Neighborhoods and Sleep Health among Adults: A Systematic Review

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Abstract

Objective: Sleep is an important determinant of various health outcomes, and insufficient sleep and sleep disorders are a public health crisis in the United States. The objective of this review is to provide an update on scientific contributions to our understanding of the social/built environmental determinants of sleep health. In particular, this review focuses on the diverse measurements of neighborhood characteristics and sleep outcomes, as well as analytic approaches for quantifying the effect of neighborhood on sleep health.

Methods: Two major electronic databases were searched and reviewed for relevant articles that examined the associations of social/built environments with sleep health. Inclusion criteria included peer-reviewed empirical studies on neighborhood-level characteristics and sleep health among adult populations.

Results: Systematic searches in MEDLINE/PubMed and SCOPUS identified 52 eligible articles (out of 11,084). Various social/built environmental characteristics of neighborhoods were identified as potential determinants of sleep health, and the majority of studies examined neighborhood social capital, safety, and environmental stressors. However, 88% of included articles employed cross-sectional study designs, limiting causal identification. We found substantial differences in neighborhood measures, variations in sleep health measurements with the majority employing self-reported methods, and inconsistent model specifications. While the majority of articles (48%) utilized perceived neighborhood conditions as the main exposure, more recent studies (23%) employed geographic information systems to measure neighborhood characteristics.

Conclusions: To establish the causal relationships between social/physical neighborhood characteristics and sleep health, more studies should be conducted with longitudinal, quasi-

experimental, and randomized trial designs coupled with objectively measured neighborhood and sleep health parameters.

Keywords: systematic review, neighborhood, social determinants, spatial analysis, sleep health, study design

Introduction

Sleep has been recognized as a major determinant of physical and mental health.[1] Laboratory and epidemiological studies demonstrate that sleep deficiency may contribute to a variety of adverse chronic conditions and outcomes among adults, including cardiovascular diseases (CVDs), neurocognitive disorders, and psychiatric disorders. Laboratory and physiologic studies suggest that insufficient sleep disrupts neuroendocrine controls, glucose regulation and metabolism,[2, 3] and biological pathogenesis models of circadian rhythm and neurodegenerative process are suggested.[4, 5] Epidemiological studies show that adults who report short sleep duration (less than 5-6 hours per day) have increased body mass index (BMI),[6] and higher risks of hypertension,[7] type-2 diabetes,[8] and other CVDs.[2] Neurocognitive disorders related to sleep deficiency include decreased executive functions, impaired vigilant attention, and memory loss, which may be due to reduced neuroplastic processes during sleep that are important for functional recovery.[9] Lastly, observational studies demonstrate reciprocal relationships between multiple sleep disorders and psychiatric illnesses.[10-12] Specifically, short sleep duration is associated with depression, anxiety,[13] and risk of developing post-traumatic stress disorder.[14] Despite such importance of sleep, nocturnal sleep duration among adults in the United States (U.S.) has declined from 1960, and in 2014, more than one third of U.S. population had short sleep duration, defined as sleep less than 7 hours.[15] Another study from a national representative sample estimated that more than 70 million U.S. adults had less than 6 hours of sleep duration in 2012.[16]

Emerging studies recognize social and physical environmental factors as important determinants of sleep health.[17, 18] The theory of social production of disease discusses social and structural barriers as major determinants of health outcomes and health behaviors.[19] Similar to

other chronic conditions and health outcomes examined under the "social production of disease" theory, sleep health is also socially patterned by economic and political factors.[17] Sleep is comprised of three components; sleep need (i.e. biological requirement for sleep), sleep opportunity (i.e. the amount of time an individual can make available for sleep), and sleep ability (i.e. the amount of sleep an individual can achieve),[20] and these components are modified by the society to which an individual belongs. In addition, the psychosocial theory suggests that adverse environmental factors can create a vulnerability to physical and psychological stress[21] which may influence sleep health consequently.[22] Studies have reported that physical and psychological stress, operationalized as allostatic load and stress biomarkers, are associated with sleep health.[23, 24] In a similar vein, the socioecological model of sleep health suggests the interwoven interactions of individual-level characteristics, including age, sex, race/ethnicity and occupation, with supra-individual factors of sleep health, such as familial, and social/built environments.[25]

In fact, various built and social environmental factors have been documented as potential risk factors for poor sleep health: ambient noise, artificial light, air pollution, obesogenic environments, neighborhood disinvestment, lack of green space and recreational facilities, limited social cohesion and social capital, and neighborhood violence.[18, 26] Some definitions of neighborhood stressors are interchangeably used indicating different measures of neighborhood conditions. For example, the term "neighborhood disadvantage" refers to adverse socioeconomic status of a neighborhood. In addition, the methods of measuring neighborhood characteristics are substantially different across studies. The utilization of diverse methods to assess neighborhood is not a problem in itself, as each method has its own strengths and limitations. However, the splintered nature of quantifying neighborhood factors makes it difficult or even impossible to assess the consistency of findings

across studies, and it is important to discuss the most appropriate approaches for sleep health research. Self-reported measures (i.e. survey-based questions) of neighborhood characteristics which are commonly employed in studies on neighborhood and sleep health have strengths in capturing subjective perceptions closely related to the lived reality,[27] however such measures are susceptible to recall bias and same-source bias when sleep outcomes are measured via self-report as well, threatening the reliability and validity issues of the collected data.[27, 28]

To overcome the above-mentioned limitations, objective methods for defining and measuring neighborhood characteristics have been widely employed in sleep epidemiology. Such objective methods include systematic field observations, use of census data to characterize administrative neighborhoods, and geographic information system (GIS) techniques. Such objectively-measured social/built environments have strengths in objectively capturing actual neighborhood conditions.[27] The findings based on objectively measured neighborhood characteristics may deliver feasible and effective place-based interventions and policy implications. However, the use of administrative boundaries may introduce inadequate assessment of exposure areas and spatial misclassifications which is attributable to potential biases due to the artificial aggregation of point-based data.[29, 30] For example, a census tract has heterogeneity within its boundary due to the shape and scale of the aggregation unit, therefore the aggregated data is limited in capturing specific and actual exposure within the unit, and the quality of these variables also depends on where the participant lives in an area.

