5
Potharajaroen 2018 Thailand[56]	To evaluate effect of BLT on post-operative delirium	RCT	SICU n=62: 31 control, 31 interventions Adults aged ≥ 50, with APACHE II Score ≥ 8 without coma, life-time history or current delirium, neuro-degenerative, psychiatric, or neuroinflammatory disease	BLT: Bright Light therapy, 5000lx from 0900 to 1100 for 3 days, at a distance of 1.40 m from the patient's face Control group: usual lighting: 500lx	Delirium incidence (CAM-ICU) Sleep (Assessing insomnia by ISI)	Decreased delirium incidence Higher ISI score was associated with development of delirium, and BLT lowered ISI scores.
Yang 2012 South Korea[54]	To determine impact of BLT with antipsychotic treatment in delirious patients	Randomized open parallel group	Consulting psychiatry division of a general hospital n=36: 16 control, 20 intervention Hospitalized adults with psychiatry referral, with DRS≥ 12 without any other axis I disorders on DSM-IV or antipsychotics or benzodiazepines use	BLT as adjunctive treatment with risperidone: 10,000 lx from 0700 to 0800 for 5 days by a height-adjustable light box Control group: Resperidone	Delirium severity (DRS, MDAS) Sleep (Sleep log with total sleep time, efficiency, onset latency, awake times questions)	Decreased delirium severity Improve total sleep time and sleep efficiency
Chong 2013 Singapore[55]	To examine effect of GMU on sleep, cognitive, and functional outcomes in delirious patients	Prospective cohort study	GMU n=228 Adult delirious patients>65 years old, without coma, or terminal illness, or BLT contraindications (manic disorders, severe eye disorders, photosensitive skin disorders, or photosensitizing use)	BLT: 2000- 3000lx from 1800 to 2200 delivered by ceiling lights in addition to HELP protocol	Delirium severity (CAM, DRS-98, locally validated CMMSE) Sleep (Sleep log with total sleep time, number of awakenings, number and length of sleep bouts questions)	No significant effect on DRS severity scores, but improved DRS sleep–wake disturbance sub-score, No significant improvement on CMMSE scores Improved mean total sleep time, and functional status score

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Multi-component environmental interventions including light modification components						
Demoule 2017 France[57]	To evaluate effect of earplugs and eye mask on sleep in ICU	RCT	ICU (General) n=43: 28 control, 15 intervention Adult, non-sedated, Ramsay Sedation Scale <3, no history of sleep or neurological disorder, sepsis, encephalopathy, ICU stay >48 hrs	Earplugs and eye-masks during sleep from 2200 to 0800 Control group: No earplugs or eye mask	Delirium incidence (CAM-ICU) Sleep (PSG on first day of study, Self-reported sleep quality by simplified visual analogue scale (VAS; 10 cm horizontally) at discharge, and by Pittsburgh Sleep Quality Index at day 90)	No effect on delirium No effect on sleep proportion of N3, but improved sleep quality only by increasing duration of N3 stage and reducing long awakenings in compliant subjects.
McAndrew 2016 USA[58]	To evaluate effect of quiet time on delirium, sedation level, and physiologic measures in MV patients	Prospective cohort study	MICU n=72 Mechanically ventilated adults until extubated	Quiet time from 1400 to 1600; Dimmed lights, closed window shades, TVs off, closed doors, clustered care-activities	Presence of delirium (CAM-ICU) Sleep (Nurse perception of patient's sleep by an investigator created tool with uninterrupted sleep time, and overall quality of sleep questions)	No significant effect on delirium; however reported no increase in delirium Improved sleep perception moderately Improved respiratory rates, and nursing satisfaction of quiet time protocol
Patel 2014 UK[7]	To test a non-pharmacologic bundle with environmental noise and light reduction components on delirium and sleep	Pre- post Intervention	MICU, SICU n=338: 167 control, 171 intervention Non-delirious, non-sedated adults with ≥1 ICU night, and no sleep, or cognitive, or neurologic disorder	Multidisciplinary intervention from 2300 to 0700; Limited bedside conversation, clustered care-activities, minimized devices noise levels, dimmed lights, earplugs and eye mask, patient orientation, early mobilization, and sedation targets. Control group: usual care	Delirium incidence and duration (CAM-ICU) Sleep quality (RCSQ, and the Sleep in Intensive Care Questionnaire) Level of noise, and light (Two environmental meters placed centrally; mean level of noise reported in dB, illuminance reported in lx)	Decreased delirium incidence and duration Increased sleep quality, decrease daytime sleepiness Decreased level noise Decrease level of light

Study (Author, Year, Country)	Study Purpose	Study Design	Study Setting Population Subjects Characteristics	Intervention Details	Outcomes[1] (Methods of Assessment)	Findings
Kamdar 2013 USA[59]	To determine impact of a multi-faceted quality improvement program on ICU delirium, and sleep	Pre- post Intervention	MICU n=300; 122 control, 178 intervention Adults with ≥1 night ICU stay, who discharged to an inpatient ward bed or pending discharge from ICU; without ≥1 night in another ICU during admission, any cognitive disorder, alcohol or drug abuse, cardiac arrest during admission, any ICU discharge>96 hrs prior to assessment	Multi-faceted sleeping promotion protocol; 3 additive stages of 1) quiet time, and realignment of circadian rhythm, 2) earplugs, eye-masks, and soothing music, 3) pharmacological targets to reduce sedatives. Control group: usual care	Delirium incidence (CAM-ICU) Sleep (RCSQ)	Decreased incidence of delirium No effect on quality of sleep ratings

