



Full length article

Daylight during winters and symptoms of depression and sleep problems: A within-individual analysis

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ABSTRACT

Background: With climate change Northern areas of the globe are expected to have less daylight during winters due to less snow and more cloudiness. While wintertime has been linked to mental health problems, the role of wintertime daylight has been scarcely studied. We examined longitudinal associations for wintertime objective exposure to global radiation and self-reported daylight exposure with symptoms of depression and sleep problems.

Methods: Our analytical sample included 15,619 respondents from three Swedish Longitudinal Occupational Surveys of Health (2012, 2014 and 2016). *Objective exposure* was global radiation (MJ/m², November-January and November-February). *Subjective exposure* was based on self-reported time spent outdoors in daylight (<1 h vs. ≥ 1 h, November-January). Symptoms of depression were evaluated using a six-item subscale of the (Hopkins) Symptom Checklist. Fixed-effects method with conditional logistic regression controlled for time-invariant participant characteristics by design and time-varying covariates were added into models.

Results: One unit increase in the four-month averaged global radiation was associated with lower odds of depressive symptoms (OR 0.69, 95 % CI 0.52–0.91). These findings were confirmed using four-month cumulative exposure (OR 0.91, 95 % CI 0.85–0.98). Individuals reporting ≥ 1 h exposure to daylight during winter months were less likely to report depressive symptoms (OR 0.72, 95 % CI 0.60–0.82) compared to time when their exposure was < 1 h. Higher three-month exposure to global radiation suggested a protective association for sleep problems.

Conclusion: These findings suggest that higher exposure to daylight during winters may contribute to lower likelihood of depression symptoms.

1. Introduction

In the Northern latitudes the days during winter are short and amount of daylight is low. The light conditions may further worsen as climate change has already led to decrease in snow cover (Masson-Delmotte et al., 2021), that reflects radiation, and increases in precipitation and cloudiness are expected. In terms of health, less winter-time global radiation might be detrimental. Seasonal affective disorder has been associated with low exposure to daylight (Magnusson, 2000; Partonen and Lönngqvist, 1998). According to a recent review, the research of climate change and mental health is important but challenging

(Charlson et al., 2022), and most studies have focused on the effects of temperature (Hwong et al., 2022; Lee and Kim, 2016). The scarce literature on the associations between exposure to global radiation or sunlight and depression has reported inconsistent findings (Burns et al., 2021; Cui et al., 2021; Kent et al., 2009; Kim et al., 2021; Komulainen et al., 2022; Sarran et al., 2017; Son and Shin, 2021). Moreover, most of the studies have been cross-sectional, therefore prohibiting assumptions of causal associations. Further examining the mental health effects of winter-time light conditions is particularly important, as mental disorders are among the top ten leading causes of disease burden, not only in Northern latitudes, but worldwide (Collaborators, 2022).

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Therefore, we examined, using a longitudinal setting, the associations for objectively measured winter-time global radiation and self-reported exposure to daylight in winter months with depressive symptoms and sleep problems. We hypothesized that lighter conditions during the day in winter have positive effects on mental health.

2. Materials and methods

2.1. Study sample

The Swedish Longitudinal Survey of Health (SLOSH) is a biennial national survey of work-life participation, work environment, and health and well-being that started in 2006. Since then, every second year two types of questionnaires are sent; one for those who on average were in paid work for $\geq 30\%$ of full-time during the three months prior to the survey, i.e., gainfully employed, and another for those in paid work $< 30\%$ of full-time, and temporary or permanently unemployed. SLOSH is administered by Statistics Sweden.

Our study participants include respondents of both types of questionnaires from years 2012, 2014 and 2016. Total number of individuals who responded to any SLOSH wave from 2012 to 2016 was 40,876. Participants with missing information on daylight exposure, symptoms of depression, sleep, and covariates were excluded. In the analytical sample, 15,619 participants had minimum two responses and had information on all covariates with total of 35,538 observations. Of the 15,619 participants, 10,430 had data on subjective exposure with total of 23,581 observations.