In addition, the measurements of sleep health vary across studies. While polysomnography, a multi-parametric measure that includes assessment of brain wave activity, blood oxygen level,

heart rate and breathing, as well as eye and leg movements during sleep, is considered the gold standard, most of the current studies on neighborhood and sleep health employed self-reported sleep health or actigraphy-based measurements (i.e. monitoring sleep/active cycles via wristwatch-like accelerometer devices) of sleep duration and quality, due to logistic difficulties of utilizing polysomnography in population-based studies.

Moreover, there is little consensus on the analytic approaches and model specifications to employ. It is expected that the selection of covariates can be heterogeneous based on different research questions and conceptual models, however omitting relevant factors or including potential mediators/colliders as covariates may result in biased estimates or different interpretations. For example, beyond individual-level confounders (e.g. age and gender), family-level characteristics, such as family socio-demographic or household structure, have been identified as salient factors in the relationship between neighborhood and sleep health,[31] which should be adjusted for. In addition, a large body of literature has suggested that psychological stress can play important mediating roles in neighborhood and sleep health,[24] as neighborhood stressors may cause psychosocial stress and cumulative biological risks.[32, 33] Epidemiological studies have also reported close relationships between sleep and physical activity, and physical and social environments can significantly change individuals' levels of physical activity.[34, 35 31]In these cases, adjusting these potential mediators (i.e. psychological stress and physical activity) as confounders without careful considerations of hypothesized causal mechanisms will yield biased estimates and/or different interpretations.

There are a few published systematic reviews[26, 36] as well as narrative reviews[37-39] on this topic, however, the extant reviews did not provide specific information on neighborhood definitions and model specifications, thus did not fully address these methodological concerns. Therefore, the objective of this systematic review is to synthesize the recent literature on the associations between neighborhood characteristics and sleep health and to critically assess the evidence derived from empirical studies. The present systematic review assesses the methodological differences in measurements of neighborhood features and sleep heath as well as evaluates inconsistent model specifications and covariate selections across studies. We also discuss future research directions and caveats in examining neighborhood effects on sleep health.

Methods

Search Strategy and Study Selection

This systematic review was based on the literature that was identified and referenced from a systematic search for papers published between January 2000 and February 2021, using two large data bases, PubMed and SCOPUS. PubMed has relatively wider coverage than other databases in the biomedical science, including public health and neuroscience, in which sleep health has been widely studied. SCOPUS covers a comprehensive range of journals, encompassing variety of social science studies where characteristics of social and built environments are extensively investigated. Additional relevant articles were identified and included from the reference lists of selected articles as well as from relevant review articles. The PRISMA Statement was utilized to guide the conduct of the review.[40] The neighborhood characteristics were captured from a set of terms [neighborhood, social environment, built environment, spatial, geospatial], and then we included multiple dimensions of sleep health as the outcome: [sleep, sleep disorder, sleep

quality, sleep hygiene, sleep deprivation, sleep problem, obstructive sleep apnea (OSA), insomnia]. The search criteria required at least one term present from the exposure and from the outcome.

No filters or language restriction was applied within the databases. The search process was limited to empirical studies on neighborhood social/built environments and sleep, disregarding reviews or theoretical articles. The search strategy also limited the scope to studies focusing on adult populations. The neighborhood characteristics may affect children's and adolescents' sleep health via disparate mechanisms from adults, as the sleep epidemiology and etiologic processes of an individual systematically vary across life course.[17] In addition, perceptions, experiences, and potential health effects of a similar neighborhood may differ by the developmental stages, even for people residing in the same dwelling. Sequential inclusion screens were conducted based on title, abstract, and full-text review (Figure 1). The detailed inclusion criteria were the following: (1) investigation of neighborhood-level characteristics (no indoor environments), (2) investigation of human sleep health, (3) empirical study with findings published in peer-reviewed original research journals (i.e. no reviews, editorial letters, protocols, book chapters), (4) no ethnographic or qualitative studies, and (5) adult populations only (exclude infant, child, and adolescent studies).

Data Extraction

The title/abstract reviews of selected abstracts from initial web search was conducted by one reviewer (BK) based on the inclusion criteria. One additional reviewer (DTD) assessed potential misclassifications of the selected studies from the first screening. The lead reviewer performed full-text reviews and data extraction, followed by quality checks of final 52 publications by the second reviewer. Articles that met the inclusion criteria were reviewed and classified according to

study design, target population, measurements of the exposure and the outcome variables as well as variable selection strategies. The main findings of each study were extracted. Specifically, data were extracted from each paper on the study characteristics including country, year of publication, study design, and sample profile (e.g. sample size and specific sub-population of studies). Detailed information on exposure and outcome assessments, such as neighborhood characteristics assessed, definitions of neighborhood (e.g. perception or residence-based boundaries), measurement tools of neighborhood exposures (e.g. survey, secondary dataset, or field observation) and outcomes (e.g. survey, objective measures), as well as covariates and intermediary variables were examined. In case of missing methodological information, further articles explaining the study design were retrieved.

Neighborhood characteristics were classified into several categories to facilitate the interpretations of study findings. To illustrate, measurements of neighborhood-level social capital and social cohesion, commonly measured from questionnaires on group memberships, neighborhood belonging, trust, and shared-values,[41] were grouped as "social capital" as the two dimensions of social environments are not fundamentally different from each other.[42] Neighborhood-level socioeconomic status, including poverty, mother-only households, unemployment, education attainment, and crowding was classified as "neighborhood disadvantage" referring to the landscape of economic and social resources.[43] A set of physical and social conditions of neighborhoods, such as vacant lots and housings, litters on streets, graffiti/vandalism, selling/using drugs or drinking in public, loud noise, neighborhood stigma, as well as neighborhood disinvestment was classified as "neighborhood disorder".[44] The neighborhood disorder category comprised objectively measured neighborhood conditions, investment in

neighborhoods, as well as perceived neighborhoods. “Neighborhood safety” included reported crime rates as well as perceived safety and observed violence collected from questionnaire. Perceived safety is commonly included as one of items for neighborhood disorder, and it was classified as neighborhood safety along with crime rates, in case the perceived safety was independently analyzed as a single exposure variable. A set of physical characteristics that provides pleasant walking environments and facilitates physical activity, such as urban design (e.g. street connectivity and sidewalk condition), accessibility to amenities and parks, and green space was classified as “walkability” category.[45] Walkability also included survey-measured perceived conditions and quantitatively assessed physical environments. Other measures, such as neighborhood noise, light pollution, air quality, as well as urbanicity linked with aforementioned stressors were grouped as “environmental stressors”.

