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Associations of long-term solar insolation with specific depressive symptoms: Evidence from a prospective cohort study

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ABSTRACT

Evidence suggests that sunlight counteracts depression, but the associations of long-term sunlight exposure with specific symptoms of depression are not well known. We evaluated symptom-specific associations of average 1-year solar insolation with DSM-5 depressive symptoms in a representative cohort of Finnish adults. The sample included 1,845 participants from the Cardiovascular Risk in Young Finns Study with data on DSM-5 depressive symptoms, place of residence and covariates. Daily recordings of global solar radiation were obtained from the Finnish Meteorological Institute. Each participant's residential zip code on each day one year prior to the assessment of depressive symptoms was linked to the solar radiation data, and 1-year average daily solar insolation was calculated. Associations of the average 1-year solar insolation with depressive symptoms were assessed with linear and logistic regression analyses adjusting for season, sex, age, as well as individual- and neighborhood-level socioeconomic characteristics. Average daily solar insolation over one year prior to the depressive symptom assessment was not associated with the total number of depressive symptoms reported by participants. In symptom-specific analyses, participants exposed to higher levels of solar insolation in their residential neighborhood were less likely to report suicidal thought (OR = 0.61, 95% CI, 0.39–0.94), and more likely to report changes in appetite (OR = 1.24, 95% CI, 1.00–1.54), changes in sleep (OR = 1.30, 95% CI, 1.06–1.59) and feelings of worthlessness/guilt (OR = 1.33, 95% CI = 1.07–1.65). These findings suggest that solar insolation may contribute to symptom-specific differences in depression. Studies in other populations residing in different geographical locations are needed.

1. Introduction

Several lines of evidence suggest that sunlight counteracts depression. Seasonal variation in sunlight has been implicated in the pathophysiology of mood disorders (Wehr and Rosenthal, 1989), especially in that of seasonal affective disorder (SAD) which is characterized by recurrent depressive episodes in the fall and winter with remission in spring and summer (Magnusson, 2000; Partonen and Lönnqvist, 1998). Evidence also suggests that aberrant light, disturbances in the light-dark cycle and disrupted circadian rhythms have a role in the etiology of depressive disorders (Walker et al., 2020). Bright light therapy is considered as an effective treatment for SAD (Westrin and Lam, 2007),

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and some evidence also suggests light treatment is appropriate for non-seasonal major depressive disorder (Lam et al., 2016). Studies among hospitalized patients with depression have reported that greater amounts of daylight may expedite remission, since patients located in hospital rooms with greater exposure to daylight have been observed to be discharged sooner (Beauchemin and Hays, 1996; Canellas et al., 2016; Gbyl et al., 2016). The exact mechanisms explaining the antidepressant properties of light are unknown, but they are hypothesized to involve successful resynchronizing of disrupted circadian rhythms and restoring optimal neurotransmitter function (LeGates et al., 2014; Oldham and Ciraulo, 2014; Walker et al., 2020).

While previous evidence suggests that a greater exposure to light counteracts depression, epidemiological studies in the general population have observed mixed findings in terms of sunlight exposure and depression. In particular, studies assessing relatively short-term sunlight exposures – from 1 to 14 days – have not found consistent evidence supporting an association between sunlight and depression (Kerr et al., 2013; Kim et al., 2021). However, other studies suggest that a longer-term exposure to sunlight is relevant in the pathophysiology of depression. For instance, a matched case-control study of over 500,000 depressed and non-depressed individuals in Korea observed that a longer-term exposure to a shortened daily sunshine duration was associated with depression, while the association was not observed at shorter time intervals (Kim et al., 2021). Another study observed that a greater level of solar insolation on average over one year was associated with a lower prevalence of SSRI-treated disorders, but not with disorders not treated by SSRIs (Wortzel et al., 2019). An Irish study of 8,027 participants observed that people living in areas with a greater 30-year average of daily hours of sunshine experienced fewer depressive symptoms than people living in areas with lower averages of daily sunshine (O'Hare et al., 2016). In contrast, a similar-sized study in a different climate zone in Spain found the opposite: a 30-year average of daily hours of sunshine was associated with a greater incidence of depression (Henríquez-Sánchez et al., 2014).