2.2. Exposure measures

Objective exposure: global radiation was based on incoming solar radiation on a horizontal surface. Global radiation measurements were provided by the Swedish Meteorological and Hydrological Institute (SMHI). SMHI used STRÅNG model, (SMHI, 2023) a mesoscale model for solar radiation, which has a horizontal resolution of 11×11 km and a temporal resolution of one hour. SMHI summed hourly values (00:00 to 23:00 h) in Watts per square meter (W/m^2) to daily cumulative values in Watts hour per square meter (Wh/m^2). Daily averages thus include both day and night light exposure outdoors. We used daily cumulative values to calculate monthly averages over three (November to January) and four (November to February) winter months for each year. We also calculated three-month and four-month cumulative exposure by summing monthly averages. These time windows were chosen to match the time duration asked for self-reported time spent in daylight. To compare with previous studies, we converted the values from Wh/m^2 to Mega Joule per square meter (MJ/m^2) by multiplying with 0.0036. The exposure was matched with SLOSH participants at residential municipality level.

Subjective exposure: self-reported daylight exposure was based on the SLOSH questionnaire that asked: "How much time per day do you spend outdoors in daylight during November-January? a) during business days, and b) during days off", with the response options: 1) less than 30 min, 2) 30 min to one hour, 3) 1–2 h, and 4) more than 2 h. Weekday-weighted average per day exposure to daylight was calculated and categorized as 0 if exposure was less than one hour/day and as 1 if equal to or more than one hour/day.

2.3. Outcome measures

Symptoms of depression was self-reported in the questionnaires. It was assessed using a six-item subscale of the (Hopkins) Symptom Checklist (SCL) resulting in SCL-Core Depression scale. Respondents scored on a five-category scale the extent that they felt blue, had no interests in things, were lethargic or low in energy, were worrying too much about things, blamed oneself for things, and felt everything is an effort. The scores on all items were summed to a continuous scale measuring the

severity of depression. A score of 17 has been identified as the best cut-point for major depression (sensitivity 0.68, specificity 0.98) which predicted subsequent purchases of antidepressants as well as hospitalizations with a depressive episode (Magnusson Hanson et al., 2014), thus, we used ≥ 17 as the cut-off point for reporting depressive symptoms while score < 17 meant no symptoms.

Disturbed sleep was based on the Disturbed Sleep Index from the Karolinska Sleep Questionnaire (Nordin et al., 2013). Participants were asked if they had difficulties falling asleep, restless sleep, repeated nocturnal awakenings, and premature awakening. There were six response alternatives: never, rarely, few times per month, 1–2 times per week, 3–4 times per week, and 5 or more times per week. Disturbed sleep was defined as having one or more sleep problems 3–4 times a week or more (Raza et al., 2021).

2.4. Covariates

Based on available literature (Cui et al., 2021; Kim et al., 2021; Komulainen et al., 2022), we identified factors previously considered as potential confounders in studies investigating associations between sunlight exposure or global radiation and mental health outcomes. Data on age, sex, and civil status (married/cohabiting vs. not) was obtained from registers. Occupational position (low, intermediate, high, and self-employed) and number of children were self-reported (one or more children under 12 years). Unlike prior studies, we controlled for work-related stress. Job strain was based on Swedish Demand Control Questionnaire and was defined as having high demands (higher than the study-specific median of the demands scores) and low control (lower than the study-specific median of the control scores) (Sanne et al., 2005). We evaluated physical inactivity of participants by using a question "How much do you exercise? including walking and cycling to and from work" with response alternatives: never exercise, move very little or take occasional walks, exercise now and then, and exercise regularly. Participants were categorized as physically inactive if they selected the first or second response alternative and active otherwise (Raza et al., 2021). Alcohol use was assessed using a modified Cut-Annoyed-Guilty-Eye (CAGE) (O'Brien, 2008) questionnaire. The questions included: (i) Have you felt you should cut down on your drinking? (ii) Have people annoyed you by criticizing your drinking? (iii) Have you felt bad or guilty about your drinking? (iv) Have you had a drink first thing in the morning to steady your nerves or get rid of a hangover? Response options were "yes" or "no". Participants' alcohol consumption was categorized as risky if they reported a minimum of two problem drinking behaviors.

