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PSYCHOSOCIAL ASPECTS (SS JASER, SECTION EDITOR)

Sleep and Environmental Factors Affecting Glycemic Control in People with Type 2 Diabetes Mellitus

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Abstract

Purpose of Review Sleep and environmental factors both impact glycemic control in persons with type 2 diabetes mellitus (T2DM). This narrative article aims to review research within the past 5 years, focusing on chronotype, light, noise, and neighborhood disparities in relation to sleep in people with T2DM.

Recent Findings Sleep quality and duration have been shown to impact glycemic control in patients with T2DM. Later chronotype can lead to poorer glycemic control due to disruption of circadian rhythms. Light exposure also has similar effects, likely due to its inherent influence on sleep quality. Environmental determinants, were associated with lower T2DM incidence, and noise and air pollution were associated with increased risks for T2DM.

Summary Findings were mixed; while most studies found that later chronotype, light/noise exposure, and neighborhood disadvantages were associated with poorer glycemic control in patients with T2DM, other environmental factors, such as green space, were not significantly associated with diabetes outcomes.

Keywords Type 2 diabetes · Chronotype · Social jetlag · Neighborhood disparities · Light · Noise

Introduction

The intersection between sleep disturbances and environmental factors has gained increasing attention in relation to their roles in suboptimal glycemic control in people with type 2 diabetes (T2DM). While adherence to behavioral modifications such as exercise, healthy eating, and self-monitoring is known to improve glycemic control, the effects of sleep and other non-modifiable environmental risk factors, such as light and noise exposure, need further exploration. Investigating the extent to which these factors influence glycemic control, through their effects on sleep, could potentially pave the way for the development of novel interventions to reduce the prevalence of morbidity and diabetic sequelae.

With the frequency of sleep disturbances rising in the general population, the implications for people with T2DM are wide-ranging. The 2019 American Diabetes Association's Standards of Medical Care in Diabetes recommends that clinicians assess sleep habits and sleep quality as part of a comprehensive medical evaluation. Subsequently, many studies have examined the effect of sleep in relation to the risk of diabetes development [1] but few have investigated the impact of sleep on glycemic control in patients with pre-existing T2DM. Variability in sleep timing and duration can induce "social jetlag," or an altered circadian rhythm and natural sleep cycle and predispose individuals to accruing sleep debts [2]. These changes in chronotype are also linked to increased insulin resistance and poor glycemic control.

Likewise, few studies have assessed the impact of light and noise on sleep and blood glucose levels in people with T2DM.

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Light exposure plays a key role in sleep initiation, duration, quality, and chronotype. According to LeGates, Fernandez and Hattar of Nature Review Neuroscience, consistent light exposure delays the sleep-wake cycle, leading to circadian arrhythmicity, and should be regarded as a risk factor for disease secondary to irregular hormonal and metabolic coordination [3].

Comparatively, vast attention has been given to the implications of neighborhood disparities on chronic disease and people with T2DM. Studies have shown that factors such as violent crime, food insecurity, and socioeconomic status are correlated with diabetic complications as well as glycemic control. These non-modifiable environmental factors influence the behavioral modifications of patients with T2DM, such as regular exercise, adding to the risk of suboptimal glycemic control.

Thus, in this review, we synthesize the literature on how sleep and environmental factors in people with T2DM to identify further opportunities to implement non-medical interventions aimed at improving glycemic control.

Methods

Data Sources and Search Criteria

In December 2018, PubMed, PsycINFO, Scopus, Cochrane Library, and SocIndex were searched for environmental factors affecting people with T2DM. The search was limited to studies published within the past 5 years (2013 and onward). The search included a term from each of four categories: (1) chronotype (ex: shift work, social jetlag), (2) noise (ex: noise exposure), (3) light (ex: light exposure), (4) neighborhood disparities (ex: neighborhood problems, neighborhood perception, neighborhood disadvantage) and T2DM. Terms were interlinked with "AND."

Study Eligibility

Inclusion criteria include the following: (1) study participants with a pre-existing diagnosis of T2DM, (2) studies analyzing impact of chronotype, light, noise, and neighborhood disparities on glycemic control in people with T2DM, (3) studies published in English. Studies were excluded if they were done on people with exclusively type 1 diabetes, pre-diabetes, people without diabetes, and those on non-human subjects. Studies were also excluded if they assessed incidence (diabetes risk), were published prior to 2013, or were systematic reviews and meta-analyses. The search criteria resulted in 20 published articles (Fig. 1). Authors MD, AAH, and AKM independently reviewed each abstract of the identified articles. Articles were then excluded based on the criteria above. Full text of the remaining articles (20) were then reviewed independently by each author (Appendix Table 1).