Results

The database search and screening resulted in 52 empirical studies from the year of 2000 to February 2021. (Figure 1) The first searches provided a total of 11,084 papers, and after excluding duplicates, 5,508 studies remained. Titles were first screened to determine eligibility. Following this, 757 abstracts were reviewed, with the full-text retrieved for 214 papers. The majority of the excluded studies from the 214 studies was targeting infants, children, and adolescents sleep health. In total, 52 studies were identified to be included in this systematic review (Figure 1). Table 1 illustrates the characteristics of the included studies.

Study Characteristics

Most of the empirical studies on neighborhood effects on sleep health have emerged from the mid-2000s and have increased in the recent years. Among the 52 included papers, 46 articles (88%) employed cross-sectional study designs whereas 6 studies (12%) utilized longitudinal settings. Among the 6 longitudinal studies, only one recent study employed a quasi-experimental design comparing two similar neighborhoods with repeated measures of sleep health. The majority of studies (71%) on this topic was conducted in the U.S. followed by European countries (12%: 6 studies) and Asian countries (8%: 4 countries). Many of these studies focused on specific sub-populations, such as Black or Hispanics (29%), middle to older aged populations (12%), and other vulnerable populations (4%) including sexual minorities and mothers.

Among the 52 articles, there were three neighborhood characteristics commonly studied: social capital (14 studies: 27%), neighborhood safety (14 studies: 27%), and neighborhood disorder (14 studies: 27%). Neighborhood disadvantage was examined as potential determinants of sleep health in 7 studies (15%). Environmental stressors, such as neighborhood noise, light and air pollution were investigated in 10 studies (19%), and 6 studies (12%) analyzed neighborhood walkability as the main exposure of interests.

Neighborhood Definitions and Measurements

Most of the studies (73%) investigated participants' residential neighborhoods, and 13 studies (25%) did not specifically mention how participants should define their neighborhoods when answering the surveys. For example, most of the surveys in this category asked questions such as "In your neighborhood, is violent crime a problem?" rather than defining neighborhood as "Within 10 minutes walking distance from your home". Only one study specified neighborhoods as areas

of residence, work, and socializing to capture diverse experiences in daily life. In terms of the geographical boundaries of neighborhood definitions, about a half of the articles (25 studies: 48%) used perceived neighborhood boundaries without specified geographic borders, whereas 14 studies (27%) employed small administrative boundaries, such as census tract or postal codes, and 3 studies (6%) used boundaries of larger areas (e.g. city and county levels). Twelve studies (23%) used GIS-based measures involving no administrative boundaries, yet the methods for defining neighborhood boundaries were varied. For example, ego-centric circular buffers, defined as a radius around a particular point of interest, based on participants' home addresses were used in 7 studies (13%), whereas proximity (i.e. distance) to certain points of interests was employed in 5 studies (10%).

As the majority of studies employed perceived neighborhood definitions, survey-based questionnaires were the major measurement tools of neighborhood characteristics (33 studies: 63%). Beyond such perceived neighborhood characteristics, 22 studies (42%) utilized secondary datasets, such as census data, point-level crime data and noise measures, and 6 studies (12%) used direct measures including field observation and direct noise measurements from sensors.

Sleep Outcomes and Measurements

The most common sleep outcomes among selected studies were sleep duration including insufficient sleep (32 studies: 62%). Among the 32 studies on sleep duration, 78% (25 studies) utilized self-reported sleep duration, whereas only 10 studies used quantitatively evaluated sleep duration through actigraphy. Among the studies with self-reported sleep duration, different sets of questionnaires were utilized including questions developed by the investigators and validated

questionnaires such as Pittsburgh Sleep Quality Index. Twenty-four studies (46%) investigated sleep quality, and among those 16 studies (67%) employed self-reported sleep quality, such as Patient-Reported Outcomes Measurement Information System (PROMIS) sleep disturbance and sleep-related impairment questionnaires, whereas 8 studies (33%) utilized actigraphy-based sleep efficiency as an indicator of sleep quality. Sleep problems (e.g. sleep disturbances, wake up after sleep onset (WASO), etc.) were examined in 16 studies (29%), and among those 16 studies, 5 studies (31%) utilized WASO based on actigraphy. Three studies investigated insomnia using self-reported survey items, and sleep apnea (obstructive sleep apnea) was examined in 4 studies using polysomnography or home sleep apnea testing devices. No other clinically significant sleep disorders, such as restless leg syndrome or narcolepsy, were examined pertaining to neighborhood characteristics.

Analytic Approaches

All studies adjusted the associations of interest for basic individual characteristics, such as age and sex. Education attainment (43 studies: 83%), and household/individual income or poverty status (47 studies: 90%) were controlled in the majority. Only 12 studies (23%) included race/ethnicity as a covariate, but most of the studies in which the individual characteristics were not controlled were based on racially/ethnically homogenous populations (e.g. Black community, Hispanic, or Asian countries). A few papers (4 studies) examined the heterogenous effects of neighborhood characteristics by selected sociodemographic characteristics within the contexts of U.S. The selection of additional covariates and confounders showed substantial inconsistency. Particularly, family characteristics and household size/type (e.g. marital status and number of household members) are potential confounders in the associations between neighborhood and

sleep, as family structure over different life courses can determine sleep health,[46] as well as preferences of neighborhood characteristics.[47] However, among 52 included studies, 20 studies (38%) omitted such measures in the analysis, which introduces residential confounding issues.