Data on relative humidity at two meters above ground (percentage) and daily precipitation (millimeter) were provided by SMHI from its Gridded Climatology (Andersson et al., 2021) (SMHI-Gridclim) dataset. SMHI-Gridclim is a gridded climatological dataset covering the Nordic countries on a grid with 2.5×2.5 km horizontal resolution. The gridding is performed using optimal interpolation of meteorological observations with statistically downscaled forecast fields as the first guess. The values were provided as daily averages that were used to calculate monthly averages and further three-month and four-month averages corresponding the time periods of the exposure variables. Temperature was highly correlated with global radiation (correlation co-efficient 0.9) therefore it was not used as a covariate.

As Sweden is a long country ($447,425 \text{ km}^2$ from South to North), regional differences in the amount of global radiation exists. To control for this, we formatted a region of residence variable that was based on the geographical location of the residential municipality and categorized as North, Middle, South. Location of the residential municipality, available at Statistics Sweden, is considered sensitive information and was not provided to the authors because of strict confidentiality issues.

2.5. Statistical analyses

For descriptive statistics, missing values from both exposure measures and covariates were dropped in separate datasets to get the total number of individuals who responded to minimum of two surveys from 2012 to 2016 with complete data on covariates in datasets for objective and subjective exposures.

We used fixed-effects methods, also known as within-individual approach, with conditional logistic regression to analyze associations between objective exposure to global radiation and self-reported daylight exposure (≥ 1 h/day vs. < 1 h/day) with symptoms of depression and sleep during winter months from 2012 to 2016. For sensitivity analysis, cumulative exposures for similar time periods were used.

Individuals with minimum two responses were included in the analysis, since the within-individual method requires that the dependent variable must be measured for each individual on at least two occasions, and that the predictor variable, i.e., global radiation and self-reported daylight exposure must have a different value at the two occasions for a substantial portion of the sample. This method uses each individual as his or her own control, thus time-invariant unmeasured individual characteristics like sex, race, parents' child-rearing activities, and genetic makeup, etc., are controlled for by the design (Allison, 2009).

Models were first adjusted for age, region of residence, relative humidity, and precipitation (model 1). The subsequent models were additionally adjusted for number of children under 12 years of age, occupational position, civil status, type of questionnaire, and job strain (model 2); as well as alcohol use, and physical inactivity (model 3). All covariates were used as time-variant. Models using self-reported time spent in daylight were not adjusted for meteorological factors.

To test whether association of global radiation with depressive symptoms and sleep disturbance was affected by self-reported time to daylight exposure, an interaction term was included in the model. Differences by sex, civil status, job strain, alcohol use, and physical inactivity have been associated with symptoms of depression and sleep disturbance (Cui et al., 2021). Occupational position and having small children might affect exposure to global radiation or self-reported daylight exposure (Burns et al., 2021). Therefore, possible effect modification of the association between exposure to global radiation and self-reported daylight exposure with symptoms of depression and sleep by these variables was also investigated by including interaction terms. Effect estimates are expressed as odds ratios (OR) with 95 % confidence intervals (CI). All analyses were performed using SAS 9.4.

3. Results

At baseline, a slight majority of the analysis sample were women (58 %), nearly half had intermediate occupational position (48 %), and most (82 %) were gainfully employed (Table 1). At the time of their first response, 42 % individuals reported to have been exposed to one or more hours of daylight per day between November and January prior to the response time, 13 % reported symptoms of depression and 18 % sleep problems. There were 3107 individuals who had one change in their self-reported daylight exposure between two survey waves and 360 had two changes. Three-month average global radiation changed one time for 11,347 individuals and for 6396 the exposure changed twice, and the same was observed for four-month average exposure period.

