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The Association of Sleep with Neighborhood Physical and Social Environment

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Abstract

Objectives.—While sleep is critical for good health, it remains a major public health concern because millions of individuals do not obtain a sufficient amount of sleep at night to reap proper health benefits. When examining factors that contribute to deleterious sleep outcomes, few researchers to-date have examined the physical and social environments together.

Study Design.—This manuscript is an analytical essay.

Methods.—For the current manuscript, eighteen empirical articles on environmental factors that promote sleep loss were analyzed and synthesized according to study type, exposure measures, outcome measures, methodology, and findings.

Results.—Data from the literature demonstrate that neighborhood airplane, roadway, and rail noise pollution; air pollution from ozone and particulate matter (PM₁₀); and, to some extent, ambient light interfere with residents' ability to fall asleep, stay asleep, and wake feeling rested. There is also some evidence that neighborhood green space, walkability, safety, built environment, and other social characteristics, like neighborhood disorder and ability to trust one's neighbors, dramatically impact residents' sleep.

Conclusions.—This paper provides a critical assessment of the multidimensional relationship between neighborhood physical and social characteristics and sleep, addresses major methodological concerns that limit current empirical knowledge, and suggests steps to shape future research.

INTRODUCTION

The characterization of sleep as a critical, yet frequently overlooked, component of both physical and mental health makes sleep disturbance of primary concern to public health researchers and practitioners.¹ The American Thoracic Society recommends that adults obtain 7-9 hours of sleep nightly to maximize wellness and reduce risk for negative health

consequences.² However, many Americans do not meet these recommendations. In an analysis of 324,242 adults in the United States (US), the mean self-reported sleep duration was 7 hours; nearly one-third (29.2%) slept 6 hours.³ Inadequate sleep has been associated with drowsy driving, increased risk for chronic diseases like diabetes and heart disease, and mental health problems.^{2,4} Lack of sleep lowers immune function⁵ and may lead to obesity,^{6,7} and individuals who get either too much or too little sleep have a higher mortality risk than those who obtain adequate sleep.⁸

Understanding the complex relationship between sleep and health requires a holistic assessment of the built environment and social context in which sleep occurs. The *built*, or manmade, environment consists of roads and highways, homes, schools, workplaces, and recreational sites comprising a person's physical community.⁹ Neighborhood built environment can be influenced by the climate conditions, such as temperature, and the social features of a neighborhood. *Social* environment is often operationalized as encompassing the built environment, as the latter is created through social contracts and practices, but it also includes social relationships and cultural norms that impact a person's health, behavior, and overall wellbeing.¹⁰

The Socioecological Model offers a unique framework for understanding how person-environment interactions impact health and health behaviors.¹¹ Health does not occur in a vacuum. An individual is surrounded by a social environment, which is embedded, in turn, in a larger context that includes a physical environment; a person's health evolves from the interplay of these forces. It follows that sleep quality, a significant determinant of health, is vulnerable to social and physical environmental assaults.¹² These hazards may include noise, safety concerns, pollution, or other challenges, and they may be more burdensome for people in less affluent regions.¹

Identifying environmental conditions that impede sleep is critical for developing multilevel interventions to improve health. This manuscript synthesizes current empirical evidence of relationships between the built environment and sleep, and the social environment and sleep. The rationale is that, as the environment changes, the quality and quantity of sleep will change. The manuscript assesses the strength of evidence across methods and measures by examining study design (experimental vs. observational), number of participants included, method of collecting data (self-report vs. objective measures such as actigraphy), and setting (in-home vs. laboratory). Finally, the work suggests next steps for future research.

METHODS

Twenty-eight empirical articles concerning the effects of built and social environment on sleep behavior and outcomes were analyzed; of those, eighteen were retained for the current manuscript. Using the PubMed database, articles were identified via searches of "sleep" in conjunction with each of the following pertinent search terms: "pollution," "air," "traffic," "light," "environment," "built environment," "social environment," and "neighborhood." (For example: "Sleep[Title/Abstract] AND Environment[Title/Abstract]".) The selection criteria were: published within 10 years (2006 to 2017) to maximize relevance, contain original research or a meta-analysis, be written in the English language, have sleep as its

primary outcome in association with physical or social environment, and have human participants. Searches occurred between December 18, 2016, and February 14, 2017, and some research teams were contacted during that time to obtain further information about their studies. Researchers followed PRISMA guidelines¹³ by retaining records for search terms, articles returned, and review criteria; assessing bias; and synthesizing findings by comparing outcomes across studies. This analysis was intended to be a brief, evidence-informed synthesis and discussion of an important issue facing modern public health.