Pertaining to potential mediators between neighborhood and sleep health, 23 studies (44%) controlled for psychological factors such as stress, depression, and anxiety as confounders (i.e. adjusting for the variables in the regression analysis) posing potential risk of bias due to conditioning on a mediator. Only 3 studies examined the psychological factors as potential mediators or effect modifiers with appropriate analytic approaches and modeling rather than conditioning on them, and the methods used included mediation analysis or adding interaction terms.[34, 48, 49] In addition, seventeen studies (33%) controlled for physical activity as a covariate (i.e. treating as a confounder), potentially resulting in biased estimates of the main effects, and none of the included articles examined its mediating role. Such psychological and behavioral factors may be salient mediators and/or effect modifiers (but not confounders) on the associations between neighborhood and sleep, but most of the studies misspecified the causal models without careful considerations on theoretical mechanisms. Similarly, inclusion of body mass index and health behaviors, such as smoking status and alcohol use, were not consistent across studies.

Study findings

Most of the studies (51 studies: 98%) reported associations between neighborhood exposures of interest and sleep health. However, 15 studies reported inconsistent findings within the studies for specific neighborhood measures whereas other measures showed expected effects. For example, one paper found positive association between neighborhood crime and sleep disturbance (e.g.

WASO) yet null associations with sleep duration.[48] In general, neighborhood social capital, physical/social disorders, safety, and walkability were associated with sleep duration, sleep quality, and sleep problems after adjusting for potential confounders and relevant risk factors. However, the model specifications varied considerably across studies. For example, low social capital was associated with short sleep durations in 9 cross-sectional studies. Ten cross-sectional studies reported safe neighborhood condition as a protective factor of sleep duration, and the associations were ranged from 0 to 10 minutes increase sleep durations. Neighborhood disorder was associated with decreased sleep duration ranging from 7 to 14 minutes in 5 cross-sectional studies. Walkability measures were reported as a protective factors of short sleep duration in 6 cross-sectional studies. Overall, most of the desirable neighborhood environments showed positive effects on sleep duration and quality. However, the results from cross-sectional studies cannot be directly interpreted as causal associations without well-defined temporal orders between the exposure and outcomes. Two longitudinal studies with repeated sleep assessments reported associations between neighborhood disorder and short sleep duration. Lastly, two cross-sectional studies attempted to examine mediating mechanisms between neighborhood characteristics and sleep health considering psychological distress as a mediator, yet those finding may not be interpreted as a causal relationship due to the cross-sectional study design.

Discussion

This systematic review provided comprehensive and in-depth information related to reported associations of social and physical neighborhood characteristics with sleep outcomes. Various social and physical neighborhood features have been identified as potential determinants of sleep health, and the studies that make up this knowledge space contain diverse sample populations and

locations of study suggesting greater catchment and possible generalizability of the associations reported. Neighborhood social capital and social cohesion, neighborhood safety, and physical and social disorders were frequently examined using different measures and metrics, and the desirable characteristics had positive associations with sleep health

The use of different measurement strategies to capture neighborhood characteristics and other differences in study designs could have contributed to varied effect sizes across studies, despite the similar directions of the various study estimates. Most of the studies employed perceived neighborhood conditions based on residential areas, whereas several studies utilized secondary datasets using residential administrative boundaries such as census tracts or ZIP codes to define residential neighborhoods. Considering the potential spatial misclassification issues related to static administrative boundaries, several recent studies utilized ego-centric neighborhood definitions with point-level exposure measures and GIS techniques. [51]Perceived neighborhood conditions may reflect real experiences among study participants, while some of the objective measures of neighborhood characteristics may portend modifiable risk factors and feasible place-based interventions. Optimal study design would consider both objective and subjective measures of neighborhood environments, and could model the latter as mediators of the effect of the former. Lastly, only one study defined neighborhood as areas of residence, work, and socializing.[49] This scant study on neighborhood exposures based on daily mobility pattern indicates potential areas of further investigations.

In addition, divergent measures of sleep health outcomes (e.g. self-reported vs. objectively measured sleep health) make it difficult to compare the findings across studies. Furthermore, the

questionnaires for measuring self-reported sleep were varied across studies (e.g. total sleep time, time spent in bed, daily sleep time log, etc.), hindering consolidation of findings even among studies with self-reported sleep. While most of the studies used self-reported sleep duration and sleep quality which are susceptible to recall bias and same-source bias, recent studies started employing actigraphy-measured sleep duration and efficiency, which may be regarded as improved methods from self-reported sleep. Again, optimal studies may be those collecting both objective and self-reported measurements of sleep. Except a few studies investigated clinically significant sleep disorders such as obstructive sleep apnea and insomnia, most of the studies examined sleep duration, quality, and efficiency. Some of clinical sleep disorders may not directly associated with neighborhood conditions as closely as commonly used sleep variables, however, this scarcity remains as research gap, particularly for preventable sleep disorders through physical activity and psychological well-being in relations with neighborhood characteristics.

This systematic review also compared the various model specifications used and found substantial differences in covariate selection and multivariable model building strategies across studies. Specifically, mediators and effect modifiers in the hypothesized associations were controlled without careful considerations of their causal mechanisms, and several papers omitted critical confounders in the analyses. The divergent nature of these models together with the different measurement strategies may result in inconsistent effect sizes that cannot be readily compared across studies.

This systematic review is not without limitations. The search strategy based on the two major scientific databases might miss some relevant studies in other databases and did not include a

potential grey literature of unpublished studies, such as thesis and report, as well as non-English studies. Restricting the search to studies with individual-level exposure may have missed publications which employed ecological study designs for large-scale ambient environmental characteristics (e.g. air pollution and noise). Such environmental stressor measures were commonly estimated with aggregated data in larger contexts, for instance city- and county-levels.

Future directions

Twelve percent of the included articles employed longitudinal study settings, and only one study used a natural experimental design. In order to more fully investigate the causal relationships between social/physical neighborhood characteristics and sleep health, more studies should be conducted with longitudinal designs (i.e., with repeated sleep assessments) and experimental study designs coupled with objectively measured neighborhood and sleep health addressing above mentioned limitations of self-reported measures when those are used alone (but optimal studies may collect both objective and subjective data). Due to ethical and feasibility limitations of random assignments of neighborhood characteristics, quasi-experimental designs with recent neighborhood changes would be preferred. Also, repeated measures of neighborhood characteristics over longer period of time and utilizations of rigorous neighborhood definitions are critical in establishing valid causal inferences and suggesting feasible place-based interventions, given the limited numbers of articles that examined changes in neighborhood characteristics with refined definitions of a neighborhood.