Data Abstraction and Narrative Synthesis

A narrative synthesis approach was utilized to review 20 included articles as they varied in study design and methodology. A table was created to summarize the characteristics, methods, and results of each study (environmental factor, study design, sample size, mean age, major ethnicity, mean Hemoglobin A1c (HbA1c), percent of patients with T2DM, study duration, intervention, and outcomes) (Appendix Table 1).

Results/Discussion

The initial search resulted in 101 articles; however, 81 were excluded based on eligibility criteria (Fig. 1). The remaining 20 articles were included in this review, of which 11 were focused on neighborhood disparities, 6 on chronotype, 2 on light, and 1 on noise. The majority of the studies were cross-sectional (12); the remaining were longitudinal studies (3), prospective cohort studies (3), retrospective cohort studies (1), or randomized control trial (1). All articles were published in the past 5 years (2013–2018). A summary of the articles included in this review are shown in Appendix Table 1.

All of the studies reviewed included at least a subset of people with T2DM (13 had 100% of participants with T2DM), with mean HbA1c ranging from 5.5% to greater than 9%. HbA1c was greatly impacted by the number of participants with both pre-diabetes and diabetes in each study. The sample size varied greatly among these studies from 16 to 270,600; however, mean age was approximately in the same range (50s–70s). While some studies only included one ethnicity, overall, they captured a fairly diverse patient population (majority ethnicity non-Hispanic Whites (8), Hispanic (4), Asian (4), African American (2), and 2 studies with ethnicity not reported).

Although one study failed to show a significant relationship between sleep and glycemic control, the majority of the articles reviewed (19) demonstrated a positive correlation between the studied sleep or environmental factor and glycemic control. As expected, these studies found that later chronotype, frequent light/noise exposure, and neighborhood disadvantage was associated with poorer glycemic control in patients with T2DM.

Chronotype

Chronotype is the variation in people's sleep time preferences and is regulated by each individual's circadian rhythm or biological clock. It is impacted by environmental light, genetics,