Each paper was reviewed by the lead author to determine the quality of the study and the relevance of the material to the goals of the manuscript. Quality was judged by study type (experiments being preferred over observational studies), number of participants, method of data collection (objective measures preferred to self-reported ones), and study setting (laboratory versus at-home, with laboratory being preferred). Owing to the sparse literature in this understudied area of inquiry, weaker studies were included to provide general context, though evidence from these studies was not as heavily weighted as that from stronger studies. As the system for categorization of articles was simple (for example, a study is observational, quasi-experimental, or experimental; it cannot be a combination), it is unlikely that a single reviewer approach created bias.

An important factor in critically assessing current knowledge regarding sleep health is the manner in which the exposures and outcomes of interest were measured. Frequently, studies use self-reported sleep measures, collected through surveys rather than objectively (e.g., not using polysomnography or actigraphy). Self-reported data compromise construct validity and are vulnerable to recall bias and exaggeration.¹⁴ Sleep researchers have demonstrated that the correlation between actigraphic and self-reported sleep measures is <0.40.¹⁵ Thus, current empirical data should be interpreted cautiously, acknowledging that objective measurement provides more reliable evidence than self-reports.

Also of concern is the distinction between manifest and latent variables. Manifest variables, such as measures of the physical environment, can be assessed directly: amount of ozone (O₃) or 2.5-micrometer particulate matter (PM_{2.5}) in the air or decibels of regional noise. Social determinants, such as neighborhood socioeconomic status and safety, are latent: they cannot be measured directly but rely on approximation through validated measures. Using validated instruments that are clear and precise improves legitimacy; for example, salary information provides important information about socioeconomic status.

The sleep-wake cycle is comprised of periods of wakefulness, rapid eye movement (REM) sleep, and non-REM (NREM) sleep.¹⁶ NREM sleep occurs when the sleeper first falls asleep. It has three stages (N1 through N3), which are increasingly deeper. The body relaxes in REM sleep, as this is when dreams occur.¹⁷ Brain wave frequency is fastest during REM sleep.¹⁶

RESULTS

Appendix 1 presents key study findings. These findings will be presented in the text below by first exploring the built environment and then proceeding to assess literature that describes the social context.

Pollution in the built environment

Noise pollution from air, rail, and road traffic interferes with sleep in a dose-response fashion where sleep worsens as distance from the source decreases.¹⁸ In a study using polysomnography and controlling nighttime noise in a laboratory setting, exposure to air traffic noise was associated with lengthened stage 1 sleep by 3.2 minutes over controls ($p<0.05$);¹⁹ disturbed sleep continuity; and a 33% increase in morning sleepiness ($p<0.001$).¹⁹ In a polysomnographic study of German adults, railway traffic noise was associated with lengthening of Stage 1 sleep by 4.3 minutes ($p<0.01$), reduction in slow wave sleep by 6.1 minutes ($p<0.05$), 1.4 more sleep stage changes per hour ($p<0.01$), and 29% more morning sleepiness ($p<0.001$), compared to controls.¹⁹ Another study examined the impact of environmental railway noise on sleep using polysomnography in a bedroom setting and found railway noise was associated with shorter duration REM sleep than road traffic noise by 5 minutes ($p=0.02$).²⁰

Roadway noise was associated with the most profound changes in sleep structure and continuity in a study using laboratory-based measures in which noise was controlled and sleep was measured by polysomnography.¹⁹ Simulated road traffic noise was associated with 7.1-minute longer latency for slow wave sleep ($p<0.05$), 4.8-minute extended stage 1 sleep ($p<0.001$), 6.7-minute decrease in length of slow wave sleep ($p<0.01$), 1.7 more arousals ($p<0.05$), 1.0 more sleep stage change ($p<0.05$), and 18% sleepier mornings ($p<0.05$), as compared with controls.¹⁹ In another study with objectively measured nighttime noise and self-reported sleep, every 5 dB increase in noise level was associated with a 5% increase in difficulty falling asleep (Odds Ratio[OR]: 1.05, 95% Confidence Interval [CI]: 1.01, 1.09); a 7% increase in night awakenings (OR: 1.04, CI: 1.00-1.08); and a 6% increase in waking up too early (OR: 1.06, CI: 1.02-1.11).²¹

