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The association between time spent outdoors during daylight and mortality among participants of the Adventist Health Study 2 Cohort

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Background: Prolonged exposure to sunlight increases the risk of skin cancer. However, multiple sunlight-related health benefits have been identified. The overall effect of sun exposure on mortality remains inconclusive. This study investigated the association between daylight exposure and mortality (all-cause and cause-specific: cancer, cardiovascular disease (CVD), and noncancer non-CVD mortalities).

Methods: This study utilized the Adventist Health Study (AHS) 2 cohort of North America. Sun exposure was defined using time spent outdoors during daylight in warmer and cooler months. Mortality outcomes were identified through 2015. Multivariable Cox regression was used to examine the association between sun exposure and mortality.

Results: This study included 83,205 AHS-2 participants enrolled between 2002 and 2007. We observed nonlinear (reverse J-shaped) associations between time outdoors in warmer months and the risks of all-cause, CVD, and noncancer non-CVD mortalities. Compared with spending 30 min/day during daylight in warmer months, spending 2 hours/day was associated with a lower risk of all-cause (hazard ratio: 0.90; 95% confidence interval = 0.86, 0.93), CVD (0.89; 0.83, 0.95), and noncancer non-CVD mortalities (0.83; 0.78, 0.89), but was not significantly associated with cancer mortality risk (1.02; 0.93, 1.13) after adjusting for physical activity and important confounders. All associations were weaker with the time spent outdoors in cooler months.

Conclusions: Moderate time outdoors in daylight during warmer months could be associated with lower risks of all-cause, CVD, and noncancer non-CVD mortality; however, there was no clear evidence of an association with cancer mortality. Epidemiological studies need to investigate the balance between sun exposure's health benefits and risks.

Keywords: Time outdoors; Daylight; Sunlight; Sun exposure; Mortality

Background

Public health messages regarding sun exposure have been mixed. Prolonged exposure to solar ultraviolet radiation (UVR) increases the risk of skin cancer in all skin tones, but mostly among whites.[1] Cumulative and intermittent exposure to solar UVR is associated with an increased risk of nonmelanoma skin cancers. In contrast, intermittent exposure to high-intensity solar radiation is associated with a higher risk of melanoma skin.[2] The International Agency for Research on Cancer concluded that there is sufficient evidence that solar radiation is carcinogenic to humans.[3] The general population is advised to limit prolonged sun exposure and follow photoprotective behaviors.[1] However, benefits of moderate sun exposure have also been reported. Solar radiation plays a significant role in vitamin D photosynthesis in the skin,[4] regulates the circadian rhythm, and may have cardiovascular benefits independent of vitamin D photosynthesis.[5] Consequently, it remains unclear whether the health benefits of sun exposure outweigh its harmful effects.

Previous studies have reported geographical variations in incidence and mortality from multiple cancer types that are higher in regions with lower solar radiation.[6–10] Differences in solar UVR exposure/vitamin D photosynthesis in the skin have been hypothesized to be a potential reason. In addition, seasonal diagnoses of several cancer types have been found to influence

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Data described in the manuscript will be made available upon request, pending application and approval, payment, and other conditions. Requests for data from the Adventist Health Study 2 can be sent to Dr. Gary E. Fraser, Adventist Health Study, Loma Linda University, School of Public Health (e-mail: gfraser@llu.edu). Questionnaires can be found online at adventisthealthstudy.org.