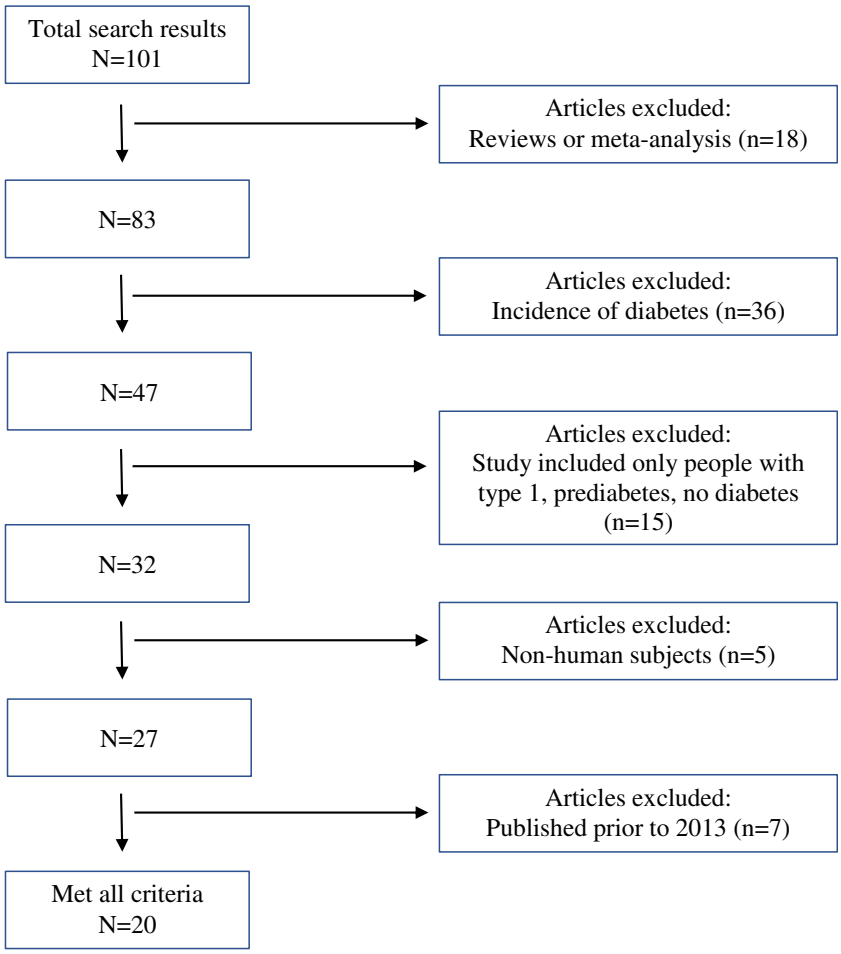

Fig. 1 Flow chart for article exclusion from review

and human development [4]. Changes in chronotype and circadian cycle impacts metabolism and hormones like leptin, ghrelin, and insulin, which can, in turn, influence glycemic control [5–7]. Reversal of the typical circadian pattern of wakefulness during the day and sleep at night, as seen in shift workers, is associated with increased insulin resistance. Additionally, shift workers have a tendency to consume more snacks food and eat at night, which increases risk of obesity and other components of the metabolic syndrome [8].

The six studies that assessed chronotype used a variety of questionnaires to determine sleep habits. One study utilized a morningness–eveningness questionnaire (MEQ) and calculated scores, where a high score represented *morningness* [9]. In this cross-sectional study, where 100% of the study participants had T2DM, HbA1c in the morning-type group (7.2% ± 0.8) was significantly lower than those of the evening-type group (8.3% ± 1.8). Furthermore, MEQ correlated negatively and significantly with HbA1c, showing that higher MEQ (morning subgroup) was associated with lower HbA1c. In addition, those who were in the morning group had better self-reported sleep quality on the Pittsburgh Sleep Quality Index (PSQI). This study was limited, as it included only middle-aged Japanese males and participants were recruited from a single center. Similar findings were also shown in two other cross-sectional studies, where later chronotype was significantly associated with poorer glycemic control in participants with T2DM independent of sleep disturbances as reported on the PSQI, and evening-type was associated with higher HbA1c [10•,11]. Some of the demographic and clinical characteristics associated with the later chronotype included younger age, insulin use, depressive symptomatology, and higher body mass index (BMI) [10•].

Age may be a moderating factor in the relationship between chronotype and HbA1c. This was demonstrated in a nationwide study of Hispanic and Latinos; among those 35 years or less, later sleep timing was associated with lower HbA1c, but the opposite association was observed among older participants. Of note, younger participants had lower BMI. Although overall HbA1c differed by age group in this study, overall higher fasting glucose was associated with later sleep time (approximately 3% increase in fasting glucose with each additional hour of later sleep) in participants with T2DM [12]. Later sleep times influences sleep quality and can result in later eating times. These factors can potentiate insulin resistance and in turn lead to higher fasting glucose in those with later sleep times.

All studies assessing chronotype demonstrated an association with poorer glycemic control in patients with T2DM. This is consistent with studies showing that night shift workers have higher risk of developing diabetes and have worse metabolic outcomes [13]. The difference in metabolic outcomes is likely due to later chronotype seen in night-shift workers and people with later sleep times. Later bedtime is often associated with larger consumption of calories at a later time [10•]. Researchers hypothesize that the combination of decreased glucose tolerance in humans from morning to evening as a result of reduced glucose utilization, decreased insulin sensitivity, and inappropriately low insulin secretion likely leads to poor glycemic control in patients with T2DM who have a later chronotype [14].

Shift Work

Shift work sleep disorders are found in 2–5% of the working population [15] as shift workers often experience sleep/wake disturbances which lead to circadian misalignment and poor metabolic outcomes. These observations correlate with a study conducted in Thailand that examined glycemic control in night-shift workers with T2DM. In this cross-sectional study, 100% of the participants had T2DM. Day-shift workers had an average HbA1c of 7.2% compared to night-shift workers with an average HbA1c of 7.7% [16]. This difference was likely the result of chronotype misalignment, as the analysis was adjusted for other factors (age, body mass index, insulin use, sleep duration, morningness–eveningness preference, percentage of daily intake from carbohydrates) that may vary in night shift workers and influence glycemic control.