However, depression is a heterogeneous disorder characterized by multiple distinct symptoms which can form unique combinations within individuals. Different symptoms of depression have been shown to differ from each other in terms of the etiology, risk factors as well as psychosocial outcomes and prognosis (Fried and Nesse, 2015), and symptom-level research into depression is needed to further elucidate this heterogeneity. Although it is possible that sunlight exposure is differently associated with specific symptoms of depression, studies are sparse on the associations of long-term sunlight exposure with specific symptoms of depression.

Here, we linked meteorological data to accurate residential data over one year to assess the associations of long-term exposure to solar insolation with specific depressive symptoms in a representative sample of Finnish adults. Finland is a Northern European country extending 1,200 km from north to south (60–70° N), where the levels of solar insolation differ considerably across regions.

2. Methods

2.1. Study sample

The Cardiovascular Risk in Young Finns study is a prospective multicenter cohort study on the precursors of atherosclerosis among Finnish people (Raitakari et al., 2008). The initial sample included 3,596 participants aged 3–18 years in 1980. In this study, we used data from the 2010–2012 data collection phase. We included 1,963 participants who had data on the date of the outcome (depressive symptoms) assessment in the 2010–2012 data collection phase, and data on their residence each day one year prior to the outcome assessment date and on the outcome assessment date (365 days). Of these, we excluded 118 participants due to missing data on individual-level or neighborhood-level socioeconomic factors and depressive symptoms, which yielded a final sample of 1,845 participants. The study was conducted according to the Declaration of Helsinki as revised in 1989 and was approved by the Ethics Committee of the Hospital District of Southwest Finland. All participants gave a written informed consent after the nature of the study procedures had been fully explained.

2.2. Measures

The DSM-5 depressive symptoms were derived from questionnaire self-reports to the 21-item Beck Depression Inventory (BDI-II), where participants rate the severity of 21 depressive symptoms experienced in the past two weeks on scales ranging from 0 (symptom absent) to 4 (very severe). We assessed all nine symptoms included in the DSM-5: sad/depressed mood, diminished interest/pleasure, changes in appetite, changes in sleep, agitation, fatigue/loss of energy, worthlessness/guilt, problems concentrating/indecisiveness, and suicidal thought. The responses to these nine symptoms were dichotomized into symptom present vs. absent (coded as 1 vs. 0).

Participants' residential history was obtained from Statistics Finland. Meteorological data on sunlight were obtained from the Finnish Meteorological Institute. Spatial mean values of 10 km × 10 km gridded daily data on global solar radiation (MJ/m^2) were calculated for each residential zip code area (Aalto et al., 2013). Each participant's residential zip code on each day one year prior to the outcome assessment and on the day of the outcome assessment (365 days) was linked to the solar radiation data, and the average 1-year daily exposure to global solar radiation was calculated based on the exact residential location of the participant on each day during the 1-year follow-up.

Seasons (winter (December–February), spring (March–May), summer (June–August) and fall (September–November)) were determined based on the date of the outcome assessment. Educational attainment (highest level of educational attendance or completed education) was measured through questionnaire self-reports in 2011, categorized into four ascending groups: primary and lower secondary education, upper secondary education, Bachelor's degree program or equivalent, Master's degree program or higher. Three neighborhood-level socioeconomic characteristics in each zip code area were obtained from the records of Statistics Finland (Paavo postal code area statistics) – percentage of adult residents with a college degree, percentage of unemployed adult residents and mean income per resident – and linked to the participants based on their residential history.

2.3. Statistical analysis

The associations of the 1-year average daily exposure to solar insolation with the total number of DSM-5 depressive symptoms were assessed with linear regression analysis adjusting for the season of the outcome assessment, sex and age. This analysis was further adjusted for individual-level educational attainment as well as for the percentage of residents with a college degree in the zip code area, the percentage of unemployed residents in the zip code area, and the mean income per resident in the zip code area. The associations of 1-year average daily exposure to solar insolation with the presence of each DSM-5 depressive symptom were assessed in a series of logistic regression analyses (separate models for each outcome symptom), first controlling for season, sex and age, and then additionally for individual-level educational attainment, the percentage of residents with a college degree in the zip code area, the percentage of unemployed residents in the zip code area and the mean income per resident in the zip code area.