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What this study adds

The association between sun exposure and mortality is inconclusive. Ultraviolet radiation increases the risk of skin cancer; however, sunlight-related multiple health benefits have been reported, such as stimulating vitamin D photosynthesis, regulating the circadian rhythm, and it may have cardiovascular benefits independent of vitamin D. Utilizing data from the AHS-2, a large regionally diverse cohort in North America, this research shed light on the potential health benefits of moderate sun exposure. Self-reported time spent outdoors in daylight during warmer and cooler months enabled the study of seasonal variations in mortality risk by daylight exposure.

disease progression and mortality, which were lower in summer and autumn.[11,12] However, few longitudinal studies have evaluated the impact of sun exposure on mortality.[13–16] Studies conducted in Sweden support an inverse association with all-cause mortality, cardiovascular disease (CVD) mortality, and noncancer non-CVD mortality but not with cancer mortality.[13–15] In these studies, sun exposure was measured based on the annual frequency of sunbathing vacations or swimming, tanning beds, and history of sunburns. These indicators of sun exposure may not accurately measure cumulative exposure but rather episodic exposure to high-intensity solar radiation over time. In contrast, longitudinal studies conducted in the United Kingdom and the United States have reported inconsistent results on the association between ambient UVR based on individuals' residential locations and all-cause, CVD, and cancer mortality.[16,17] None of these studies accounted for the time spent outdoors in the daylight.

This study was conducted to investigate the association between sun exposure using time spent outdoors in daylight and mortality risk (all-cause and cause-specific, namely cancer, CVD, and noncancer non-CVD) in the Adventist Health Study (AHS)-2. This large, regionally diverse cohort provides an opportunity to study the association between daylight exposure and mortality.

Methods

Study population

The AHS-2 is a prospective cohort consisting of approximately 96,000 participants living in the United States and Canada, ages 30 and above, recruited at churches from 2002 to 2007 and followed through 2015. Informed consent was obtained from all participants before enrollment. After recruitment, participants completed a validated lifestyle and health questionnaire. The study consists of about 65% white (non-Hispanic) and 27% black, and 65% females. Further details of AHS-2 are provided elsewhere.[18] This study was approved by the Institutional Review Board of Loma Linda University.

Exclusion criteria

Missing observations (obs) on residential locations (134 obs) and residential locations not in the contiguous USA (9931 obs), body mass index (BMI) less than 15 kg/m^2 or higher than 50 kg/m^2 (3098 subjects), and estimated dietary energy less than 500 kcal/d or greater than 4500 kcal/d (6124 subjects) were excluded. After exclusion, 83,205 participants were included in the final analysis. In sensitivity analyses, participants with the following preexisting chronic diseases were additionally excluded: prevalent cancers, not including nonmelanoma skin cancers, for cancer mortality (6793 subjects); CVD, including ischemic heart disease, congestive heart failure, CVD surgeries (coronary bypass, stent, carotid artery surgery), and stroke for CVD mortality (5853 subjects); chronic obstructive pulmonary diseases (COPD), including asthma, bronchitis, and emphysema for noncancer non-CVD mortality (9996 subjects); and all four chronic diseases from all-cause mortality.

Variables

Exposure

Participants were asked to report the number of hours spent outdoors from 9 AM to 5 PM on typical weekdays and weekends during the warmer and cooler months of the previous year, without specifying whether this time was work-related. The average weekly hours spent outdoors per day were calculated for both warmer and cooler months ([time outdoors in daylight on weekdays × 5 + time outdoors in daylight on weekends × 2]/7) and total (annual) exposure. Equal weights were assigned to the warmer and cooler months.

Outcome

Mortality data were obtained using the National Death Index (NDI) through 31 December 2015. The International Statistical Classification of Diseases, 10th Revision (ICD-10) codes were used to clarify the underlying cause of death as follows: CVD-related deaths were assigned to the ICD-10 starting with letter I; cancer-related deaths were assigned to the ICD-10 starting with letter C; and all other causes of death were categorized as noncancer non-CVD mortalities.