Mean value of the three-month average global radiation was slightly lower than the four-month average (Table 2) and demonstrated moderate (0.4) and weak (0.2) correlation with precipitation, respectively.

3.1. Objective exposure

When a participant's responses at two time points were compared, one-unit higher exposure to four-month averaged global radiation was associated with lower odds of reporting depressive symptoms in both model 2 (OR 0.72, 95 % CI 0.55–0.95) and model 3 (OR 0.69, 95 % CI

Table 1

Characteristics of the study participants eligible for the analysis in their first and last measurement point.

	First (N = 15619)	Last (N = 15619)
Self-reported exposure, n (%)		
< 1 h/day	5703 (37)	5347 (34)
≥ 1 h/day	6507 (42)	5197 (33)
Outcomes		
Symptoms of depression	2057 (13)	2070 (13)
Sleep disturbance	2815 (18)	2836 (18)
Covariates		
Sex		
Women	9012 (58)	9012 (58)
Cohabiting	9219 (59)	9348 (60)
Age		
18–35	1813 (11)	828 (5)
36–50	4754 (30)	4118 (26)
51–65	7432 (47)	7174 (46)
> 65	2135 (13)	3499 (22)
Occupational position		
Low	4681 (30)	4535 (29)
Intermediate	7400 (48)	7373 (47)
High	3410 (22)	3571 (23)
Self-employed	128 (1)	140 (1)
Job strain	3159 (20)	3186 (20)
Type of questionnaire		
Employed less than 30 % of full time, unemployed,	2859 (18)	4297 (28)
Employed more than 30 % of full time	12,760 (82)	11,322 (73)
Physically inactive	2806 (18)	1036 (7)
Problem drinking	1018 (7)	2891 (19)
Region of residence		
North Sweden	953 (6)	1897 (12)
Middle Sweden	1894 (12)	945 (6)
South Sweden	12,772 (82)	12,777 (82)

Table 2

Descriptive statistics of meteorological variables for the survey years.

Variables	Survey years		
	2012	2014	2016
Three-month average ^a	Mean (SD) ^c	Mean (SD)	Mean (SD)
Radiation	1.1 (0.3)	1.1 (0.3)	1.2 (0.3)
Rain	2.0 (0.7)	2.2 (0.8)	2.2 (1.1)
Temperature	1.5 (2.1)	1.1 (2.6)	0.7 (2.8)
Humidity	89.7 (1.6)	88.3 (1.7)	89.1 (1.9)
Four-month average ^b			
Radiation	1.7 (0.4)	1.4 (0.4)	1.7 (0.3)
Rain	1.9 (0.7)	2.2 (0.8)	2.0 (1.0)
Temperature	0.2 (2.2)	1.2 (2.3)	0.4 (2.7)
Humidity	88.0 (1.6)	89.3 (1.6)	88.9 (1.9)

^a November-January; ^b November-February; ^c SD, Standard deviation.

0.52–0.91). These findings were confirmed when using four-month cumulative exposure (model 2: OR 0.92, 95 % CI 0.86–0.99; Model 3: OR 0.91, 95 % CI 0.85–0.98; see Supplemental Table 1). Risk estimates for three-month averaged exposure window were positive in all models, but the associations were not statistically significant (fully adjusted model 3: OR 1.23, 95 % CI 0.66–2.27; see Table 3).

One unit increase in three-month average global radiation was associated with lower odds of sleep disturbance in the fully adjusted model (OR 0.60, 95 % CI 0.35–0.99). However, the estimates of four-month averaged global radiation were in the opposite direction and the association was not significant (Table 3). These results were confirmed in sensitivity analysis where cumulative exposures were used (Supplemental Table 1).

No effect modification by self-reported exposure to daylight, sex, children at home, civil status, occupational position, job strain, alcohol use, or physical inactivity was observed (P-values for interaction larger than 0.05 with both 3-month and 4-month exposures).

Table 3
Odds Ratios for one MJ/m² increase in three-month^a and four-month^b averaged global radiation and symptoms of depression and sleep disturbance.