3. Results

Table 1 shows the sample characteristics. There were 1028 (56%) women, the mean age was 41.8 years (SD = 5.0). The variation in average daily solar insolation across different zip code areas in Finland in 2011 is illustrated in Fig. S1. On average, the participants reported the

Table 1
Characteristics of 1,845 participants from the Cardiovascular Risk in Young Finns Study in 2011.

	Mean (SD)	N [%]
Age	41.8 (5.0)	
Sex (women)		1028 [56%]
Season of outcome assessment		
Winter		579 [31%]
Spring		612 [33%]
Summer		228 [12%]
Fall		426 [23%]
Individual-level educational attainment		
Primary or lower secondary		61 [3%]
Upper secondary		1058 [57%]
BA		396 [24%]
MA or higher		330 [18%]
Educational attainment in zip code area	10.5 (3.5)	
Unemployment in zip code area	4.9 (1.8)	
Mean income in zip code area (EUR)	23488.5 (4162.2)	
Radiation (MJ/m^2)	9.4 (0.5)	
Total number of depressive symptoms	2.6 (2.5)	
Sad/depressed mood		294 [16%]
Diminished interest/pleasure		584 [32%]
Changes in appetite		640 [35%]
Changes in sleep		856 [46%]
Agitation		444 [24%]
Fatigue/loss of energy		855 [46%]
Worthlessness/guilt		617 [33%]
Problems concentrating/indecisiveness		467 [25%]
Suicidal thoughts		104 [6%]

Abbreviations: BA, Bachelor's degree program or equivalent; MA, Master's degree program. Educational attainment and unemployment in zip code area were calculated based on the percentage of adult residents with a college degree and percentage of unemployed adult residents the in zip code area.

presence of 2.6 (SD = 2.5, range 0–9) DSM-5 depressive symptoms. The average total number of DSM-5 depressive symptoms as well as the BDI-II sum scores were greater among participants with depressive symptom assessment in the fall and winter compared to spring and summer (Table S1, Table S2). The average daily exposure to solar insolation over one year prior to the depressive symptom assessment was not associated with the total number of depressive symptoms when adjusting for season, sex and age (b = 0.01, 95% CI, −0.22, 0.23). This result remained after additional adjustment for the percentage of residents with college degree in the zip code area, the percentage of unemployed residents in the zip code area, the mean income per resident in the zip code area, and the individual-level educational attainment (b = 0.23, 95% CI, −0.02, 0.47).

Fig. 1 presents the associations of the 1-year average daily exposure to solar insolation with the specific symptoms of depression. In models adjusted for season, sex and age, exposure to higher levels of solar insolation was associated with a lower probability of suicidal thoughts. After additional adjustment for the percentage of residents with a college degree in the zip code area, the percentage of unemployed residents in the zip code area, the mean income per resident in the zip code area, and the individual-level educational attainment, exposure to higher levels of solar insolation was associated with a lower probability of suicidal thoughts, and a higher probability of changes in appetite, changes in sleep and feelings of worthlessness/guilt.

4. Discussion

In this study of 1,845 people residing in Finland, we found that long-term exposure to solar insolation was associated with specific symptoms of depression. Participants who were exposed to higher levels of solar insolation in their residential neighborhood over one year of follow-up were less likely to report suicidality, and more likely to report changes in sleep or appetite and feelings of worthlessness/guilt at the end of the