Covariates

Age was the timescale (continuous in years); sex (categorical: women and men); race/ethnicity (categorical: black and non-black); BMI (continuous in kg/m^2); marital status (categorical: single, married, and previously married, including separated, divorced, and widowed); educational attainment (categorical: high school or below, some college, and college graduate or higher); income during the last 12 months (categorical in US dollar/year: ≤20,000; 21,000–50,000; 51,000–100,000; and ≥101,000); geographical region of residence (Categorical: five regions were created based on the annual average solar irradiance[19] in kilojoule/meter^2 [kJ/m^2] of 2005—approximately mid-the recruitment period—using the baseline state of residence [refer to Table 1 footnotes for more details]); dietary patterns of participants using the self-reported frequency for meat consumption per month (categorical: Nonvegetarian [participants who consumed red meat, and/or poultry and fish {consumption of nonfish meat ≥1/month} and vegetarian {all others}]); total vitamin D intake calculated from diets and supplements (continuous in microgram [μg]/day); nuts consumption (continuous in gram [g]/day); exercise (continuous in minutes/week [refer to Table 1 footnotes for definition]); sunscreen use last summer (categorical: hardly ever, partially, and always); smoking status (categorical: never smoked, quit ≥30 years, quit 21–30 years, quit 11–20 years, quit 6–10 years, and quit smoking <5 years or current smokers); alcohol consumption (separate categorical variables for wine, and beer and liquor drinking: never, past user of ≤3 glasses/month, past user of ≥1 glass/week, current user of ≤3 glasses/month, and current user of ≥1 glass/week); menopausal status for women (categorical: yes vs. no); hormone replacement therapy use among postmenopausal women (categorical: never, past, and current); preexisting chronic diseases (categorical: yes vs. no): cancers not including nonmelanoma skin cancer, CVD, COPD, type II diabetes, hypertension, and high blood cholesterol; aspirin use for 2 years in the last 5 years.

Statistical analysis

Descriptive statistics with means and standard deviations (SD) for continuous variables and counts and percentages for categorical variables were calculated using quartiles of time spent outdoors during daylight in warmer months. Multivariable Cox regression was used to examine the association between sun exposure and mortality risk. Attained age was used as the timescale in the Cox model. The survival time of participants was calculated from inclusion to one of the following: mortality, migration outside the contiguous USA, or the current end of outcome follow-up (December 2015), whichever occurred first. For cause-specific hazard ratio (HR), nonevent mortalities were censored as noncases at times of mortality occurrence.[20]

The variables included in the models were selected a priori for their confounding, effect modification potentials, or for being

Table 1.

The baseline characteristics of 83,205 participants of the Adventist Health Study 2 by quartiles of times spent outdoors in warmer months from 9 AM to 5 PM, North America, 2002–2015