Social Jetlag

Social jetlag is the variability in bedtime and wake time or differences in mid-sleep time that occur due to individual variations in social time. Biological time is the body's natural sleep time preference (i.e., chronotype), whereas social time is determined by school/work schedules. These two times are often misaligned in people and manifest as earlier than natural wake times on school/work days and later wake times on weekends (free days). This inconsistency between biological/social time and work/free days results in social jetlag, which has been associated with poor health outcomes [17]. Although research in this area is limited, some studies suggest that social jetlag can lead to increased visceral obesity and elevations in glucose. Higher social jetlag scores have been shown to correlate with higher BMIs, larger waist circumference, metabolic syndrome, and disease indicators of inflammation and diabetes—higher C-Reactive Protein (CRP) and HbA1c respectively [18]. Similar observations were made in the Koopman et al. who utilized data from the Dutch New Hoorn Study cohort, and calculated social jetlag as the difference in mid-point sleep (in hours) between weekdays and weekend days. After adjusting for gender, employment status, education, smoking, physical activity, sleep duration, and body mass index, the analysis showed social jetlag was associated with a higher prevalence of both diabetes and pre-diabetes in those less than 61 years of age. In the younger group (< 61 years), the adjusted prevalence ratios were 1.39 (95% CI 1.1–1.9) and 1.75 (95% CI 1.2–2.5) for diabetes and pre-diabetes respectively for participants with 1–2 h and > 2-h social jetlag, respectively, compared with participants with < 1-h social jetlag (p 0.01) [19•]. Results of this study were limited by the cross-sectional design and the fact that only those with high risk for diabetes had an HbA1c. Moreover, age moderated these effects, as the prevalence of social jetlag is lower in older adults while the prevalence of T2DM increases with age.

Light

Circadian rhythms are greatly influenced by light exposure. Retinal light-sensitive cells communicate with the central nervous system, in both day and night, to determine sleep patterns. With the advancement of electricity and technology, humans now have much more control of light exposure in their surroundings. While this has allowed for flexibility in work hours not limited by natural daylight, off-cycle artificial light exposure can reset circadian rhythms and alter natural sleep/wake cycles which have potential implications for glycemic control [3].

As sleep disturbance is negatively correlated with glycemic control, and light can impact sleep quality, it is expected that light would have a similar effect on glycemic control. Two studies examined the impact of evening light exposure on glycemic control in people with T2DM. In the first study, associations between evening light exposure in home settings and T2DM were cross-sectionally examined in 513 adults. Ambulatory light intensity was measured using wrist light meters 4 h prior to bedtime and used as an index of evening light exposure. Using a multivariate logistic regression model (adjusted for gender, body mass index, duration in bed, and night-time light exposure), the study determined that average evening light intensity was significantly and independently associated with increased prevalence of diabetes [20].

The second study was a randomized controlled trial that compared two cohorts—one with 8 healthy lean men and the other with 8 obese men with T2DM. Study participants were randomized to be in the bright light or dim light group to assess the impact of light exposure on glycemic control. Although this study did not measure sleep duration among the bright and dim light groups, light intensity affects the hypothalamus and sympathetic nervous system which can impact sleep quality and in turn glycemic control. After consuming a standardized meal at 2130 h, subjects stayed in normal

room light (200 lux) until 2330 h and slept in darkness until 0730 h. Participants were subsequently exposed to 10 lux light intensity in the dim light group and 4000 lux intensity in the bright light group for 6 h (730–1330 h). Primary endpoints were fasting and postprandial plasma glucose levels. In men with T2DM, bright light increased both fasting and postprandial plasma glucose levels, whereas in participants without T2DM light did not have any effect [21]. This observation indicates the negative relationship between light exposure and glycemic control in people with T2DM is likely mediated by the impact of light on sleep quality.

Limited studies have examined the impact of light exposure on glycemic control in people with T2DM. Although causality was not demonstrated in these studies, the association between evening light exposure and poorer glycemic control was significant and correlates with metabolic outcomes in night shift workers inherently exposed to evening light as consequence of work schedules. Evening light exposure alters circadian rhythm, which in turn affects metabolic and hormonal responses.

Noise

Sleep quality is crucial for development/health and is greatly affected by noise disturbance [22]. From an evolutionary perspective, humans are able to monitor their surroundings even in their sleep through their hearing ability and sensitivity to noise [22]. While this is an advantage to sense potential danger, noise-disturbed sleep can lead to poor health outcomes, as uninterrupted sleep is needed for regulating growth/stress hormones and the immune system. Increased levels of noise pollution have been associated with greater risk of developing T2DM [23]. For example, in one study conducted in Bulgaria, participants completed a questionnaire used to explore the associations between various neighborhood characteristics and several health endpoints. One of these characteristics was noise, with road traffic being the dominant source of noise. In this cross-sectional study, T2DM was positively associated with exposures to noise (odds ratio (OR) = 4.49, 95% (CI) 1.38, 14.68), $p = 0.01$ [24]. While these findings suggest an association between residential noise exposure and increased risk for T2DM, the association between noise and glycemic control was not assessed. Given that noise can lead to sleep disturbance, which impacts glycemic control, it is expected that those with T2DM would have positive associations with both noise and sleep disturbance. More studies are needed to study the impact of noise on diabetes-related outcomes in people with T2DM, including more objective measures of noise exposure, and measures of glycemic control.