	Odds Ratio (95 % Confidence Interval)	
	Three-month average	Four-month average
<i>Model 1^c</i>		
Symptoms of depression	1.29 (0.74–2.24)	0.80 (0.62–1.03)
Sleep disturbance	0.73 (0.46–1.18)	1.14 (0.92–1.42)
<i>Model 2^d</i>		
Symptoms of depression	1.24 (0.68–2.27)	0.72 (0.55–0.95)
Sleep disturbance	0.60 (0.36–1.00)	1.14 (0.91–1.44)
<i>Model 3^e</i>		
Symptoms of depression	1.23 (0.66–2.27)	0.69 (0.52–0.91)
Sleep disturbance	0.60 (0.35–0.99)	1.11 (0.88–1.41)

^a November–January; ^b November–February; ^c Adjusted for age, rain, region of residence, and humidity same averaged months as exposure; ^d Model 1 + number of children under 12 years of age, individual socioeconomic status, civil status, type of questionnaire, and job strain; ^e Model 2 + alcohol use, and physical inactivity.

3.2. Subjective exposure

When individuals' self-reported exposure to daylight was ≥ 1 h per day during winter months they were less likely to report depressive symptoms (OR 0.72, 95 % CI 0.60–0.82) compared to time when their exposure was < 1 h (Table 4). Risk estimates for sleep disturbance were in the same direction, but the associations were not significant (Table 4). Among participants who had children younger than 12 years of age the association was stronger (OR 0.56, 95 % CI 0.38–0.82) compared to participants who had older or no children at home (OR 0.81, 95 % CI 0.66–1.00, P-value for interaction 0.04). No effect modification by sex, civil status, occupational position, job strain, alcohol use, or physical inactivity was observed (P-values for interaction larger than 0.05).

4. Discussion

We examined within-individual associations between global radiation and self-reported time spent in daylight during winter months and self-reported symptoms of depression and sleep disturbance. We observed that higher four-month average exposure to global radiation was associated with lower odds of reporting symptoms of depression. Similar relationship was observed for self-reported time spent in daylight, such that participants who reported being exposed to daylight one hour or more per day were less likely to report depressive symptoms compared to time when their exposure was less than an hour. Participants who had children younger than 12 years of age had lower odds of reporting symptoms of depression compared to participants with older or no children when exposed to daylight one or more hour per day. We

Table 4
Odds Ratios for associations between time weighted subjective exposure of ≥ 1 vs. < 1 h/day daylight between November and January and symptoms of depression and sleep disturbance.

Outcomes	Odds Ratio (95 % Confidence Interval)
	≥ 1 vs. < 1 h/day
<i>Model 1^a</i>	
Symptoms of depression	0.71 (0.60–0.84)
Sleep disturbance	0.91 (0.79–1.05)
<i>Model 2^b</i>	
Symptoms of depression	0.71 (0.60–0.84)
Sleep disturbance	0.93 (0.81–1.07)
<i>Model 3^c</i>	
Symptoms of depression	0.72 (0.60–0.82)
Sleep disturbance	0.93 (0.81–1.08)

^a Adjusted for age and sex; ^b Model 1 + number of children under 12 years of age, individual socioeconomic status, civil status, type of questionnaire, and job strain; ^c Model 2 + alcohol use, and physical inactivity.

further observed protective effect of three-month average global radiation on sleep disturbance, however, these associations were not confirmed when self-reported time spent in daylight was used. The results of sensitivity analyses where cumulative exposures were used were in line with the main findings.