	Quartiles of time spent outdoors in warmer months (hour/day)			
Variables	Q1 N = 18377 Mean: 0.7 ± SD: 0.4	Q2 N = 21649 1.7 ± 0.3	Q3 N = 22784 2.9 ± 0.5	Q4 N = 20395 5.5 ± 1.3
Age (year), mean ± SD	58.6 ± 14.4	56.9 ± 14.1	58.1 ± 14.3	59.9 ± 14.2
Body mass index (kg/m^2), mean ± SD	27.3 ± 6.0	27.0 ± 5.7	27.0 ± 5.5	27.1 ± 5.2
Exercise[a] (min/week), mean ± SD	65.6 ± 85.7	77.2 ± 89.0	84.2 ± 96.1	91.5 ± 108.1
Gender, *n* (%)				
Women	14,075 (76.6%)	15,357 (71.0%)	15,152 (66.5%)	9391 (46.1%)
Race/ethnicity, n (%)				
Black	4248 (23.1%)	5213 (24.1%)	6185 (27.2%)	5955 (29.2%)
Education, n (%)				
Bachelor's and above	8525 (46.4%)	9758 (45.1%)	8659 (38.0%)	5768 (28.3%)
Some college	6840 (37.2%)	8307 (38.4%)	9296 (40.8%)	8451 (41.4%)
High school & below	3012 (16.4%)	3584 (16.6%)	4829 (21.2%)	6176 (30.3%)
Income (USD/year), n (%)				
≤20,000	3507 (19.1%)	3858 (17.8%)	4866 (21.4%)	5407 (26.5%)
21,000–50,000	6626 (36.1%)	7958 (36.8%)	9036 (39.7%)	9046 (44.4%)
51,000–100,000	5647 (30.7%)	6781 (31.3%)	6358 (27.9%)	4564 (22.4%)
≥101,000	2597 (14.1%)	3052 (14.1%)	2524 (11.1%)	1378 (6.8%)
Marital status, n (%)				
Single	1286 (7.0%)	1352 (6.3%)	1331 (5.8%)	1177 (5.8%)
Married	12,645 (68.8%)	15,812 (73.0%)	16,520 (72.5%)	15,112 (74.1%)
Previously married	4446 (24.2%)	4485 (20.7%)	4933 (21.7%)	4106 (20.1%)
Baseline geographical regions[b], n (%)				
Region 1	7720 (42.0%)	7888 (36.4%)	7416 (32.6%)	5864 (28.8%)
Region 2	2714 (14.8%)	3129 (14.5%)	3027 (13.3%)	2828 (13.7%)
Region 3	3077 (16.7%)	4130 (19.1%)	4569 (20.1%)	4452 (21.8%)
Region 4	2943 (16.0%)	3826 (17.7%)	4433 (19.5%)	4068 (20.0%)
Region 5	1923 (10.5%)	2676 (12.4%)	3339 (14.7%)	3183 (15.6%)
Smoking status, n (%)				
Never	15,559 (84.7%)	17,989 (83.1%)	18,278 (80.2%)	14,861 (72.9%)
Quit 30 years or more	928 (5.1%)	1128 (5.2%)	1477 (6.5%)	1895 (9.3%)
Quit 21–30 years	693 (3.8%)	879 (4.1%)	1087 (4.8%)	1186 (5.8%)
Quit 11–20 years	577 (3.1%)	796 (3.7%)	868 (3.8%)	1071 (5.3%)
Quit 6–10 years	256 (1.4%)	328 (1.5%)	388 (1.7%)	484 (2.4%)
Quit 1–5 years ago or current smokers	364 (2.0%)	529 (2.4%)	686 (3.0%)	898 (4.4%)
Wine drinking, n (%)				
Never	16,054 (87.4%)	18,411 (85.0%)	19,214 (84.3%)	17,232 (84.5%)
Past user of ≤3 glasses/month	910 (5.0%)	1216 (5.6%)	1298 (5.7%)	1097 (5.4%)
Current user of ≤3 glasses/month	341 (1.9%)	496 (2.3%)	550 (2.4%)	452 (2.2%)
Past user of ≥1 glass/week	820 (4.5%)	1173 (5.4%)	1322 (5.8%)	1339 (6.6%)
Current user of ≥1 glass/week	252 (1.4%)	353 (1.6%)	400 (1.8%)	275 (1.4%)
Beer and liquor drinking, n (%)				
Never	14,339 (78.0%)	16,180 (74.7%)	16,409 (72.0%)	13,467 (66.0%)
Past user of ≤3 glasses/month	1339 (7.3%)	1746 (8.1%)	1901 (8.3%)	1642 (8.1%)
Current user of ≤3 glasses/month	340 (1.9%)	445 (2.1%)	527 (2.3%)	488 (2.4%)
Past user of ≥1 glass/week	2160 (11.8%)	2961 (13.7%)	3535 (15.5%)	4308 (21.1%)
Current user of ≥1 glass/week	199 (1.1%)	317 (1.5%)	412 (1.8%)	490 (2.4%)
Dietary pattern, n (%)				
Vegetarian	10,346 (56.3%)	11,669 (53.9%)	11,494 (50.5%)	9619 (47.2%)
Total vitamin D intake (µg), mean ± SD	5.2 ± 24.1	5 ± 21.1	5.4 ± 22.6	5.5 ± 23.5
Nuts consumption (g), mean ± SD	118.1 ± 132.3	124.2 ± 137.9	128 ± 142.3	131.7 ± 148.0
Sunscreen use last summer, n (%)				
Hardly ever	11,334 (61.7%)	12,235 (56.5%)	13,429 (58.9%)	13,691 (67.1%)
Partially	5051 (27.5%)	7205 (33.3%)	7205 (31.6%)	5084 (24.9%)
Always	1992 (10.8%)	2209 (10.2%)	2150 (9.4%)	1620 (7.9%)
Menopausal status among women, n (%)				
Menopaused	11,352 (80.7%)	11,737 (76.4%)	11,666 (77.0%)	7423 (79.0%)
Hormone replacement therapy[c], n (%)				
Past users	5851 (51.5%)	5801 (49.4%)	5784 (49.6%)	3386 (45.6%)
Curren users	4046 (35.6%)	4358 (37.1%)	4451 (38.2%)	3179 (42.8%)
Diabetes, *n* (%)				
Yes	1667 (9.1%)	1616 (7.5%)	1809 (7.9%)	1798 (8.8%)
Hypertension, n (%)				
Yes	5789 (31.5%)	6087 (28.1%)	6725 (29.5%)	6325 (31.0%)
High blood cholesterol, n (%)				
Yes	5447 (29.6%)	5801 (26.8%)	6313 (27.7%)	5734 (28.1%)