Future studies should especially consider daily mobility patterns and activities of daily living of individuals when defining neighborhood, as neighborhood stressors not only exist in

administratively defined areas but are perhaps more accurately measured in individually-defined neighborhood spaces experienced on a per person basis over daily activities. For example, utilizing activity space definitions based on global positioning system (GPS) as neighborhood boundaries can provide more accurate exposure measures reflecting daily mobility patterns [50].

Most importantly, given the distal causal pathways from neighborhood characteristics to sleep health relative to individual-level behavioral factors such as physical activity and psychological factors, studies should carefully consider hypothesized mechanisms based on literature and elaborate on identifying causal diagrams (e.g. directed acyclic graphs). We found considerable inconsistency in model specifications across studies, which is not a problem in itself and expected contingent on research questions. However, we found several model misspecifications which may result in biased estimates. To address this issue, conceptual diagrams or directed acyclic diagrams can assist identifying confounders, mediators, effect modifiers, and colliders. Based on such well-defined exposures, outcomes, and model specifications, greater empirical, and certainly experimental, evidence is needed to reveal how neighborhood features more accurately modify sleep health of individuals.

Lastly, the intercorrelation and co-occurrence of multiple neighborhood characteristics as well as their multicollinearity should be carefully considered, particularly aiming for possibilities to separate effects of each exposure. Most of the time, it is almost impossible to disentangle such interwoven correlations of neighborhood characteristics, and potential alternative would be using mixture modeling to explore neighborhood influences with an index for overall effects addressing multicollinearity issue. In some rare cases, such as a sharp increase of one particular exposure

when other correlated environments remain same, it would be possible to evaluate the separate effect of interest by a quasi-experimental design. Only one quasi-experimental study utilized such opportunity to evaluate the impact of neighborhood investments comparing intervention and control groups,[51] and more of such advanced studies, including clustered randomized trial designs, will be helpful in providing rigorous evidences on effects of specific place-based interventions, addressing the issues of co-occurring neighborhood environmental factors from observational studies.

Conclusion

High-quality evidence regarding the impact of neighborhood effects on sleep health is required to further inform place-based preventative and policy interventions to meaningfully address potentially inequitable variation in sleep health at the neighborhood level. Quasi-experimental studies or longitudinal designs are required to improve the quality of evidence as well as utilizations of objective measures for sleep health and neighborhood characteristics that can better inform intervention strategies. Studies which examine the direct impact of neighborhoods without careful considerations of causal mechanisms will continue to miss important mediating variables and result in potentially biased estimates, hindering our understanding and response to neighborhood effects and poor sleep health.

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Figure 1. Study selection process