Abbreviations: BLT: bright light therapy, CAM: Confusion Assessment Method, CAM-ICU: Confusion Assessment Method for the ICU, CCU: coronary care unit, CMMSE: Chinese Mini–Mental State Examination, dB: decibels, DOSS: Dutch version of the Delirium Observation Screening, DRS: Delirium Rating Scale, DRS-98: Delirium rating scale-R98, DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, GMU: Geriatric Monitoring Unit (A specialized delirium management unit), HELP: Hospital Elder Life Program (standardized protocols to manage cognitive impairment, sleep deprivation, immobility, visual impairment, hearing impairment, and dehydration), hrs: hours, ICU: intensive care unit, ISI: Insomnia Severity Index, K: Kelvin, LED: light-emitting diode, lx: Lux, MDAS: Memorial Delirium Assessment Scale, MV: mechanically ventilated, NEECHAM: Neelon and Champagne Confusion Scale, PSG: Polysomnography, RASS: Richmond Agitation and Sedation Scale, RCSQ: Richards-Campbell Sleep Questionnaire, RCT: Randomized control trial.

[1] Only outcomes of interest including delirium related outcomes, sleep quality, sound pressure levels, and light intensity levels, has listed in this table.

[2] Details of measured noise and light, such as devices, location, and frequency has not been discussed in detail in this table.

fluorescent lights which delivered a variety of bluish-white light from 0700 to 2230 with a maximum intensity of 1700 lx and a maximum temperature of 4300 K between 0900 and 1600, except between 1130 and 1330 when light intensity was 300 lx. This study was terminated early, but preliminary analysis demonstrated delirium incidence of 38% versus 33% in control versus study patients, with no significant improvement on delirium incidence or duration.

Four studies investigated the use of BLT as a single-component intervention to prevent[52,53,56] or treat[54] delirium, while one study used BLT as an element of a multi-component bundle to manage delirium[55]. BLT consisted of exposure to high intensity light (2000 to 10000 lx) for one to four hours daily. Three studies used a peak intensity of 5000 lx[52,53,56]. Taguchi *et al.*[52] conducted a randomization pilot study on 11 post-operative patients, utilizing a daily light intensity of 5000 lx from 0730 to 0930 for days 2 through 5 post-surgery. Delirium assessment scores decreased on day 3 of BLT (p = 0.014), but there was no significant effect on overall delirium incidence (16% versus 40% study versus control group, p = 0.42). In another RCT, Ono *et al.*[53] applied BLT on 22 post-operative patients, for two hours from 0730 to 0930 for four days. Light intensity started at 2500 lx, increasing to 5000 lx, then decreasing to 2500 lx. There was a non-significant tendency towards lower rates of delirium in the study group (1 of 10 patients) versus control group (5 of 12 patients), while BLT significantly reduced the amount of activity during sleep on days 4 and 5. Potharajaroen *et al.*[56] studied 62 post-operative patients by implementing BLT at 5000 lx from 0900 to 1100. Eleven of 31 control patients versus 2 of 31 patients in the intervention group developed delirium. There was a significant association between BLT and decreased delirium incidence (OR 0.12, 95% CI 0.03–0.54, p = 0.005). A study by Yang *et al.*[54] on 36 delirious patients used a higher light intensity (10000 lx) over a shorter period (0700 to 0800). This study investigated the use of BLT as an adjunctive treatment of delirium with risperidone. They found a significant decrease in delirium severity in patients receiving BLT in addition to risperidone (DRS 23.9 ± 4.9 versus 20.6 ± 3.6 in control versus study group, p = 0.03). Chong *et al.*[55] studied 228 delirious elderly patients admitted to a delirium management unit. They incorporated lower intensity BLT as part of their multi-component program, and exposed patients to 2000 to 3000 lx of light for four hours from 1800 to 2200 daily. They reported significant improvement in total sleep time and functional outcomes during treatment of delirious patients.

Intervention bundles (combination of light and noise modification)

Earplugs and eye mask

One reviewed study explored effects of earplugs and an eye mask on delirium[57], while two others used earplugs and an eye mask as part of their interventional bundle[7,59]. All three noted decreased incidence of delirium, but observed different effects on sleep quality. Demoule *et al.*[57] conducted an RCT on 43 non-sedated ICU patients to investigate the impact of sleeping with earplugs and an eye mask from 2200 to 0800 on patient outcomes. They found no improvement in delirium incidence, duration or architecture of sleep in the study group, regardless of patient compliance using the equipment. Although compliant study subjects experienced improved sleep with longer N3 (deeper sleep) duration and a lower number of prolonged awakenings, there was no significant change in delirium incidence. There were several articles in our initial screening reporting improved perceived noise or sleep quality with the use of earplugs and eye masks,however those were excluded since none reported results on delirium[75–78] (Table 9).

Quiet time, and sleep promotion bundles

Quiet time is a specific amount of time during which modifiable noise and light is actively reduced. Our review included three studies installing quiet time as the single interventional element[58] or as a part of a sleep promotion bundle[7,59]. Core elements of quiet time were behavioral strategies, minimized bedside activity by clustering care, reduced volume of devices/alarms, and dimmed lights[7,58,59]. The study that implemented daytime quiet time failed to show significant effects on delirium[58], while two sleep promotion studies decreased delirium incidence using nocturnal quiet time combined with components such as earplugs, eye masks, and pharmacological targets[7,59]. Although the multi-component sleep promotion trials decreased delirium incidence, effectiveness of the separate components is unclear.