Neighborhood Disparities

A plethora of studies have been conducted assessing the role of neighborhood disparities in the glycemic control of T2DM. Neighborhood disparities can be defined as unequally distributed environmental burdens that influence health indices in given populations. These burdens are features such as safety and violent crime, social cohesion, neighborhood organization, food insecurity, and socioeconomic status, which can subsequently influence patient self-care behaviors and glycemic control. Eleven articles examined the relationship between these factors and T2DM. While these studies did not measure sleep explicitly, the environmental factors discussed are likely to act as psychosocial stressors, negatively influencing glycemic control in patients with T2DM via poor sleep quality. According to the British Whitehall II study, sleep disturbances are greater among individuals exposed to neighborhood crime and those experiencing financial strain secondary to socioeconomic status [25].

Neighborhood Safety and Violent Crime

Although many studies have investigated the relationship between reported violent crime (i.e., murder, robbery, and assault) and T2DM, few have assessed how *perceptions* of neighborhood safety can equally affect HbA1c. In a cross-sectional study of rural Latinos, investigators explored the relationship between perceived neighborhood problems and metabolic indices including HbA1c. No statistically significant association between feelings of poor neighborhood well-being and HbA1c in T2DM was found; however, there was association with perceived neighborhood issues and increased BMI and lack of exercise [26]. Similar findings were demonstrated in a study examining the relationship among neighborhood disparities and T2DM in a cross-sectional sampling of a longitudinal cohort. Neither living in a high crime neighborhood nor neighborhood safety was associated with HbA1c, but they were associated with obesity [27]. Of note, only 15% of persons lived in a high crime area.

Food Insecurity

Nutritional therapy plays an integral role in diabetes management. Patients residing in food deserts (i.e., those living in areas of decreased produce accessibility) face unique obstacles when attempting to follow intake recommendations, possibly contributing to poorer control and prognosis. Five studies were identified as exploring the association between food insecurity and glycemic control in T2DM.

A 4-year longitudinal cohort of 160,000 participants showed those with the poorest glycemic control at baseline experienced the largest increases in HbA1c following neighborhood supermarket loss [28]. After adjusting for individual factors (LDL levels, statin use, BMI, etc.), another 3-year analysis determined food insecurity was still significantly correlated with 0.6% higher HbA1c levels regardless of increased outpatient visits [29]. Patients living in areas of food insecurity had an annual HbA1c increase of about 0.5% compared to matched controls

in areas of high accessibility [30]. When observed longitudinally at a Midwestern Community Clinic, food insecurity was also associated with elevated HbA1c in younger persons with T2DM compared to elder patients [31]. In a study comparing glycemic control to treatment intensification, patients residing in areas of low food accessibility experienced lower HbA1c reductions regardless of increases in medical management [32]. Overall, food insecurity seems to be related to poorer glycemic control in T2DM.

Neighborhood Socioeconomic Status

Studies have touched upon the possible influence of socioeconomic status (SES) on T2DM glycemic control. With a total sample size of 269,942 individuals, researchers from a 1-year study in Madrid found communities with the highest SES had a 9% lower prevalence of poor glycemic control as defined by a HbA1c of 7% or less [33]. However, in a study of elderly women aged 70–79, those who lived in a neighborhood with low SES had no statistically significant risk of hyperglycemia (as defined by HbA1c > 7%), but rather had higher BMIs [34]. In an analysis of the NYC HbA1c study, there was an association between low neighborhood SES and elevated HbA1c. Factors such as access to healthier food and walkability were noted to be significant when comparing higher and lower neighborhood SES, whereas green space, outdoor recreational spaces and unhealthy establishments were insignificant. Individuals moving from areas of low SES to higher SES experienced better diabetes control, with a HbA1c decrease of 0.40%, with the converse was true as well [35]. One study separating SES into subgroups identified education and income as the strongest influencing factors [36]. Ultimately, most studies found a negative correlation between neighborhood SES and glycemic control.