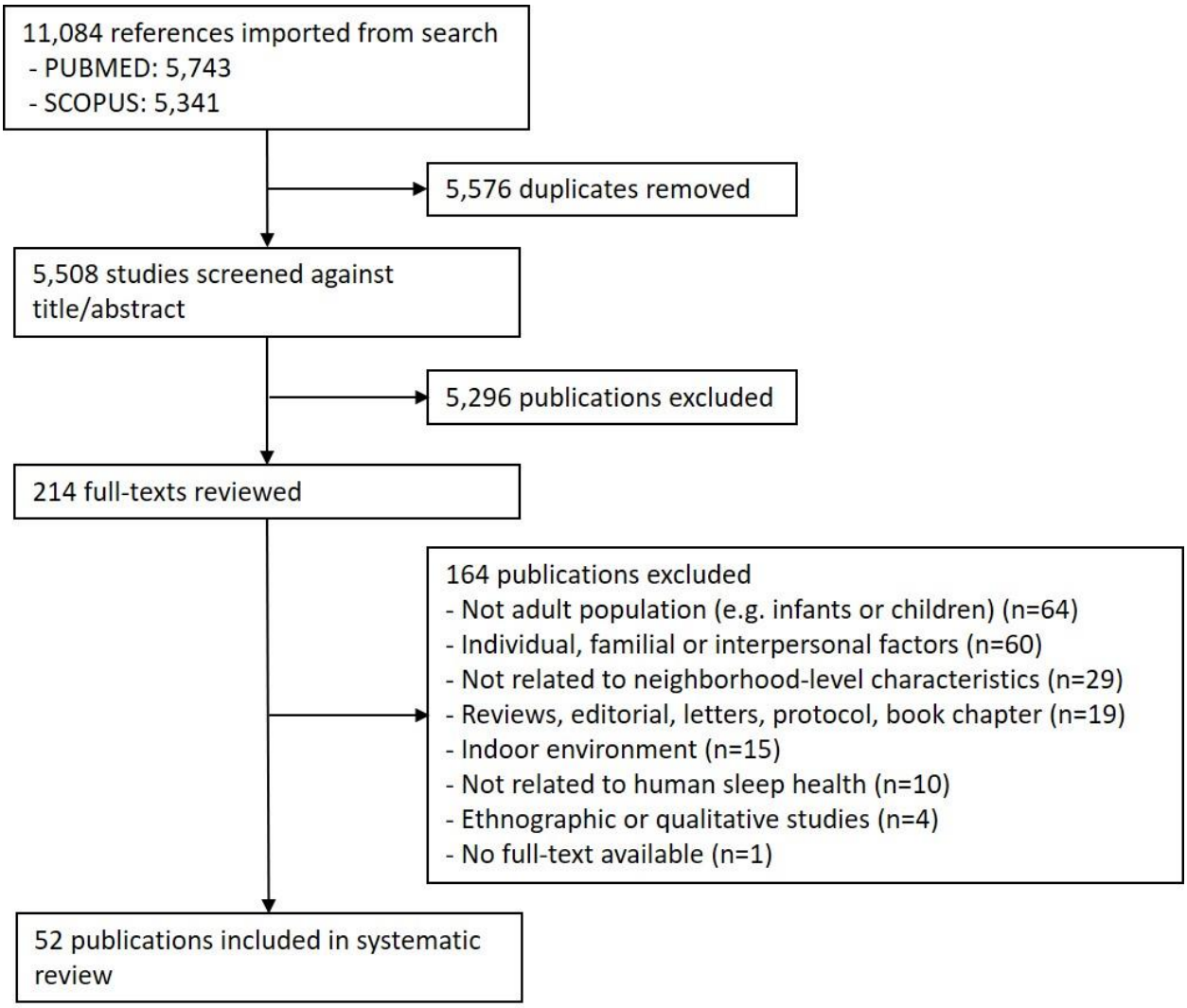

Table 1. Summary of studies on social/physical environment on sleep

Reference	Year	Study design	Population	Geographic context	NBHD characteristic studied	NBHD type	NBHD definition	Measure of NBHD factors	Sleep outcomes	Sleep measures	Psy. factor	PA factor	BMI	Health behav	Fam. factor	Main effect estimates
Dubowitz et al. [51]	2021	Longitudinal	Mostly black adults (n=676)	Pittsburgh, PA	NBHD disorder	Residential area	Proximity	Secondary data	DUR, EFF, WASO	Actigraphy	Yes	No	Yes	No	Yes	Near investment–DUR: +18.3 mins, EFF: +3.8%, WASO: -27.9 mins
Richardson et al. [48]	2021	Cross-sectional	Mostly black adults (n=515)	Pittsburgh, PA	Safety	Residential area	Buffer	Secondary data	DUR, WASO	Actigraphy	Yes	No	Yes	No	Yes	Crime–DUR: null, WASO: +5.96 mins
Alhasan et al. [52]	2020	Cross-sectional	Adults (n=167,153)	United States	Social capital	Unspecified	Perception	Survey	DUR, problems	Survey	Yes	Yes	Yes	Yes	Yes	Low social capital–short sleep PR: 1.19, problems PR:1.26
Beutel et al. [53]	2020	Cross-sectional	Adults (n= 11,905)	Rhine-Main, Germany	Env. stressor	Unspecified	Perception	Survey	Problems	Survey	Yes	No	No	No	Yes	Noise–problems RR: 1.14
Dong et al. [54]	2020	Longitudinal	Mostly black adults (n=269)	Pittsburgh, PA	Walkability	Residential area	Buffer	Street Audit	Apnea	Apnea testing device	Yes	No	Yes	Yes	No	High walkability–OSA OR: 0.83
Troxel et al. [55]	2020	Cross-sectional	Mostly Black adults (n=634)	Pittsburgh, PA	NBHD disorder	Residential area	Buffer	Street Audit	DUR, EFF, WASO	Actigraphy	Yes	No	Yes	No	Yes	NBHD disorder–DUR: -14.0 mins, EFF: -2.0%, WASO: 10.7 mins
Watanabe et al. [56]	2020	Cross-sectional	Older adults (n=16,650)	Japan	Social capital, walkability	Residential area	Perception	Survey	Quality	Survey	Yes	Yes	No	No	Yes	Social capital–poor sleep PR: null, Walkability PR: 0.59
Xiao et al. [57]	2020	Cross-sectional	Middle-older adults (n=333,365)	10 sites in US	Env. stressor	Residential area	Unspecified	Secondary data	DUR	Survey	No	Yes	No	Yes	Yes	High lighting–short sleep OR: 1.16 (women), 1.25 (men)
Yang et al.[58]	2020	Cross-sectional	Adults (n=608)	Hong Kong	Walkability	Residential area	Buffer	Secondary data	Quality	Survey	Yes	Yes	No	Yes	Yes	Low green space–poor sleep quality OR: null
Murillo et al.[59]	2019	Cross-sectional	Hispanic adults (n=13,537)	United States	Social capital	Unspecified	Perception	Survey	DUR	Survey	No	No	No	No	Yes	High social capital–normal sleep OR: 1.31~1.53
Robbins et al. [60]	2019	Cross-sectional	Adults (n=1,007)	Philadelphia, PA	Social capital	Unspecified	Perception	Survey	DUR, insomnia, sleepiness	Survey	No	No	No	No	No	Low social capital–short sleep OR: 1.6, high social capital–long sleep OR:0.4
Bierman et al. [61]	2018	Longitudinal	Older adults (n = 7,130)	United States	NBHD disorder	Residential area	20-min walking	Survey	Problems	Survey	No	Yes	No	No	Yes	NBHD disorder–sleep problem index: 0.02
Johnson et al. [62]	2018	Cross-sectional	Adults (n = 2712)	Wisconsin	Walkability, env. stressor	Residential area	Census block group	Secondary data	DUR, quality	Survey	No	No	No	No	Yes	Green space–short sleep OR: 0.76, noise OR: 1.03
Johnson et al.[63]	2018	Cross-sectional	Adults (n=1,889)	6 sites in US	Walkability	Residential area	Buffer	Survey	DUR, EFF	Actigraphy	Yes	Yes	Yes	Yes	No	Walkability–short sleep OR: 1.2, DUR: -8.1 mins
Mellman et al.[64]	2018	Cross-sectional	Black adults (n=85)	Washington DC	NBHD disorder, safety	Residential area	Perception, census tract	Survey, census data	Nervous system activity	Electrocardiogram and actigraphy	Yes	No	No	Yes	No	NBHD disorder–normalized high frequency: -0.24 (all), safety: -0.35 (female)
Nam et al.[65]	2018	Cross-sectional	Black adults (n=252)	New Haven, CT	Social capital, walkability, safety	Unspecified	Perception	Survey	Quality, sleep behaviors	Survey	Yes	No	Yes	No	Yes	Social capital–sleep quality: +0.21, walkability: +0.22, safety: +0.15
Ruff et al.[66]	2018	Cross-sectional	Adults (n=120)	New York, NY	NBHD disorder	Unspecified	Perception	Survey	DUR, quality	Survey	No	No	Yes	No	No	Media stigma–DUR: -0.96hr, poor sleep quality RR: 2.64