McAndrew *et al.*[58] applied quiet time from 1400 to 1600 among 72 mechanically ventilated ICU patients. In the 24 hours after starting quiet time, there was no increase in delirium rate and 19% of delirious patients improved to a negative CAM-ICU status. However, there was no significant effect on delirium in their analysis. Quiet time did lead to moderately improved sleep quality and less frequently administered sedatives which helped remove patients from mechanical ventilation. A pre-post research by Patel *et al.*[7] studied a nocturnal multidisciplinary environmental sleep promotion program in 338 non-delirious, non-sedated ICU patients. Their program included nocturnal quiet time with earplugs, eye mask, patient orientation, early mobilization, and sedation targets. The study group showed significant reduction in delirium incidence (by 33% p < 0.001), and a decrease in delirium duration (3.4 ± 1.4 versus 1.2 ± 0.9 days, p = 0.021). Sleep quality and night-time light and noise levels were also improved in the study group, however reported noise levels were still higher than the WHO limits[17]. They additionally reported a significant association between sleep efficiency and a lower risk of developing delirium (OR 0.90, 95% CI 0.84–0.97). A larger pre-post study (n=300) by Kamdar *et al.*[59] initiated a multi-faceted sleep promotion protocol consisting of three additive stages: 1) nightly quiet time and realignment of circadian rhythm, 2) sleeping with earplugs, eye masks, and soothing music, and 3) pharmacological targets to reduce sedatives. They reported decreased delirium incidence (OR = 0.46, 95% CI 0.23–0.89, p = 0.02) and perceived night-time noise in the study group, but no improvements in sleep quality.

Table 8. **Effectiveness of environmental interventions on delirium.**

Intervention	Studies	Delirium incidence	Delirium prevalence	Delirium duration	Delirium severity	Statistics
Architectural design modification						
Acoustic modified ICU room	Johansson, 2018[18]	--	NA[1]	--	--	No analysis done due to small sample size
Private room with less noise and more light exposure	Zaal, 2013[48]	NSE[2]	--	↓[3]	NSE	Delirium incidence: 51% control 45 % intervention, (OR 0.6, 95 % CI 0.3–1.6, p = 0.53) Delirium duration: Decreased number of days with delirium by 0.4 (95 % CI 0.1–0.7, p = 0.005) Delirium severity: DSI score per day with delirium, mean (SD): 2.3±0.7 control, 2.5±0.8 intervention, p = 0.34
Noise modification interventions						
Sound reduction protocol (Behavioral strategies and earplugs)	van de Pol, 2017[14]	↓	--	--	--	Delirium incidence decreased by 3.7% per time period (p = 0.02)
Earplugs	Van Rompaey, 2012[49]	NSE, Decreased risk of confusion	--	--	--	Delirium incidence: 20% control, 19% intervention Risk of confusion/ early delirium: decreased by 53% (HR .0.47, 95% CI 0.27 to 0.82) Median NEECHAM score: 24 (829) control 26 (5-29) intervention (Mann-Whitney U, p = 0.04) Time to cognitive disturbance onset: Increased, p = 0.006
Light modification interventions						
Artificial dynamic/ circadian lighting	Estrup, 2018[15]	NSE	--	--	--	Delirium incidence: 28% control, 30% intervention, (OR 1.14; 95% CI 0.55-2.37; p = 0.73)
	Pustjens, 2019[50]	NSE	--	--	--	Delirium incidence, n(%): 19/379 (5.0) control 20/369 (5.4) intervention, p = 0.802
	Simons, 2016[51]	NSE	--	NSE	--	Delirium incidence, n(%): 123/373 (33) control 137/361 (38) intervention, (OR 1.24, 95 % CI 0.92–1.68, p = 0.16) Delirium duration (hours): 2 (1-5) control, 2 (2-5) intervention, p = 0.87
Bright light therapy	Taguchi, 2007[52]	NSE, Decreased delirium scores on day 3 of BLT	--	--	--	Delirium incidence: 40% control, 16 % intervention, p = 0.42 by Fisher's exact probability test. There was a significant difference in NEECHAM delirium score between the two groups on the morning of day 3 of BLT by the Mann—Whitney U-test (p = 0.014)
	Ono, 2011[53]	NSE	--	--	--	Delirium incidence, n(%): 5/12 (42) control, 1/10 (10) intervention, p > 0.05
	Potharajaroen, 2018[56]	↓	--	--	--	Delirium incidence, n(%): 11/31 (35) control 2/31 (6) intervention, (OR 0.12, 95 % CI 0.03–0.54, p = 0.005)
	Yang, 2012[54]	--	--	--	↓	DRS score: decreased in study group (F=2.87, p = 0.025) MDAS score: Not significantly different between the two groups
	Chong, 2013[55]	--	--	--	NSE, Improved functional and sleep outcomes	DRS severity score: decreased by 6.2±6.3 (22.5±5.8 versus 14.6±6.1 in initial versus discharge DRS, p > 0.05)

Intervention	Studies	Delirium incidence	Delirium prevalence	Delirium duration	Delirium severity	Statistics
Environmental modification targeting both noise and light						
Earplugs & eye mask	Demoule, 2017[57]	NSE	--	--	--	Delirium incidence, n(%): 2/22 (6) control 2/23 (7) intervention, p = 1
Quiet time	McAndrew, 2016[58]	--	NSE	--	--	No significant effect on delirium scores (p = 0.648)
Multi-component sleep promotion protocol	Patel, 2014[7]	↓	--	↓	--	Delirium incidence, n(%): 55/167 (33) control 24/171 (14) intervention, (OR 0.33, 95% CI 0.19–0.57, p < 0.001) Delirium duration (length of time spent delirious), mean ±SD: 3.4±1.4 control, 1.2 ±0.9 intervention, p = 0.021 Improved sleep efficiency index was associated with a lower risk of developing delirium (OR 0.90, 95% CI 0.84–0.97)
	Kamdar, 2013[59]	↓	--	--	--	Incidence of delirium/coma, n (%): 76/110 (69) control, 86/175 (49) intervention, (OR 0.46; 95% CI 0.23-0.89, p = 0.02) Daily delirium/coma-free status, n (%): 272/634 (43) control, 399/826 (48) intervention, (OR 1.64, 95% CI, 1.04-2.58, p = 0.03)

Abbreviations: OR: Odds Ratio, CI: Confidence Interval, DSI: Delirium Severity Index, SD: Standard Deviation, HR: Hazard Ratio, NEECHAM: Neelon and Champagne Confusion Scale, BLT: Bright light therapy, DRS: Delirium Rating Scale, MDAS: Memorial Delirium

[1] No statistical analysis was done

[2] No significant effect

[3] Decrease

Table 9. List of excluded studies investigating impact of environmental interventions on delirium risk factors[1].