A limited pool of mixed evidence provides some support for the temperature-moderated association between sleep disturbance and common forms of air pollution: particulate matter <10 microns in diameter (PM_{10}), black carbon (BC), and ozone (O_3). A study of Egyptian school children found significant positive associations between objectively measured neighborhood PM_{10} exposure and subjectively measured difficulties initiating and maintaining sleep, as reported by parents [$p=0.012$].²² Short-term outdoor PM_{10} variation was associated with increased respiratory disturbance and greater percentage of sleep time spent at <90% oxygen saturation, but findings were only significant for summer months.²³ Others were unable to substantiate an association between PM_{10} exposure and disturbed sleep at any time of year, but their data showed that an interquartile range (IQR) increase in O_3 was associated with a 10.1% increase in apnea-hypopnea index (AHI) score, measured objectively.²⁴ This association was strongest during the summer. A survey of adults living in Boston found that men reported 0.23 hours less sleep per IQR increase in annual BC in their neighborhood environments.²⁵ For African Americans, sleep duration was paradoxically

longer for each IQR increase in annual BC emission ($\beta=0.34$ per IQR; 95% CI: 0.12, 0.57).²⁵ No significant findings emerged for women or Caucasians, and the main effects model was null.

Light pollution.—There is a paucity of information regarding the impact of light pollution on sleep, but limited evidence indicates that ambient lighting at night interferes with sleep. The presence of artificial light during sleep was associated with increased apnea-hypopnea index and disordered resting breathing compared to participants who slept in darkness.²⁶ Research has not, however, established a threshold of how much light is too much for restful sleep. In a recent study of Korean young men, exposure to artificial light at night during sleep was associated with increased wake time following the onset of sleep, decreased Stage N2 sleep, and increased Stage R sleep. The amount of light (5 lux versus 10 lux) to which the men were exposed was inconsequential to the amount of sleep loss experienced.²⁷

Structural environment

Neighborhood physical disorder is an indicator of litter, graffiti, abandoned buildings and cars, poor building maintenance, and other signs of disarray in a residential area; it is a correlate of sleep disturbance and a predictor of other health concerns. Among 1,504 participants in the Survey of Texas Adults, the mere perception of neighborhood physical disorder was associated with poorer self-reported sleep quality ($p < 0.05$), which in turn was associated with greater psychological distress.²⁸ A population-based inquiry of 1,406 adults found that living in a neighborhood rated high in physical disorder was associated with obtaining 20 minutes less sleep per night, on average, and increased daytime sleepiness, compared to those in other neighborhoods.²⁹ Similarly, in 7,231 community dwellers, a one-unit increase in neighborhood physical disorder was associated with 9% greater self-reported difficulty in falling asleep (OR: 1.09, CI: 1.04-1.14).³⁰

Limited evidence indicates the presence of walkable, natural amenities in neighborhoods may have implications for sleep. Green space and natural amenities, including bodies of water and land formations, were each independently associated with fewer self-reported days of insufficient sleep for adult men in the US.³¹ After controlling for body mass index, comorbidities, health behaviors, and demographic factors, living in a neighborhood with poor walkability was associated with more severe sleep apnea measured by AHI.³²

Neighborhood social environment

A growing but mixed literature addresses the association between neighborhood social cohesion and sleep. Social cohesion is the feeling that one belongs to the area, trusts their neighbors, and believes neighbors are friendly and available to help in times of trouble.³⁰ In a recent study, living in a neighborhood with low social cohesion was associated with shorter self-reported sleep time compared to neighborhoods with high social cohesion in unadjusted models, but this relationship did not persist after adjusting for comorbid conditions and demographic factors.²⁹ Other research showed that each one-standard deviation improvement in neighborhood social environment score was associated with a 6.09-minute improvement in sleep duration, as measured via actigraphy.³³ In another study, every one-unit decrease in social cohesion was associated with 6% greater odds of self-reported trouble

falling asleep (OR: 1.06, CI: 1.01-1.11) and 9% greater odds of self-reported feeling unrested in the morning (OR: 1.09, CI: 1.04-1.15).³⁰

The manner in which social environment impacts sleep may differ according to gender. Bassett and colleagues found that, for women, feeling that they were able to trust neighbors decreased the odds of restless sleep by 25% (OR: 0.75, CI: 0.59-0.94), while living in a socioeconomically disadvantaged neighborhood increased odds of restless sleep by 18% (OR: 1.18, CI: 1.01-1.38). For men, access to network social capital increased the likelihood that their sleep would be restless by 25% (OR: 1.25, CI: 1.04-1.50).³⁴

Neighborhood socioeconomic status (NSES) and perceived neighborhood safety contribute not only to stress, but also to sleep difficulties. In a seminal paper, DeSantis and colleagues found that NSES was weakly but statistically significantly associated with self-reported daytime sleepiness such that, for every one-standard deviation decrease in SES, participants were 6% sleepier (CI: 0.11, 0.01).²⁹ Perceiving one's neighborhood as unsafe is associated with fewer hours of sleep and greater daytime sleepiness.²⁹ Further, for every one-standard deviation positive difference in perceived neighborhood safety, participants slept 6.07 minutes longer, measured by actigraphy (CI: 1.91, 10.27).³³

DISCUSSION

Evidence supports a direct relationship between environmental conditions and sleep. There is strong evidence for the association of environmental noise,¹⁹ lack of social cohesion,³³ and feeling unsafe³³ with negative sleep outcomes. These findings characterize sleep as being malleable to more than just intrapersonal factors; rather, sleep research must be conducted using a hierarchical approach to accommodate the influence of environmental factors. These associations are supported by multiple, independent studies and arise in part from objective measures of sleep. Compelling, though frequently contradictory, evidence regarding air pollution and social factors that may impact sleep is emerging.