Troxel et al.[67]	2018	Cross-sectional	Mostly black adults (n=788)	Pittsburgh, PA	Social capital, NBHD disorder, safety, walkable	Residential area	Buffer, perception	Street audit, survey	DUR, EFF, WASO	Actigraphy	Yes	No	Yes	No	Yes	Capital, disorder, walkability-null, safety–DUR: null, EFF:1.1%, WASO: -5.7 mins
Reference	Year	Study design	Population	Geographic context	NBHD characteristic studied	NBHD type	NBHD definition	Measure of NBHD factors	Sleep outcomes	Sleep measures	Psy. factor	PA factor	BMI	Health behav	Fam. factor	Main effect estimates
Win et al.[68]	2018	Cross-sectional	Adults (n=12,321)	Rural Japan	Social capital	Residential area	Perception	Survey	DUR	Survey	No	Yes	Yes	Yes	No	Low social capital–short sleep PR: 1.22
Xiao and Hale [69]	2018	Longitudinal	Middle-older adults (n=208,537)	8 sites in US	NBHD disadvantage	Residential area	Census tract	Census data	DUR	Survey	No	Yes	Yes	Yes	Yes	High NBHD disadvantage–short sleep RR: 1.46 (men), 1.72 (women)
Young et al.[70]	2018	Cross-sectional	NHOPI adults (n=2,464)	United States	Social capital	Unspecified	Perception	Survey	DUR, quality	Survey	Yes	Yes	No	Yes	Yes	Low social capital–short sleep OR: 1.14, quality OR: null
Duncan et al.[71]	2017	Cross-sectional	Sexual minority men (n=580)	Paris, France	Safety	Unspecified	Perception	Survey	DUR, quality, problems	Survey	No	No	No	No	No	Unsafe NBHD–short sleep RR:1.92, poor sleep quality RR:1.6, problems RR:1.57
Evandt et al.[72]	2017	Cross-sectional	Adults (n=13,019)	Oslo, Norway	Env. stressor	Residential area	Geographic coordinates	Noise modeling	Insomnia	Survey	No	Yes	No	Yes	Yes	Noise–insomnia symptoms OR: 1.04~1.06
Johnson et al.[73]	2017	Cross-sectional	Adults (n=1,949)	6 sites in US	Social capital, safety	Residential area	20-min walking	Survey	DUR, EFF	Actigraphy	Yes	No	Yes	Yes	Yes	High social capital–DUR: 6.1 mins, high safety–6.1 mins, EFF: null
Simonelli et al.[74]	2017	Cross-sectional	Hispanic adults (n=2,156)	4 sites in US	Safety, env. stressor	Unspecified	Perception	Survey	DUR, EFF, insomnia	Actigraphy, survey	Yes	No	No	No	No	Unsafety NBHD–short sleep risk: +7.7%, noise–insomnia risk: +4.4%
Billings et al.[75]	2016	Cross-sectional	Adults (n=1,896)	6 sites in US	Walkability	Residential area	Perception	Survey	Apnea	PSG	Yes	Yes	Yes	Yes	No	Low walkability–apnea hypopnea index: 3.21 events/h
Chambers et al.[76]	2016	Cross-sectional	Hispanic adults (n=385)	Bronx, NY	NBHD disorder	Residential area	Perception	Survey	DUR, quality, problems	Survey	No	No	No	Yes	Yes	NBHD disorder–short sleep OR: null, poor sleep quality OR: 2.12
De Santis et al.[77]	2016	Cross-sectional	Mostly black adults (n=873)	Pittsburgh, PA	Social capital, NBHD disorder, safety	Residential area	Buffer, perception	Street Audit, survey	Quality	Survey	Yes	No	Yes	No	Yes	High social capital – sleep quality rate: 0.08, safety: 0.13, NBHD disorder: null
Douglas, Murphy [78]	2016	Cross-sectional	Adults (n=208)	Dublin, Ireland	Env. stressor	Residential area	Proximity	Noise measure	Problems	Survey	No	No	No	No	No	Sleep disturbance in high noise levels (32% vs 2%)
Fuller-Rowell et al.[79]	2016	Cross-sectional	Middle aged adults (n=426)	Milwaukee Midwest	NBHD disadvantage	Residential area	Census tract	Census data	DUR, EFF, WASO	Actigraphy	No	Yes	Yes	Yes	Yes	NBHD disadvantage – DUR: null, EFF: null, WASO: 3.54
Hill et al.[80]	2016	Cross-sectional	Adults (n=39,590)	7 countries	Safety	Unspecified	Perception	Survey	DUR, quality, insomnia, sleepiness	Survey	No	No	No	No	No	Safety–short sleep OR: 0.44~1.25, insomnia OR: 0.22~0.73, poor sleep quality OR: 0.49~0.79
Johnson et al.[49]	2016	Cross-sectional	Black adults (n=5,301)	Jackson, MS	Social capital, NBHD disadvantage, NBHD disorder, safety	Residential, work, socializing areas	Perception, Census tract	Survey, census data	DUR, quality	Survey	Yes	Yes	Yes	No	Yes	Social capital, NBHD disadvantage: null, low safety–DUR: -9.82 mins, NBHD disorder– DUR: -11.18 mins