Study (author, year)	Short summary	Reason for exclusion
Architectural design modification to improve environmental noise and light		
Gabor 2003[63]	**Study aim:** To identify high noise and its impact on sleep, and test the effect on noise reduced private vs multi-bed ICU rooms **Study design, and setting:** Observational, MICU & SICU (n= 6 healthy subjects) **Intervention:** Healthy subjects spent one night in a private room, and one night in a multi-bed room **Findings:** Lower mean and mean maximum noise levels, less noise peaks, improved sleep quantity, no effect on sleep quality in private room	No delirium report or measurement
Luetz 2016[64]	**Study aim:** To investigate the effect of acoustically modified ICU rooms on noise levels **Study design, and setting:** Observational, ICU modified vs standard room **Intervention:** Work room behind patient's head (window to patient room, sound protective materials, drawers opening from both work and patient rooms, place to keep alarm systems, monitors, and medical devices), noise-protection side boards between beds, automatic room doors, an LED ceiling from head to foot of each patient for dynamic lighting. **Findings:** Decreased mean and maximum nocturnal noise levels, as well as sound peaks>50 dBA	No delirium report or measurement
Environmental noise reduction (behavioral modification)		
Kahn 1998[65]	**Study aim:** To identify sources of noise peaks and effect of behavioral modification on noise reduction **Study design, and setting:** Pre-post intervention, MICU **Intervention:** Behavioral modification program targeting noise reduction **Findings:** Identified talking and televisions as the most noticeable noise origins. The number of noise peaks and mean peak level of noise decreased by 1.9 dBA after intervention	No delirium report or measurement
Monsén 2005[66]	**Study aim:** To identify sources of sleep disturbance and effect of behavioral modification on sleep and noise reduction **Study design, and setting:**Pre-post intervention, NICU (n=25) **Intervention:** Behavioral modification program targeting noise reduction **Findings:** Nursing and medical care were the main causes of sleep disturbance. The intervention decreased identified sources of sleep disturbance, and partly reduced noise levels.	No delirium report or measurement
Crawford 2018[67]	**Study aim:** To identify sources of noise and effect of behavioral modification on noise reduction **Study design, and setting:** Pre-post intervention, MICU **Intervention:** Behavioral modification program targeting noise reduction **Findings:** No clinical effect on noise reduction (<1.0 dBA). They explained that the reason was due to respiratory devices, heating, ventilation, and air-conditioning systems being the source of high noise levels.	No delirium report or measurement
Guisasola-Rabes 2019[68]	**Study aim:** To evaluate the effect of a sound-activated visual noise-warning system on noise reduction **Study design, and setting:** Pre-post intervention, SICU (n=148) **Intervention:** Using a visual noise display meter (SoundEar 2 device) with colored visual warnings on noise levels>55dBA &>60dBA **Findings:** Reduction in ambient noise. The reduction was sustained for two weeks after switching off the device.	No delirium report or measurement
Plummer 2019[69]	**Study aim:** To evaluate the effect of a sound-activated visual noise-warning system on overnight noise reduction **Study design, and setting:** Pre-post intervention, MICU, SICU, NICU **Intervention:** Using a visual noise display meter (SoundEar 3 device) with colored visual warnings on noise levels>55dBA & >60dBA **Findings:** Reduction in overnight ambient and peak noise. The reduction was sustained for 4 months after continued use of device	No delirium report or measurement