(*Continued*)

Table 1.

(*Continued*)

Variables	Quartiles of time spent outdoors in warmer months (hour/day) Q1 N = 18377 Mean: 0.7 ± SD: 0.4	Q2 N = 21649 1.7 ± 0.3	Q3 N = 22784 2.9 ± 0.5	Q4 N = 20395 5.5 ± 1.3
Aspirin use, n (%)				
Yes	2699 (14.7%)	2821 (13.0%)	3265 (14.3%)	3292 (16.1%)
Previous cancers, n (%)				
Yes	1591 (8.7%)	1672 (7.7%)	1834 (8.1%)	1696 (8.3%)
Previous stroke[d], n (%)				
Yes	303 (1.7%)	282 (1.3%)	309 (1.4%)	357 (1.8%)
Previous CVD[e], n (%)				
Yes	1143 (6.2%)	1078 (5.0%)	1291 (5.7%)	1553 (7.6%)
Previous COPD[f], n (%)				
Yes	2443 (13.3%)	2614 (12.1%)	2735 (12.0%)	2204 (10.8%)
All-cause mortality, n (%)				
Yes	2756 (15.0%)	2498 (11.5%)	2994 (13.1%)	3267 (16.0%)
Cancer mortality, n (%)				
Yes	586 (3.2%)	656 (3.0%)	834 (3.7%)	942 (4.6%)
CVD mortality, n (%)				
Yes	1104 (6.0%)	985 (4.6%)	1138 (5.0%)	1195 (5.9%)
Noncancer non-CVD mortality, n (%)				
Yes	1066 (5.8%)	857 (4.0%)	1022 (4.5%)	1130 (5.5%)

Significance tests of differences (chi-square for categorical variables and ANOVA and Kruskal-Wallis test for continuous variables): *P* values: <0.001 for all variables except cancer (P-value = 0.006).

[a]Exercise was defined as "vigorous activities, such as brisk walking, jogging, bicycling, etc., long enough or with enough intensity to work up a sweat, get your heart thumping, or get out of breath."

[b]Baseline geographic regions were assigned an annual solar irradiance in kJ/m^2 of 2005: Region 1 with solar irradiance >3352–4536 kJ/m^2 included California, Nevada, Utah, Arizona, Colorado, New Mexico, Texas, Louisiana, and Florida; region 2 with solar irradiance >3041–3352 kJ/m^2 included Wyoming, Nebraska, Kansas, Oklahoma, Arkansas, Mississippi, Alabama, Georgia, South Carolina, and North Carolina; region 3 with solar irradiance >2815–3041 kJ/m^2 included Oregon, Idaho, Montana, South Dakota, Iowa, Missouri, Illinois, Kentucky, Tennessee, and Virginia; regions 4 with solar irradiance >2628–2815 kJ/m^2 included Washington, North Dakota, Indiana, Ohio, Pennsylvania, Washington DC, West Virginia, Maryland, Delaware, and New Jersy; region 5 with solar irradiance of 1997–2628 kJ/m^2 included Minnesota, Wisconsin, Michigan, New York, Vermont, Massachusetts, Connecticut, Rhode Island, New Hampshire, and Main.