Existing literature on the associations between global radiation or sunlight/sunshine duration and depression is scarce, and the findings have been inconsistent (Kent et al., 2009; Kim et al., 2021; Komulainen et al., 2022; Sarraan et al., 2017; Son and Shin, 2021). A Korean nested case-control study measured exposure as duration of sunlight, and observed that the long-term (1 to 24-month average) shortened duration (-1 h) of sunlight was associated with increased risk of depression (Kim et al., 2021), while the association was not observed at shorter time intervals. A study from the same region using time series data investigated cumulative 1-month sunlight exposure and contrarily observed 1-month cumulative exposure to low amount of sunlight had significant effect in reducing depression hospital visits in the months of January, March, and May (Son and Shin, 2021). A study from the Netherlands included participants with seasonal affective disorder and collected weekly data in winter seasons for seven years. They observed protective effect of one week lagged exposure to global radiation on depressive symptoms, however, the opposite was observed for the duration of exposure to sunlight (Sarraan et al., 2017). A study from Finland did not observe association between 12-month exposure to global radiation and total number of depressive symptoms, but in symptom specific analyses participants exposed to higher levels of solar radiation were less likely to report suicidal thoughts (Komulainen et al., 2022).

Our finding that there was a significant association between global radiation during wintertime and symptoms of depression echoed the majority of the previous studies (Kent et al., 2009; Kim et al., 2021; Komulainen et al., 2022; Sarraan et al., 2017), nevertheless, differences particularly in the geographical location of countries and its impact on the amount of sunlight during different seasons makes direct comparison difficult. Our study had an advantage of using both the self-reported time spent in daylight and objective global radiation measurements for the same time periods. More importantly, results of the two exposure measures were aligned. The findings of our self-reported time spent in daylight are also in line with previous studies that reported cross-sectional and longitudinal associations between time spent in daylight and lower odds of depressive disorders^{7,8}, although they did not focus on wintertime.

Other factors, than location of the study, which might explain the discrepancies in the limited literature, are 1) different exposure measures, i.e., self-reported duration of sunshine/sunlight (Kim et al., 2021; Sarraan et al., 2017) or objective measures or global solar radiation (Kent et al., 2009; Komulainen et al., 2022; Son and Shin, 2021); 2) different average periods from short-term exposure of one day to two weeks (Kent et al., 2009; Kim et al., 2021; Sarraan et al., 2017; Son and Shin, 2021) to long-term exposure ranging from 1-month to one-year time period (Kim et al., 2021; Komulainen et al., 2022; Son and Shin, 2021); 3) varying study populations and different techniques of assessing outcomes (i.e., self-reported or health registers); and 4) different study designs, sets of controlled confounders, and statistical methods.

The benefits of daylight against depressive symptoms have been explained by several plausible biological mechanism. First, light exposure has been found to decrease the circulating cortisol concentration, a key stress hormone, and to help in regulating the cortisol circadian rhythm which decreases the risk of depression (Hadlow et al., 2014). Further, a study on rhesus monkeys reported that primates with longer exposure to sunlight had lower concentrations of cortisol compared to those exposed to sunlight for shorter time (Feng et al., 2019). Second, changes in serotonin metabolism in the brain have been suggested to play a causal role in depression. Sunlight and global radiation have been found to influence the rate of serotonin production in brain (Lambert et al., 2002). Third, less exposure to sunlight decreases the production of vitamin D that has been associated with the pathogenesis and

seasonality of depression (Geng et al., 2019). Last, light exposure facilitates cerebral blood flow and regulates the circadian rhythms which may have beneficial effects on mental health outcomes (Germain and Kupfer, 2008; Matthew et al., 1996).

In addition to symptoms of depression, we examined the association between exposure to global radiation and sleep problems and observed that a higher three-month average exposure was associated with a lower likelihood of sleep problems. The estimates of cumulative exposure over three-month period and self-reported time spent in daylight within the same period were in the same direction, however, the associations were not statistically significant. A study from Finland using the same assessment criteria for sleep and with similar Nordic climatic conditions reported a positive effect of sunlight exposure on sleep in two-month average period (Elovainio et al., 2022). A study from UK using self-reported time spent in daylight with median 2.5 h of time spent outdoors (similar trend in summer and winter) reported that a greater time spent in outdoor light was associated with a lower frequency of insomnia symptoms and tiredness (Burns et al., 2021).