Study (author, year)	Short summary	Reason for exclusion
Environmental noise reduction (alarm noise abatement)		
Schlesinger 2017[70]	**Study aim:** Creation of a wearable frequency-selective silencing device to filter alarm noises **Study design, and setting:** Interventional, Simulated ICU setting (n=24 healthy subjects) **Intervention:** Noise cancelling headphone with frequency-Selective Silencing Device, filtering alarms while passing other sounds **Findings:** Removed the ICU alarm noise while allowing the patient to hear all other environmental sounds without distortion	No delirium report or measurement
Environmental noise reduction (earplugs)		
Wallace 1999[71]	**Study aim:** To test the effect of earplugs on the sleep of healthy subjects in simulated ICU noise **Study design, and setting:** RCT- feasibility, Sleep study center with simulated ICU noise (n=6 healthy volunteers) **Intervention:** Earplugs during sleep **Findings:** Improved sleep quality by shorter REM latency and increased REM sleep	No delirium report or measurement
Scotto 2009[72]	**Study aim:** To evaluate the effect of earplugs on sleep **Study design, and setting:** Quasi-RCT, MICU, SICU (n=88; 49 control, 39 intervention) **Intervention:** Earplugs during sleep **Findings:** Improved the perception of sleep	No delirium report or measurement
Litton 2017[73]	**Study aim:** To explore the feasibility, effectiveness, and implementation of earplugs on sleep and delirium in ventilated patients **Study design, and setting:** RCT, SICU, (n=40 intubated patients; 20 control, 20 Intervention) **Intervention:** Earplugs (All day when on mechanical ventilation, and during sleep when extubated) **Findings:** Earplugs were feasible on the basis of acceptability and protocol compliance with a mean noise abatement of 10 dB, and a reduced perceived noise level by half. No significant effect on sleep quality	No delirium report or measurement
Gallacher 2017[74]	**Study aim:** Quantifying the ability of headphones with and without active noise control technology on noise exposure **Study design, and setting:** Pre-post Intervention, ICU-CS (n=3 polystyrene model heads placed in patient bay) **Intervention:** Headphones without and with active noise cancelling system **Findings:** Headphones with active noise cancellation resulted in 6.8dB reduction in noise exposure, and decreased exposure to high intensity sounds	No delirium report or measurement
Environmental noise and light reduction (earplugs and eye masks)		
Richardson 2007[75]	**Study aim:** To identify sleep disturbing factors, and test the effectiveness of earplugs and eye masks on sleep **Study design, and setting:** post-test quasi-experimental, CTICU, (n=64; 28 control, 34 Intervention) **Intervention:** earplugs and eye mask **Findings:** Improved sleep while noise was reported as an still a disturbing factor	No delirium report or measurement
Hu 2010[76]	**Study aim:** To investigate the effect of earplugs and eye masks in healthy subjects. **Study design, and setting:** Randomized cross-over experimental, Sleep study center with simulated ICU noise (n=14 healthy volunteers) **Intervention:** earplugs and eye masks **Findings:** Improved architecture and perceived quality of sleep, and higher night levels of melatonin	No delirium report or measurement
Jones 2012[77]	**Study aim:** To study perceived sleep quality with earplugs and eye masks. **Study design, and setting:** Pre-post Intervention, ICU, (n=100; 50 control, 50 Intervention) **Intervention:** earplugs and eye masks **Findings:** Increased sleep duration but no effect on sleep quality	No delirium report or measurement
Le Guen 2014[78]	**Study aim:** To assess the effect of earplugs and eye masks on the sleep of surgical ICU patients **Study design, and setting:** RCT, PACU, (n=41; 21 control, 20 Intervention) **Intervention:** earplugs and eye mask **Findings:** Preserved sleep quality, decreased the need for daily nap, but no effect on sleep duration	No delirium report or measurement

Study (author, year)	Short summary	Reason for exclusion
Environmental light modification (Nocturnal light modification)		
Albala, 2019[79]	**Study aim:** To evaluate the effectiveness of using nocturnal blue-depleted lighting pods **Study design, and setting:** Non-RCT trial-feasibility study, Non-intensive care medical unit (n= 33 nurses and 21 patients) **Intervention:** Reduce nocturnal light exposure by using wireless proximity-sensing, blue-depleted lights for night-time bed-side tasks **Findings:** Use of nocturnal blue-depleted lighting pods for overnight lighting purposes found to be feasible	No delirium report or measurement
Multi-component interventions with environmental noise and light modification components		
Walder 2000[80]	**Study aim:** Effectiveness of nocturnal behavioral rules on ICU light and noise levels **Study design, and setting:** Pre-post Intervention, SICU (n=17; 9 pre, 8 post) **Intervention:** Nocturnal light and noise reduction (Systematic door closures, lowered staff voice and alarm noise, less use of direct light, limited care activities). **Findings:** Lowered mean light disturbance intensity with a greater variability of light. Decreased the noise level equivalent, and peak noise level. No effect on background noise level. Decreased estimated sleep duration and higher number of awakenings.	No delirium report or measurement
Olson 2001[81]	**Study aim:** To examine the efficacy of quiet time on frequency of sleep **Study design, and setting:** Pre-post Intervention, NICU (n=239; 118 control, 121 intervention) **Intervention:** Quiet time from 0200 to 0400 and 1400 to 1600 **Findings:** Improved quality of sleep, Reported association between improved sleep and decreased levels of light and noise	No delirium report or measurement
Dennis 2010[82]	**Study aim:** Effectiveness of the Quiet time protocol on sleep, ICU light and noise levels **Study design, and setting:** Pre- post Intervention, ICU (n=50) **Intervention:** Quiet time including dimmed lights, lowered staff and devices noise, grouped and limited care activities, limited family visits from 0200 to 0400 and from 1400 to 1600 **Findings:** Decreased daytime level of light and noise, improved observed sleep	No delirium report or measurement
Bartick 2010[83]	**Study aim:** Effect of the quiet time protocol on sleep **Study design, and setting:** Pre-post Intervention, Non-intensive care, Medical-surgical unit (n= 267;161 pre, 106 post) **Intervention:** Somerville Quiet time Protocol from 2200 to 0600; automated lights-off, warning for noise levels >60dBA, lullaby, minimized staff and care activities, Minimized alarms by following a bedtime routine program **Findings:** Decreased reporting of noise as a sleep disruption factor, decreased need of as needed overnight sedatives.	No delirium report or measurement
Li 2011[84]	**Study aim:** To study the efficacy of nocturnal noise control on sleep quality in SICU patients **Study design, and setting:** Interventional (Quasi-experimental), SICU (n=55; 27 control, 28 intervention) **Intervention:** Noise and light control guidelines for sleep **Findings:** Improved quality of sleep, and significantly reduced average and peak noise levels	No delirium report or measurement
Boyko 2017[85]	**Study aim:** To investigate the effect of an improved ICU environment on sleep quality of ventilated patients **Study design, and setting:** RCT (cross over design), ICU (n= 17) **Intervention:** Quiet protocol from 2200 to 0600 **Findings:** No significant effect on sleep patterns (measured by polysomnography) or noise levels	No delirium report or measurement
Goeren 2018[86]	**Study aim:** To decrease noise levels by quiet time intervention **Study design, and setting:** Interventional (Pre-post Intervention), NSICU (4 location of noise recording) **Intervention:** Dimmed lights, lowered staff and devices noise, quiet time signs, and optional earplugs and eye masks from 0300 to 0500 and from 1500 to 1700 **Findings:** Reduced noise levels in 2 of the 4 investigated locations by 10-15 dB	No delirium report or measurement

Abbreviations: CTICU: cardiothoracic Intensive care unit, dBA: A-weighted decibel, ICU: intensive care unit, ICU-CS; post cardiac surgery intensive care unit, LED; light-emitting diode, MICU: medical intensive care unit, NICU; neurology intensive care unit, NSICU; neurosurgical intensive care unit, PACU; post-anaesthesia care unit, RCT: randomized control trial, SICU: surgical intensive care unit.