Reports from studies using objectively measured sleep outcomes provide the strongest support for this relationship. Many studies, especially reports concerning the social environment, relied on participant self-report of sleep, and some papers utilized self-report of neighborhood conditions. Self-report strategies may be appropriate when studies are conducted in the home and a naturalistic recollection is desired, but they provide weaker evidence than objectively reported data.¹⁴ The use of different metrics to assess sleep makes comparing effect sizes across studies very difficult. Because all of the research assessed is cross-sectional, it is important to note that, while association can be inferred, causality cannot be determined.

The evidence is broad and diverse regarding gender, location/nationality, race/ethnicity, and age, increasing generalizability. Women were equitably sampled or oversampled. Most data on physical environments came from individuals of unspecified race or ethnicity, perhaps owing to the fact that the studies were conducted in northern European countries with less racial variation compared to the United States. Studies on the impact of social environment on sleep were usually conducted with more diverse samples. Inclusiveness is critical because

it allows for the determination of nuances that could be targets of intervention. For example, in the study of black carbon air pollution and sleep in Boston, Massachusetts, exposure to the toxin was associated with longer sleep durations for African Americans but shorter sleep durations for Caucasians.²⁵

Little is known about the synergistic effects of these environmental factors. For example, is living in an unsafe neighborhood near a busy highway more toxic for sleep than either factor would be on its own? The literature offers some evidence of synergy; for instance, air, road, and rail traffic together create more sleep disturbance than any factor alone.¹⁹ There is a lack of data detailing effects on sleep outcomes across physical and social environmental lines.

This evidence base has some weaknesses. Many studies relied upon self-reported (survey-based) measures of sleep and environment quality; this methodology is weak compared to using more objective measures. Even though one can assume directionality (it is unlikely that a person's sleep patterns affect the environment), it is difficult to assign causation because of the inability to determine non-spuriousness and temporality. Measures used in the studies reviewed were exclusively cross-sectional. Some studies—the laboratory studies in particular—had very small sample sizes, which limits their generalizability. However, these studies remain important because of their rigorous methods. Finally, while most studies controlled for the presence of sleep disorders in participants, participants with pre-existing sleep disorders may be more aware of light, noise, and other effects from their environment. This concern could be addressed with longitudinal models or by screening for sleep disorders.

Future directions and implications for public health

Settings for future research studies should be flexible in accordance with the participants' needs and the research question. Often it is impossible to replicate real-world conditions in a laboratory setting, which necessitates having better equipment and methodologies for testing at home. Testing at home also has the added benefit of having increased comfort for the participants, which may make sleep more feasible. Moreover, being in a comfortable, familiar setting might relieve some anxiety about being in a sleep study, which may facilitate deeper sleep. However, experimental studies may be difficult for studying phenomena like air pollution, as it would be unethical to subject healthy subjects to highly polluted air in a laboratory setting, as doing so could harm their health.

In the spirit of public health, a broad perspective should be taken when assessing root causes of poor sleep and their ultimate impact on wellness. Attention must be shifted to a biopsychosocial model in which obtaining a good night's sleep depends not only on individual-level factors, such as health behaviors, and interpersonal variables, but also on contextual influencers of the physical and social environment. As a focal determinant of many negative health outcomes, from cardiovascular disease to mental illness,^{2,4-7} sleep disruption remains a critical public health issue for all branches of public health.

The following suggestions are offered as next steps to be made in understanding the impact of physical and social environment on sleep. (1) Consider ways in which sleep and environments can be measured objectively, including the assessment of sleep characteristics,

and social environmental factors, such as neighborhood physical disorder and safety. Having objective measures will strengthen the evidence and provide insight into potential points for intervention. (2) Systematic reviews and meta-analyses would provide additional knowledge about the relative contributions of environmental factors on sleep. (3) Another priority should be an examination of synergy between physical and social environmental factors in determining poor sleep. Future work in this area will provide a better understanding of antecedents to negative sleep outcomes and identify priorities for intervention.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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