Exposure to light drives the synchronization of human circadian rhythms and is thus crucial in terms of sleep (Wright et al., 2013). The timing of light exposure has different impact on circadian rhythms and mistimed light exposures disrupts the rhythm and leads to sleep problems (Wright et al., 2013; Khalsa et al., 2003). It has been observed that morning exposure to sunlight shifts the rhythm earlier, while evening or night exposures to light shifts rhythm later (Khalsa et al., 2003). This is reflected in our results, and considering the geographical location of Sweden on the Northern latitudes of 55 to 69 degrees, days in February give longer exposure to daylight in the afternoon and evening hours compared to before noon, and thus the timing of light exposure may interfere with the quality of sleep (Giuntella and Mazzonna, 2019).

In the context of climate change these findings are important particularly for countries in the Northern latitudes. In these areas snow cover has decreased already since 1950s (Masson-Delmotte et al., 2021) and further warming means that precipitation is more often water than snow. Together with increasing precipitation (Masson-Delmotte et al., 2021) and cloudiness this means that the amount of global radiation is likely to decrease (Ruosteenoja and Jylhä, 2021). According to our findings it is thus likely that mental health problems may become more prevalent if preventive actions are not taken. Any actions to mitigate climate change is one thing, but the impacts from mitigation efforts are slow. On the other hand, health promotion can take place at any time. For example, winter-time bright light therapy is one option that can be administered at home or at working place in the morning. Another option is fitness exercise that can be done at home, indoors or outdoors, or as a commuting exercise in the morning as well as in the afternoon. Both options are known to improve mood and sleep as such (Amiri et al., 2021; Chambe et al., 2023; Heissel et al., 2023; Reis et al., 2023) or in combination (Leppämäki et al., 2002), thereby favoring countermeasures against climate change.

There are some limitations to this study. One is that the outcomes were self-reported at one time point in the spring few months later than the exposure period, which may not correspond with the actual time lag between exposure to wintertime light and the occurrence of depressive symptoms. We used information on residential municipality to link health data with global radiation that may have led to some exposure misclassification. While we controlled for several known or possible confounding variables, and the fixed-effects design controls for time-invariant factors such as genetics, we cannot rule out potential unmeasured or residual confounding. Also, our data is from a cohort mainly consisting working population in which loss to follow-up cannot be avoided, and the so-called healthy worker bias may have affected the effect estimates towards the null.

The major strength of our study was use of repeated within-individual measurements to examine whether change in exposure to global radiation or self-reported exposure to daylight was associated with symptoms of depression and sleep problems. We were also able to

use both objective and subjective measures for the exposure, that indicated similar associations, providing further support for the observed associations. Our study population was geographically representative of the working Swedish population, and the survey data enabled us to control for several possible confounding variables.

5. Conclusions

These findings suggest that higher exposure to daylight during winter may contribute to decrease in symptoms of depression.

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Author's contribution

Auriba Raza was involved in acquiring funding, data, and study design; prepared the data for analyses and performed all statistical analyses; involved in interpretation of the results; drafted manuscript, compiled and addressed co-authors' comments. Timo Partonen was involved in the study design, interpretation of the results, and critically reviewed the manuscript. Linda M Hansson and Hugo Westerlund were acquiring funding for survey data collection and lead the survey data collection and management, they critically reviewed the manuscript. Erik Engström and Magus Asp provided meteorological data and expert advice on modeling of the data, and they critically reviewed the manuscript. Jaana I. Halonen designed the study, acquired funding and data for the study, involved in interpretation of the results, critically reviewed the manuscript at different stages.

Declaration: AI was not used in the writing process.

CRedit authorship contribution statement

Auriba Raza: Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. **Timo Partonen:** Conceptualization, Writing – review & editing. **Linda Magnusson Hanson:** Data curation, Writing – review & editing. **Magus Asp:** Data curation, Writing – review & editing. **Erik Engström:** Data curation, Writing – review & editing. **Hugo Westerlund:** Data curation, Writing – review & editing. **Jaana I Halonen:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envint.2023.108413>.

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