[1] This table does not provide complete summary of characteristics and findings of these excluded studies. The purpose of this table is only to present a list of excluded studies investigating impact of environmental interventions on delirium modifiable risk factors. These studies were excluded from this review since no delirium outcome was reported.

Discussion

In this scoping review, the existing literature was searched for studies on the impact of environmental risk factors and interventions on delirium: 21 studies were retrieved reporting the effects of environmental risk factors on delirium and 16 studies reported experiments on possible solutions to modify the environment. Small sample sizes, heterogeneous study methods, and inconsistent results among reviewed studies proved the need for expanding research on the impacts of environmental risk factors and efficacy of mitigations related to delirium.

Modifiable ICU environmental risk factors for delirium

ICUs are high-tech environments with round-the-clock activities that have a negative impact on patients' experience and clinical outcomes due to excessive noise, light, and disturbed sleep and circadian rhythm[13,48,49].

Noise. The WHO set recommendations for hospitals not to exceed an average of 30 dBA or a maximum of 35 dBA in treatment areas (maximum of 40 dBA at night)[17]. A 2016 study by Hu *et al*. found average sound levels of 62.8 dB, with a mean level of 59.6 dB between 0000–0700, when investigating sound in various ICUs[88]. Consistently, five reviewed articles measuring ICU sound pressure with or without noise modification interventions reported levels exceeding the WHO recommendations[14,18–20].

A 2009 WHO report set night-time noise guidelines and reported on relationships between night-time noise, sleep, and health. According to the report, excessive night-time noise (above 35 dB) disturbs sleep, provokes annoyance and agitation, reduces cognition, impairs communication and comprehension of surroundings, and contributes to psychiatric disorders. The combination of sleep disruption, decreased cognitive function, and lowered comprehension of surroundings associated with high noise levels may contribute to acute confusion and delirium[89,90]. In our review, two of three observational studies investigating the association between high noise levels and ICU delirium found that high noise levels had no significant effect on delirium incidence[19,20]. This result is surprising as it has been suspected that noise levels exceeding a normal threshold have detrimental effects on patient recovery, especially with regard to sleep and mental status. It is worth considering the difficulty in assessing the true effect of high noise levels in these two studies. First, there is no available baseline research to compare delirium incidence in high noise level ICUs versus those with statistically lower decibel values. It is possible the threshold for adverse effects is lower or higher than the most recently investigated decibel levels. In addition, Knauert *et al*.[19] mentioned a limitation for their study in the inadequate statistical power to detect differences in decibel level between patient comparisons. For the study by Johansson *et al*.[20], their results need to be taken in context of using a non-validated delirium diagnosis protocol.

Light. During the daytime, normal light intensity is around 10000 lx and recommended night-time light levels conducive to sleep are below 30 lx[60]. Natural fluctuation of light levels throughout the day contributes to the natural sleep-wake cycle by triggering the release and suppression of melatonin. Alteration of the sleep-wake cycle and a lack of daylight schedule have been shown to be associated with psychiatric diseases[60]. Daytime light levels in the ICU are below normal daylight levels and above the threshold for sleep disruption at night[60]. In a study by Hu *et al*. light intensity was measured over 24 hours near windows, in the center of rooms, and at the eye level of mechanically ventilated patients. Average light intensity at these locations were 425 lx, 191 lx, and 388 lx respectively over 24 hours and 84 lx, 103 lx, and 87 lx between 2401 and 0759[88]. Minimal variation in daytime and night-time light levels disrupts the natural sleep-cycle and may contribute to patients becoming unable to distinguish day from night.

Abnormal natural light cycles are cited in recent literature as a potential modifiable risk factor for delirium management[60]. Seven studies analyzing the impact of natural light on delirium incidence suggest this element of the ICU lacks a definitive causative relationship with development of the condition. Most of these studies enrolled critically ill patients whose condition gives them a higher likelihood of having consistently closed eyes compared to the general hospital population. It should be considered for future research that these patients' retinas may not receive the same strength light stimulus as other populations, suggesting the need for ICU-specific lighting strategies. For the two seasonal studies, one found delirium was diagnosed significantly more in the winter than summer[30], while the other found exhaustive evidence ruling out a link between delirium and pre-hospital photoperiod exposure year-round[32]. These findings suggest there are factors aside from seasonal light exposure affecting delirium. Additionally, of the three studies with a positive correlation between exposure to natural daylight or season of admission, the two natural daylight studies had vague descriptions of their measurements of patient's exposure to natural or artificial light[13,47]. It is hard to assess whether the patient could have received benefits when the proximity of the stimulus to the patient is unclear.

As with excessive noise levels, further research into abnormal natural lighting cycles is necessary to delineate any threshold for adverse effects to patients' well-being.