People in these environments may experience higher levels of noise and light at night, and they may be more likely to have jobs requiring shiftwork. These differences, having a negative impact on sleep, may account for differences in glycemic control long-term. Further investigation into these factors may lead to interventions in low socioeconomic communities/low education to offset this phenomenon.

Conclusions

While T2DM develops from underlying metabolic and hormonal derangements, recent studies have highlighted the impact of external exposures on sleep and their subsequent effect on glycemic control in patients with T2DM. With the examination of these studies, several limitations should be noted. Many articles focused on specific racial and ethnic groups and may not be generalizable to greater populations. Twelve out of the 20 articles reviewed were cross-sectional in design and could not provide insight into causal relationships. The data presented in these studies are based upon associations at a given moment in time rather than a period of extended observation. Additional prospective cohort studies and randomized controlled trials are needed to provide information regarding causal links and deepen our understanding of the effects of chronotype, light, noise, and neighborhood disparities on glycemic control in T2DM. Although none of these studies yielded statistically significant results, they may still hold clinical significance for improving glycemic control.

Overall, most studies examining the environmental factors influencing glycemic control focused on chronotype and neighborhood disparities, while very few studies assessed the impact of light and noise exposure. Regardless, among the articles reviewed, later sleep patterns and evening light exposure were associated with poorer glycemic control whereas noise exposure correlated with risk for T2DM. The studies reviewed in this narrative indicate exposures can impact circadian rhythm, and subsequently affect glycemic control in people with T2DM. In terms of neighborhood disparities, controversies exist in terms of the influence of perceived environmental safety on T2DM, with violent crime being the most commonly perceived problem. These concerns contribute to decreased walkability, with associated higher HbA1c levels, increased BMI, and/or poorer health outcomes overall. Food insecurity was identified as a risk factor for poor glycemic management. Decreases in SES were associated with poorer glycemic control and higher BMI. To date, studies have not directly assessed the relationship among neighborhood disparities, sleep, and glycemic control in patients with T2DM. However, literature on neighborhood disparities in the general population indicates that sleep quality is poorer among people living in neighborhoods with violent crime, food insecurity, and socioeconomic disparities, which may translate to higher HbA1c levels. This concept can be further extrapolated to include patients with T2DM.

Overall, this review indicates that sleep and environmental factors play a role in glycemic control in T2DM. While more studies are needed, these findings support the need for comprehensive screening for the factors (i.e., evening light and noise exposure and neighborhood disparities) and sleep disturbances when treating patients with T2DM. By identifying patients at risk, providers can individualize care and promote better outcomes.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Appendix

Table 1 Summary of articles reviewed

Authors (reference)	Environmental factor	Study design	Sample size, mean age, major ethnicity, mean A1C, % T2DM	Methods	Duration	Outcomes
Iwasaki et al. [9]	Chronotype	Cross-sectional	$N = 101$; mean age 53.9 years; 100% Asian, mean A1c 7.3; 100% T2DM	A morningness–eveningness questionnaire (MEQ), where a high score representing morningness were completed.	3 months	HbA1c in the morning group (7.2 ± 0.8) was significantly lower than those of the evening group (8.3 ± 1.8), $p < 0.05$. MEQ correlated negatively and significantly with HbA1c (regression coefficient − 0.238, $p < 0.05$)
Koopman et al. [19•]	Chronotype	Cross-sectional	$N = 1585$; mean age 60.8 years; 100% White, mean A1c 5.9; 11% T2DM	Participants filled out questionnaires about their physical activities, medical history, quality of life, diet, and sleeping behavior	2 years	Social jetlag was associated with higher prevalence of DM in younger population (age < 61). In the younger group (< 61 years), the adjusted prevalence ratios were 1.39 (95% CI 1.1–1.9) for patients with diabetes with 1–2 h and > 2 h social jetlag respectively, compared with those with < 1 h social jetlag (p 0.01)
Knutson et al. [12]	Chronotype	Cross-sectional	$N = 13{,}426$; age range 18–74 years; 100% Hispanic/Latino, mean A1c 5.5; 14% T2DM	Sleep questionnaire to determine bedtime/wake time. Glucose, insulin, and hemoglobin A1c levels were measured on the fasting blood sample, and glucose was measured again on the 120-min blood sample.	3 years	In participants with DM, later sleep timing was associated with higher fasting glucose (regression coefficient 0.027, $p < .01$) Associations differed by age, among those < 36 years, later sleep timing was associated with lower HbA1c, opposite in older group.
Manodpitipong et al. [16]	Chronotype	Cross-sectional	$N = 249$; mean age 56.4 years; 100% Asian, mean A1c 7.4; 100% T2DM	Sleep duration, sleep quality, morningness–eveningness preference, depressive symptoms and dietary intake were assessed using standardized questionnaires.	1 year	Night-shift work, compared with day work, was associated with significantly higher HbA1c ($B = 0.059$, $p = 0.044$), while there were no differences between unemployed participants and day workers ($B = 0.016$, $p = 0.572$). Night-shift work is associated with poorer glycemic control in patients with type 2 diabetes.
Osonoi et al. [11]	Chronotype	Cross-sectional	$N = 725$; mean age 57.8 years; 100% Asian, mean A1c 7.0; 100% T2DM	Various lifestyles were analyzed using self-reported questionnaires, including morningness–eveningness questionnaire	8 months	Evening type group was associated with high HbA1c.
Reutrakul et al. [10•]	Chronotype	Cross-sectional	$N = 194$; mean age 58.4 years; 28% White, mean A1c 7.5; 100% T2DM	Structured interviews and questionnaires were used to collect information on diabetes history and habitual sleep duration, quality, and timing.	Not reported	Later chronotype was significantly associated with poorer glycemic control in patients with T2DM (coefficient $R = 0.34$, $p < 0.001$)