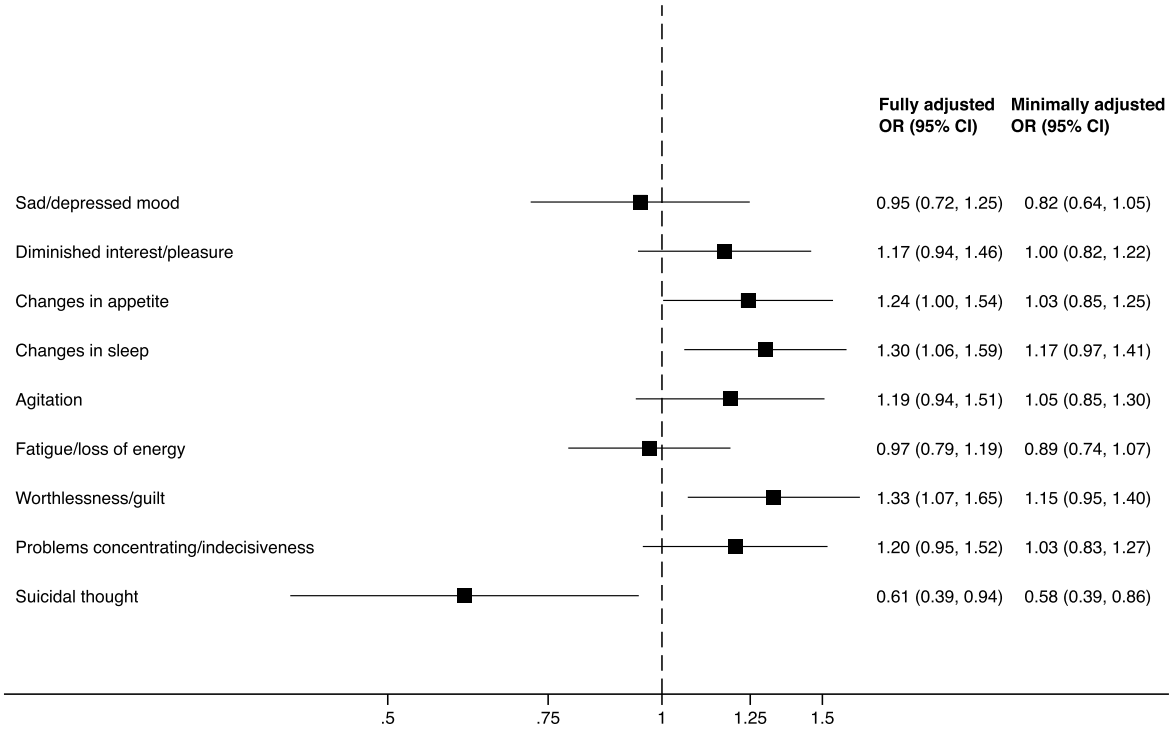

Fig. 1. Adjusted odds ratios for the associations of the 1-year average daily exposure to solar insolation and DSM-5 depressive symptoms
Abbreviations: OR, odds ratio.
Minimally adjusted models adjusted for season, sex and age. Fully adjusted models additionally adjusted for individual-level educational attainment, the percentage of residents with a college degree in the zip code area, the percentage of unemployed residents in the zip code area, and the mean income per resident in the zip code area. Estimates plotted in the figure are from the fully adjusted models.

follow-up. There was no evidence for an association of the long-term exposure to solar insolation with the total number of depressive symptoms.

Previous observational studies have yielded inconsistent findings in terms of sunlight exposure and depression. Studies assessing relatively short-term sunlight exposures did not observe any evidence of an association of sunlight with depression (Kerr et al., 2013; Kim et al., 2021). Most previous studies assessing sunlight exposure over longer time periods have reported a smaller risk of depression or fewer depressive symptoms among people receiving greater amounts of sunlight (Kim et al., 2021; O'Hare et al., 2016; Wortzel et al., 2019), but at least one study in Spain observed the opposite – a greater risk of depression at a greater sunlight exposure (Henríquez-Sánchez et al., 2014). However, long-term exposure to sunlight differs greatly between different latitudes. The inconsistent findings observed in prior studies may partially reflect differences between geographical locations.

Moreover, depression is a heterogeneous condition, and previous evidence has shown that different symptoms of depression have distinct etiology, risk factors and consequences (Fried and Nesse, 2015). We expected that the associations of solar insolation with depression may also be symptom-specific. In line with this hypothesis, we observed evidence for symptom specificity – for instance, people exposed to higher levels of solar insolation were less likely to report suicidal ideation. Previous evidence on sunlight in relation to deaths from suicide suggests a bimodal effect of sunlight. While a greater exposure to sunlight at short time lags has been associated with more suicides, sunlight exposure over longer time intervals has been found to be protective against suicidality (Papadopoulos et al., 2005; Vyssoki et al., 2014). It has been hypothesized that among depressed patients, an increase in sunlight exposure may first trigger improvement in motivation thus heightening the immediate suicide risk, and only subsequently contribute to improvement in mood to protect from the risk of suicide – a mechanism similar to one proposed to occur in antidepressant treatment with prescription drugs (Papadopoulos et al., 2005). Although our findings are in line with previous evidence suggesting a protective association of long-term sunlight exposure with suicide, they do not fully support this hypothesis. Our participants exposed to higher levels of solar insolation were also more likely to experience feelings of worthlessness/guilt, and we found no association of solar insolation with other affective symptoms of depression such as sad/depressed mood or anhedonia. It is yet possible that the proposed mechanism is particularly prominent among people with clinical depression, and that therefore it did not manifest in our analysis in a non-clinical sample.