Sleep. Similar to our findings regarding effects of noise and light levels on delirium, reviewed articles on sleep showed mixed results for both forms of measure (electronic sleep monitoring and subjective reports). Recent literature states sleep is disturbed in ICU patients regardless of delirium[19,42], and this concern is supported by the fact that unmeasurable sleep was found in non-delirious patients in included PSG studies. It is hard to compare results of included wireless monitoring studies, since different methodologies were used for each study, with different devices, leads, and levels of adherence to American Academy of Sleep Medicine standards. Similarly, it is difficult to compare findings from objective sleep monitoring protocols and subjective survey methods, and these need separate consideration. A major concern in analyzing subject sleep quality in delirious patients is patients with an altered mental state and/or confusion may not answer consistently or truthfully, and measures must be taken to assess whether answers are a correct representation of their condition.

Environmental solutions to prevent or manage delirium

Noise modification. The negative impact of patient exposure to noise led to several studies focusing on noise pollution in the clinical environment. Mitigated exposure to noise levels might promote patient outcomes and staff satisfaction[58,91]. Noise reduction or abatement strategies include architectural features, behavioral alterations, alarm optimization, earplugs, headphones, and noise cancelling devices. Whilst these strategies have been studied in relation with improved noise levels and sleep promotion (Table 9), further research is required to make evidence-based recommendations for the effect of noise reduction on delirium prevention and treatment.

Implementing ICU designs with acoustic features such as sound absorbers, reversible drawers to open both inside and outside the room, or room designs with the ability to locate alarmed devices or transfer alarms away from the patient, might improve exposure to noise and benefit delirium management[48,64,92]. Zaal *et al*. demonstrated a lower delirium duration by modifying ICU design with acoustic considerations, however there was no change in delirium incidence rate[48]. These strategies require major renovation or early construction planning, and further research is required to confirm cost-effectiveness and clinical benefits.

Staff and family conversations and care-activities are significant sources of ICU noise pollution[16,65,66]. Although behavioral modification might be ineffective as a single-component intervention[67], low-cost adjustments such as limited bedside conversation, lowered voices, clustered care-activities, minimized TV and overhead use and volume, use of vibrating pagers, and visual noise-warning devices may be necessary to achieve better results in sound reduction[7,14,65,66,68,69], sleep improvement[66], and decreased delirium[14]. To be successful, continuous awareness, education of staff on the impact of excessive noise exposure, and routine monitoring of implemented strategies is crucial[7]. Technologies that help staff and visitors recognize excessive noise might complement implementation of behavioral strategies. Visual noise-warning devices display colored warnings at higher levels of noise and can be an effective, sustained noise reduction strategy[68,69]. Use of noise-warning systems has a greater impact on the reduction of ambient noise compared with peak noise levels[68,69]. This is likely a result of change in staff behavior after visual warning while having no effect on medical equipment or alarms.

Alarms are a significant source of ICU noise pollution[16,65], and a large portion are considered false positives[93]. Studies show modifying ICU alarms by lowering volume, optimizing device settings, and filtering false alarms may reduce disturbing alarm noise[80,84,94]. Schlesinger and colleagues equipped wearable earbuds with a frequency-selective silencing device, which could successfully filter ICU alarms while allowing patients to hear and communicate effectively without experiencing the negative consequences of audible alarms[70]. Optimization of alarms was used as an element of a noise reduction bundle and sleep promotion studies of this scoping review[7,14,59].

Abating environmental noise by earplugs or headphones appears feasible and effective to reduce noise and improve sleep in the ICU[49,57,71–74]. Here, one study failed to prove benefits of using earplugs and eye masks during sleep on delirium[57], while another earplug trial decreased risk of confusion, and delayed initiation of cognitive disturbances with no significant effect on incidence of delirium[49]. Given the potential effectiveness and low costs, this method is frequently used in multi-component interventions[7,59]; however, non-compliancy is an issue in earplugs studies[57]. A recent meta-analysis[91] reported a 13.1% (95% CI, 7.8–25.4) rate of non-compliancy due to intolerance, anxiety, or accidental removal of earplugs. Headphones with active noise cancellation technology might improve patient outcomes by mitigating exposure to noise. Gallacher *et al*. modeled an experiment by embedding sound meters in the auditory meatus of polystyrene model heads located near patients' beds in a cardiac ICU[74]. They demonstrated a significant reduction in overall noise exposure and exposure to high intensity noises using noise cancelling headphones.

Despite inconsistent results of the reviewed studies on efficacy of noise modifications on delirium, this review suggests considering physical design features and multi-component noise reduction programs may benefit delirium prevention or management. This is consistent with current recommendations suggesting multi-component interventions to achieve adequate noise reduction[91]; Van de Pol *et al*.[14] reduced delirium incidence by implementing a noise reduction program consisting of behavioral strategies, device optimization, and earplugs. However, there is a need for high-quality randomized control trials with larger sample sizes to evaluate efficacy, sustainability, and long-term effects of noise modification interventions with a focus on delirium.

Light modification. Optimized circadian rhythm needs bright days and dark nights. Various light modification strategies have been proposed to follow circadian rhythms. These are categorized as such: decreasing night-time light exposure, and increasing daylight.

Round-the-clock ICU activities make nigh-time light reduction challenging to maintain a level of light sufficient for providing care, but not disturbing sleep. Dimming lights as part of quiet time strategies is effective to mitigate intensity of light during quiet time hours, however, this may cause variation in perceived light and consequently cause sleep disturbance[80]. Possible solutions are clustering care-activities to reduce bedside interruptions[7] and use of portable lighting pods with less blue wavelength during the night[79]. Whilst the trial of sleep masks and earplugs by Demoule at al.[57] failed to show benefit to delirium, eye masks are effective in promoting sleep by light abatement[7,76–77]. However, poor compliance in the use of eye masks due to accidental removal, or anxiety/claustrophobia, and the risk of sensory deprivation in mechanically ventilated patients, remains challenging[57].