Table 1 (continued)

Authors (reference)	Environmental factor	Study design	Sample size, mean age, major ethnicity, mean A1C, % T2DM	Methods	Duration	Outcomes
Obayashi et al. [20]	Light	Cross-sectional	$N = 513$; mean age 72.7 years; 100% Asian, mean A1c 6.6; 13% T2DM	Measured ambulatory light intensity during the 4 h prior to bedtime at 1-min intervals during two consecutive days	1.5 years	Evening light exposure in home settings was significantly and independently associated with DM [adjusted OR, 1.72; 95% (CI), 1.12–2.64; $p < 0.01$.
Versteeg et al. [21]	Light	Randomized Control Trial	$N = 16$; mean age 60 years (in diabetics); ethnicity not reported, mean A1c 6.8 (in diabetics); 50% T2DM	2 randomized crossover trials: (1) in 8 healthy lean men and (2) in 8 obese men with type 2 diabetes. From 0730 h, subjects were exposed to either bright light (4000 lx) or dim light (10 lx) for 5 h. After 1 h of light exposure, subjects consumed a 600-kcal mixed meal. Primary endpoints were fasting and postprandial plasma glucose levels.	Not reported	In healthy men, bright light did not affect fasting or postprandial plasma glucose levels. In men with type 2 diabetes, bright light increased fasting and postprandial glucose levels.
Dzhambov et al. [24]	Noise	Cross-sectional	N = 513; mean age 36.5 years; 85% White, mean A1c not reported; 7% T2DM	A questionnaire comprising 59 closed and open-ended questions were administered in order to explore the associations between various neighborhood characteristics and several health endpoints.	2 years 4 months	T2DM was positively associated with exposures to noise (odds ratio (OR) = 4.49, 95% (CI) 1.38, 14.68), $p = 0.01$
Berkowitz et al. [29]	Neighborhood	Longitudinal	$N = 584$; mean age 58.9 years; 100% Hispanic, mean A1c 8.4; 100% T2DM	Determined associations between food insecurity and dietary pattern and assessed whether those dietary patterns were associated with poorer HbA1c over time.	1.5 years	Food insecurity was associated with poor longitudinal glycemic control. Patients living in food insecure area had an increase in A1c of about .5 in 1 year or 1 in 2 years compared to an identical participant living in a non-food insecure area.
Berkowitz et al. [30]	Neighborhood	Prospective Cohort	$N = 391$; mean age 61.9 years; 79% White mean A1c 7.9; 100% T2DM	Patients with T2DM completed food insecurity assessments about food access and proximity. A1c levels were recorded and matched with feedback about low physical food access, glycemic control and food insecurity.	2 years	Food insecurity was associated with higher HbA1c, with no improvements over time.
Bilal et al. [33]	Neighborhood	Retrospective Cohort	$N = 270, 660$; mean age 56.5 years; major ethnicity not reported, mean A1c 6.7; 9% T2DM	Education, wealth, occupation and living conditions were determined and matched to patient records from 2013 to 2014 to assess changes in glycemic control with neighborhood changes.	1 year	As neighborhood socioeconomic status increases, diabetes prevalence, lack of control and incidence decrease in a linear fashion.
Corriere et al. [34]	Neighborhood	Cross-sectional	$N = 384$; mean age 74 years; 83% White, mean A1c 6; 9.4% T2DM	Neighborhood scores were calculated from census-derived data on median household income,	Not reported	A relatively more advantaged neighborhood was associated with a ~ 65% lower likelihood of obesity