We also found some evidence that people exposed to higher levels of solar insolation were more likely to report changes in sleep and appetite. These findings were only observed after controlling for season, sex and age, as well as individual-level and neighborhood-level socioeconomic characteristics, which we hypothesized to be confounders to the association of residential sunlight exposure with depression. Sunlight may be involved in appetite regulation through behavioral or physiological pathways, for instance, by affecting physical activity and thus energy consumption (Tucker and Gilliland, 2007), or by influencing the production of vitamin D (Major et al., 2008; Nair and Maseeh, 2012) or that of serotonin (Lambert et al., 2002), both of which are known to have a role in appetite regulation. Although sunlight is the primary environmental determinant of the human circadian rhythms and the sleep-wake schedule (Dijk and Archer, 2009), the long-term associations of sunlight with sleep are not well understood (Münch et al., 2020). Our finding that solar insolation is associated with changes in sleep aligns with other recent findings in the Young Finns study, suggesting an association of greater long-term natural light exposure with shorter sleep duration and more sleep problems (Elovainio et al., 2021).

Some limitations should be noted. First, our study is an observational study, and therefore our findings do not have a causal interpretation. We used residential information to link data on global solar radiation to participants. Due to the complex relationships between the individual-level and neighborhood-level factors as well as the climate, local and regional weather conditions, the evaluation of the associations of climatic factors with mental health outcomes is not straightforward. Although we controlled for a robust set of variables with known or hypothesized associations with the exposures and outcomes, we cannot rule out potential unmeasured or residual confounding. Also, our data is from a long-running cohort study in which loss to follow-up cannot be avoided, and a selective loss to follow-up may have affected the validity of our findings. In our study, the distribution of the season of the outcome assessment was somewhat skewed. While seasonal variation has been implicated in the pathophysiology of mood disorders (Magnusson, 2000; Partonen and Lönnqvist, 1998), the assessment of 1-year average daily solar insolation is not sensitive to seasonal variation. However, we controlled for the season of the outcome assessment in all analyses to account for potential confounding arising from differences in the timing of the outcome assessment across study centers located in different regions in Finland. In addition, some DSM-5 symptoms comprise different symptoms collapsed into one category (e.g., insomnia and hypersomnia, appetite loss and appetite gain) which may mask symptom-specific associations, and depressive symptoms assessed through self-reports can be subject to response bias. Finally, our findings are based on a homogeneous population residing in a country in Northern Europe. Given that sunlight exposure is greatly dependent on latitude, our findings do not generalize directly to other populations, especially to those residing in different latitudes. The associations of solar insolation with depressive symptoms may also differ across people – for instance, the associations could be more pronounced among people experiencing seasonal affective disorder. Further research is needed to evaluate potential effect modification.

In conclusion, we observed that exposure to higher levels of solar insolation in residential neighborhood was associated with specific symptoms of depression. These findings add to the literature on depression heterogeneity, suggesting that also climatic exposures may contribute to symptom-specific differences in the etiology of depression. Further studies are needed to assess these findings in different populations residing in different geographical locations.

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Author statement

Kaisla Komulainen: Conceptualization, Data curation, Methodology, Software, Writing- Original draft preparation, Visualization **Christian Hakulinen:** Conceptualization, Methodology, Writing- Reviewing and Editing **Jari Lipsanen:** Methodology, Writing- Reviewing and Editing **Timo Partonen:** Writing- Reviewing and Editing, Funding **Laura Pulkki-Råback:** Writing- Reviewing and Editing **Mika Kähönen:** Supervision, Resources, Writing- Reviewing and Editing **Marianna Virtanen:** Writing- Reviewing and Editing, Funding **Reija Ruuhela:** Data curation, Writing- Reviewing and Editing, Funding **Olli Raitakari:** Supervision, Resources, Writing- Reviewing and Editing **Marko Elovainio:** Conceptualization, Methodology, Supervision, Writing- Reviewing and Editing, Funding.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2022.05.038.

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