Michaud et al.[81]	2016	Cross-sectional	Adults (n=1,238)	Canada	Env. stressor	Residential area	Proximity	Secondary data	DUR, EFF, quality	Actigraphy, survey	No	No	Yes	Yes	No	Noise–sleep measures: null
Perron et al.[82]	2016	Cross-sectional	Adults (n=4,336)	Montreal, Canada	Env. stressor	Residential area	Postal code	Secondary data	Problems	Survey	No	No	No	No	No	Near noise sources–sleep problems PR: 1.85~3.76
Reference	Year	Study design	Population	Geographic context	NBHD characteristic studied	NBHD type	NBHD definition	Measure of NBHD factors	Sleep outcomes	Sleep measures	Psy. factor	PA factor	BMI	Health behav	Fam. factor	Main effect estimates
Chen-Edinboro et al.[83]	2015	Longitudinal	Older adults (n=7,231)	United States	Social capital, NBHD disorder	Residential area	20-min walking	Survey	Insomnia	Survey	Yes	No	Yes	Yes	No	NBHD disorder–insomnia OR: 1.05~1.09, low social capital OR: 1.06~1.09
Fang et al.[84]	2015	Cross-sectional	Adults (n=3,591)	Boston, MA	NBHD disadvantage	Residential area	Census tract	Census data	DUR	Survey	Yes	Yes	Yes	Yes	Yes	NBHD disadvantage–short sleep OR: 2.08
Grigsby-Toussaint et al.[85]	2015	Cross-sectional	Adults (n=255,171)	United States	Walkability	Residential area	County	Secondary data	DUR	Survey	No	No	Yes	Yes	Yes	More natural amenities–short sleep OR: 0.91~0.78
Holt et al.[86]	2015	Cross-sectional	Adults (n=745,868)	United States	Env. stressor	Residential area	ZIP code	Secondary data	DUR	Survey	No	No	Yes	Yes	No	Noise-short sleep: null
Johnson et al.[87]	2015	Cross-sectional	Mostly Hispanic (n=760)	Corpus Christi, TX	NBHD disadvantage, safety	Residential area	Census tract, perception	Survey, Census data	DUR, sleepiness	Survey	Yes	No	Yes	Yes	No	NBHD disadvantage, safety–DUR: null, safety–sleepiness OR: 0.82
Johnson et al.[88]	2015	Cross-sectional	Adults (n=1789)	Detroit, MI	NBHD disadvantage	Residential area	Census tract	Census data	Apnea	PSG	No	No	Yes	No	Yes	High NBHD crowding–apnea hypopnea index: 0.4
Bassett and Moore [89]	2014	Cross-sectional	Adults (n=2,643)	Montreal, Canada	Social capital, NBHD disadvantage	Residential area	Perception, Census tract	Survey, Census data	Quality	Survey	No	No	No	No	Yes	Low social capital–poor sleep quality OR: 1.25 (men), NBHD disadvantage OR: 1.18 (women)
Frei et al.[90]	2014	Longitudinal	Adults (n=1,122)	Basel, Switzerland	Env. stressor	Residential area	Geographic coordinates	Secondary data	DUR, EFF, problems, sleepiness	Actigraphy, survey	Yes	Yes	Yes	Yes	Yes	Noise–DUR: null, EFF: -4.1%, sleep problem score: -0.44, sleepiness: null
Brown and Mellman [91]	2014	Cross-sectional	Black young adults (n=378)	Washington D.C.	NBHD disorder	Unspecified	Perception	Survey	DUR, insomnia	Survey	Yes	No	No	No	No	NBHD disorder–Insomnia severity index: +0.002
Matsumoto et al.[92]	2014	Cross-sectional	Adults (n=4,176)	Ishinomaki, Japan	Social capital	Residential area	Perception	Survey	Problems	Survey	No	No	No	No	Yes	High social capital–sleep problems OR: 0.42~0.74
Astell-Burt et al. [93]	2013	Cross-sectional	Adults (n=259,319)	New South Wales, Australia	Walkability	Residential area	Census district	Secondary data	DUR	Survey	Yes	Yes	Yes	Yes	Yes	More green space–short sleep RR: 0.68
De Santis et al. [94]	2013	Cross-sectional	Adults (n=1,406)	6 sites in US	Social capital, NBHD disorder, safety, walkable	Residential area	Perception, Census tract	Survey, Census data	DUR, sleepiness, insomnia	Survey	Yes	No	Yes	No	No	NBHD disorder–DUR: -0.11hr, safety: 0.12hr, social capital: 0.08hr
Hale et al. [95]	2013	Cross-sectional	Adults (n=1297)	Wisconsin	NBHD disorder, safety	Unspecified	Perception	Survey	Quality	Survey	Yes	No	Yes	Yes	Yes	NBHD disorder–poor sleep quality: 1.42
Bakker et al. [96]	2012	Cross-sectional	Adults (n=725)	Netherlands	Env. stressor	Residential area	ZIP code	Secondary data	Problems	Survey	Yes	No	No	No	No	Noise–sleep problems OR: 2.98
Zanobetti et al. [97]	2010	Cross-sectional	Adults (n=3,030)	6 sites in US	Env. stressor	Residential area	City boundary	Secondary data	EFF, Apnea	PSG	No	No	Yes	Yes	No	High particulate matter (PM) 10 –sleep-disordered breathing index: 12.9%, EFF: -1.2%

Hill et al. [98]	2009	Cross-sectional	Adults (n=1504)	Texas	NBHD disorder	Residential area	Unspecified	Survey	Quality	Survey	Yes	No	No	Yes	Yes	NBHD disorder–sleep quality score: -0.7
Johnson et al. [99]	2009	Cross-sectional	Mothers (n=392)	Baltimore, MD	Safety	Unspecified	Perception	Survey	DUR, problems	Survey	No	No	No	Yes	Yes	Low safety–short sleep OR: 2.06
Hale and Do [100]	2007	Cross-sectional	Adults (n=32,749)	United States	Env. stressor	Residential area	MSA	Survey	DUR	Survey	Yes	Yes	Yes	Yes	Yes	Living in urban area–short sleep OR: 1.43

NBHD: neighborhood, Psy.: psychological, PA: physical activity, Behav.: behavior Fam.: family, OR: odds ratio, RR: risk ratio, DUR: sleep duration, EFF: sleep efficiency, WASO: wake up after sleep onset, PSG: Polysomnography, NHOPI: Native Hawaiian or Pacific Islander. Six types of neighborhood characteristics: (1) social capital - shared values and trusts among community members including social cohesion, (2) neighborhood disadvantage - aggregated socioeconomic status, including poverty, mother-only households, unemployment, education attainment, and crowding, (3) neighborhood disorder - physical and social conditions of neighborhoods, such as vacant lots and housings, litters on streets, graffiti/vandalism, selling/using drugs or drinking in public, load noise, neighborhood stigma, as well as neighborhood (dis)investment (4) safety - crime rates, perceived safety, and observed violence, (5) walkability - street connectivity, sidewalk condition, accessibility to amenities and parks, and green space (6) environmental stressors - outdoor noise, light pollution, air quality, and urbanicity