Table 1 (continued)

Authors (reference)	Environmental factor	Study design	Sample size, mean age, major ethnicity, mean A1C, % T2DM	Methods	Duration	Outcomes
				median house value, income, education, occupation. Participants were categorized by quartile of neighborhood score with a higher quartile representing relative neighborhood advantage.		and lower average BMI among older women compared to those living in the least advantaged neighborhoods with a lower prevalence of hyperglycemia and elevated A1c.
Hirsch et al. [32]	Neighborhood	Prospective cohort	$N = 13,308$; mean age 57.8 years; 96% White, mean A1c 8.2; 100% T2DM	Used mixed-effect models to assess whether community domains (community socioeconomic deprivation [CSD], food availability, fitness, physical activity) were associated with HbA1c.	Not reported	The average reduction in HbA1c over 6 months was 0.07% less in townships with a high level of CSD (third quartile versus the first). Reductions were 0.10% greater for HbA1c in townships with the best food availability (versus worst). HbA1c reductions were 0.17–0.19% greater in census tracts in the higher quartiles of utilitarian physical activity.
Moreno et al. [26]	Neighborhood	Cross-sectional	$N = 250$; mean age 50–59 years; 100% Hispanic, mean A1c not reported; 100% T2DM	Questionnaire with neighborhood problems (crime, trash, light at night, public transportation, food justice, and access to exercise facilities).	Not reported	No significant association between perception of neighborhood problems and levels of HbA1c.
Shalowitz et al. [31]	Neighborhood	Longitudinal	$N = 336$; mean age 51.8 years; 60% Hispanic, mean A1c 8.9; 100% T2DM	Completed a baseline assessment of patients' food security, demographics, clinical history when patients began receiving diabetes care at the health center	2 years	Patients with lower (vs higher) food security were more likely to be on insulin and have higher A1c levels at baseline.
Tabaei et al. [35]	Neighborhood	Longitudinal	$N = 182,756$; mean age 64 years; 47% White, mean A1c 7.7; 100% T2DM	Constructed residential-level measures and performed principle component analysis to formulate a residential composite score. On the basis of this score, divided residential areas into quintiles, with the lowest and highest quintiles reflecting the least and most advantaged residential environments, respectively.	6 years	Individuals who lived in the advantaged areas took less time to achieve glycemic control (9.9 vs. 11.5 months). Moving from less advantaged areas to more advantaged areas was related to better DM control (decrease in HbA1c = 0.40%, 95% CI 0.22, 0.55), whereas moving from more advantaged areas to less advantaged areas was related to worsening DM (increase in HbA1c = 0.33%, 95% CI 0.24, 0.44).
Tamayo et al. [27]	Neighborhood	Cross-sectional	$N = 721$; mean age 63.1 years; 23% African American, mean A1c not reported but > 9; 100% T2DM	Cross sectional questionnaires examining how perceived neighborhood safety and violent crime is associated with cardio metabolic risk factors, independent of	Not reported	There were no significant associations between neighborhood safety concerns or violent crime with HbA1c.

Table 1 (continued)

Authors (reference)	Environmental factor	Study design	Sample size, mean age, major ethnicity, mean A1C, % T2DM	Methods	Duration	Outcomes
				individual level sociodemographic characteristics.		
Walker et al. [36]	Neighborhood	Cross-sectional	$N = 615$; mean age 61 years; 65% African American, mean A1c not reported; 100% T2DM	Structured equation modeling investigated the relationship among social determinants, self-care and glycemic control.	Not reported	Lower social support was significantly related to lower glycemic control ($r = 0.10$, $p = 0.02$)
Zhang et al. [28]	Neighborhood	Prospective cohort	$N = 160{,}000$; mean age 61–64 years; 46% White, mean A1c 7.1–7.3; 100% T2DM	Measured participant A1c annually and matched patient records with geospatial measures at each member's geocoded address at the census block centroid of record to assess supermarket presence/food justice	4 years	Changes in supermarket presence were rare during study. Patients with the poorest glycemic control at baseline appeared to have the largest relative HbA1c increase following supermarket loss but supermarket gain did not decrease A1c

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