Environmental modification to increase daylight exposure is possible through the architectural considerations of promoting natural lighting or utilizing artificial illumination. Research into whether windows allow enough light to promote sleep-wake cycles and prevent delirium, and whether seasonal light levels contribute to delirium, has been conducted with inconclusive findings[31,33,87]. From our results, the greatest interventional effect on delirium was from bright light therapy.

Our review included five studies on BLT, three reporting a significant effect on delirium incidence or severity[52,54,56] with sleep promoted in four studies[53–56]. BLT has the greatest effect between 2500 and 10000 lx for 30 to 60 minutes, with a shorter duration for greater intensities of light, when administered either at twilight or dawn to obtain a circadian effect[61]. The BLT in this review applied 2000 -10000 lx of illuminance for between one and four hours. The use of 2000 lx was effective in improving sleep quantity and functional status during management of delirium as part of a bundle. The use of 5000 lx was associated with decreased delirium incidence in two of three studies and the use of 10000 lx, as an adjunctive treatment with risperidone, was associated with a decrease in delirium severity[54]. While BLT may help regulate sleep-wake cycles and prevent/treat delirium, research into melatonin secretion and circadian rhythms suggests periods of darkness play as large a role as daytime light levels in promoting sleep and preventing delirium[60,95]. The importance of light and darkness prompts a need for research into effects of dynamic lighting systems. This review included three studies focused on dynamic lighting among sedated and non-sedated patients, using lighting systems which produced cooler blue light in the mornings and shifted towards warmer tones as the day progressed. The lighting systems produced different levels of intensity throughout the day, reaching a peak of between 750 and 4000 lx and a minimum level of 0 lx. None of these studies showed significant effects on delirium[15,50,51]; however, they used peak light levels below normal daytime levels.

Maintaining a circadian rhythm, by nocturnal darkness and BLT, as a low-cost, low-risk, easy-to-apply intervention can help improve patient outcomes. Research is required to investigate the use of dynamic lighting with higher peak light intensities or the combination of dynamic lighting and BLT. Additionally, there is a need for defining effective characteristics of light modification strategies for sedated and non-sedated patients. Sedated patients may have disrupted circadian rhythm of melatonin[96], and application of light therapies might have limited retina stimuli when eyes are closed. Studies comparing efficacy of light modifications on prevention or treatment of delirium among these two groups of patients, with application of different intensity levels of light in closed-eyes patients, might be of benefit.

Intervention bundles (light and noise modification). There is a growing interest in using quiet time interventions to promote sleep. Quiet time protocols have successfully reduced sound pressure, improved sleep quality, and reduced the use of sedatives[81–83,85,87], but effects of quiet time on delirium development needs further research. McAndrew *et al*. implemented a daily quiet time protocol in ICU patients and reported inconclusive results on delirium scores and moderate improvement in sleep perception[58]. Two neurocritical ICU studies have implemented a two hour quiet time during day and night[81,82]. A significant improvement in subjective sleep and increased staff satisfaction was achieved[81,82]. They reported decreased light by 75–85% and noise by 15%, with results being more significant during day-shift quiet time; this might be due to overall lower levels of nocturnal light and noise[82].

Sleep promotion protocols utilize noise and light control strategies with other components, such as patient orientation, early mobilization, medication optimization, and sedation targets to improve sleep in quality and quantity. Here we included two sleep promotion studies reporting results on delirium, however future research is needed to evaluate which component of sleep promotions are effective in reducing delirium. Patel *et al*.[7] significantly improved sleep quality and reduced delirium incidence by implementing a non-pharmacological multidisciplinary sleep program. They raised protocol compliance to > 90% by ongoing education, signage and posters, monitoring, and spot-checking program quality by experienced nurse champions. Interestingly, a large sleep promotion study by Kamdar *et al*., decreased delirium incidence while there was no effect on sleep[59]. It is not clear if improvements in delirium are attributable to sleep, emphasizing the need for future studies focused on single interventions or single components of multifaceted interventions with regard to delirium results.

The main strength of this review is synthesizing results of both observational association studies and interventional studies. This approach details a broader picture of the current state of this research field and bridges the gap between establishing correlational relationships and continuation of experimental trials. A major limitation of this review is the narrow search method. By searching one database (Pubmed) and the included articles' reference lists, there is likely additional literature available to expand our findings, however the authors did a hand search within related journals, Embase, and Google Scholar databases to include existing interventional research articles. Another limitation was that the generated data from reviewed studies did not have full details, and quality of evidence was not evaluated among studies; however, this review was intended to be a literature mapping with limited description of relevant publications.

Conclusions

This review of studies investigating the association between delirium and either high noise levels, abnormal amounts of natural daylight, and/or sleep disruptions did not reveal a clear relationship between delirium and these variables. It is recommended to perform additional research into more comprehensive,but related, risk factors to find a stronger predictor. Additional research could include analyses of specific noise sources or a comparison between overcast, rainy, and sunny times. This review revealed the need for further research targeting the effectiveness of environmental interventions on delirium. Current literature lacks randomized control trials with larger sample sizes to evaluate the efficacy of intervention on delirium and its long-term outcomes. Another knowledge gap is the lack of adequate conclusive research on single-component interventions. The interventional bundle studies lead to uncertainty about which component impacts the result. Given the low-cost and non-invasive nature of environmental modifications and their potential beneficial role in reduction of modifiable risk factors, it is recommended to implement these interventions in current practice, especially as multi-component bundles.

Data availability

Underlying data

All data underlying the results are part of the article and no additional source data are required.

Reporting guidelines

OSF: PRISMA-ScR checklist for 'The Impact of Environmental Risk Factors on Delirium and Benefits of Noise and Light Modifications: A Scoping Review'. https://doi.org/10.17605/OSF.IO/NHWKA[29]

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