[c]Among postmenopausal women.

[d]Stroke and carotid artery surgery.

[e]Previous CVD included ischemic heart diseases, congestive heart failure treated in the past 12 months, and cardiovascular surgeries (coronary bypass and stent).

[f]COPD included (asthma, bronchitis, and emphysema).

Q, quartile (Q1 range [0–1.1], Q2 [1.2–2.1], Q3 [2.2–3.7], Q4 [3.8–8.7] hours/day).

risk factors for mortality (refer to the causal diagram, Figure S1; https://links.lww.com/EE/A351 in the Supplementary material). We adjusted the HR of mortality outcomes for major chronic diseases, namely hypertension, diabetes type II, high blood cholesterol, prevalent CVD and stroke, cancers (not including nonmelanoma skin cancer), and COPD. Chronic diseases may confound the relationship between time spent outdoors in daylight and mortality, as individuals with health problems may have spent less time outside for their health condition. The proportional hazard assumption of Cox regression was evaluated using Schöenfeld residuals and log (–log) plots. Our exposure variables did not violate the proportional hazard assumption of Cox regression, but it was violated by the following variables: race and marital status for all-cause mortality and CVD mortality models, race, marital status, and income for noncancer non-CVD mortality, and none for cancer mortality. Therefore, we included the product terms of these variables with the attained age (timescale) in the models.

Continuous variables were evaluated for distribution and outliers. Variables with strong skewness were transformed when needed. Based on prior knowledge of its nonlinear association with mortality, a restricted cubic spline was added to the BMI. Hours spent outdoors were splined with a restricted cubic spline after being log-transformed (log [hours spent outdoors in daylight +1]) for all outcomes. We estimated the HRs of mortality outcomes for the splined continuous exposure variable compared to 30 min (0.5 hour) outdoors as a reference. The results were then used to create Figures 1 and 2.

This study examined whether the association between time spent outdoors in daylight during warmer months and mortality outcomes varied by sunscreen use. The interaction was tested using the likelihood ratio test. Subgroup analysis was performed based on race and sex by restricting the analysis to each subgroup.

In a sensitivity analysis, we estimated the HRs of our outcomes after excluding selected chronic diseases, namely cancers from cancer mortality, CVD and strokes from CVD mortality, and COPD from noncancer non-CVD mortality, and all four diseases for all-cause mortality (Tables S1 and S2; https://links.lww.com/EE/A351) because individuals with health problems could have spent less time outdoors in daylight. In addition, we excluded the first 2 years of follow-up and added a 2-year lag period to account for reverse causation by preclinical diseases. Last, we tested the robustness of our models adjusting for chronic diseases that vary by the outcome, namely prevalent cancers (not including nonmelanoma skin cancer) for cancer mortality, CVD and strokes for CVD mortality, and CVD, strokes, and COPD for noncancer non-CVD mortality (Table S3; https://links.lww.com/EE/A351). Missing data were handled using a guided imputation approach[21] in R Studio using R version 4.2.1. All other analyses were conducted using SAS software, version 9.4 (SAS Institute, Cary, NC). A 2-sided *P* value of less than 0.05 was considered statistically significant.

Results

After a mean follow-up time of 11.1 years (SD: 2.5), there were 11,515 (13.8%) total deaths, 3018 (3.6%) cancer deaths, 4422 (5.3 %) CVD deaths, and 4075 (4.9%) noncancer non-CVD deaths from 83,205 AHS-2 members. Table 1 presents the characteristics of the participants by quartiles of time spent outdoors in warmer months (hours/day) at baseline. Participants in the highest quartile (Q4) spent a mean of 5.5 hours per day (SD: 1.3, range: 3.8–8.7) outdoors from 9 AM to 5 PM, were

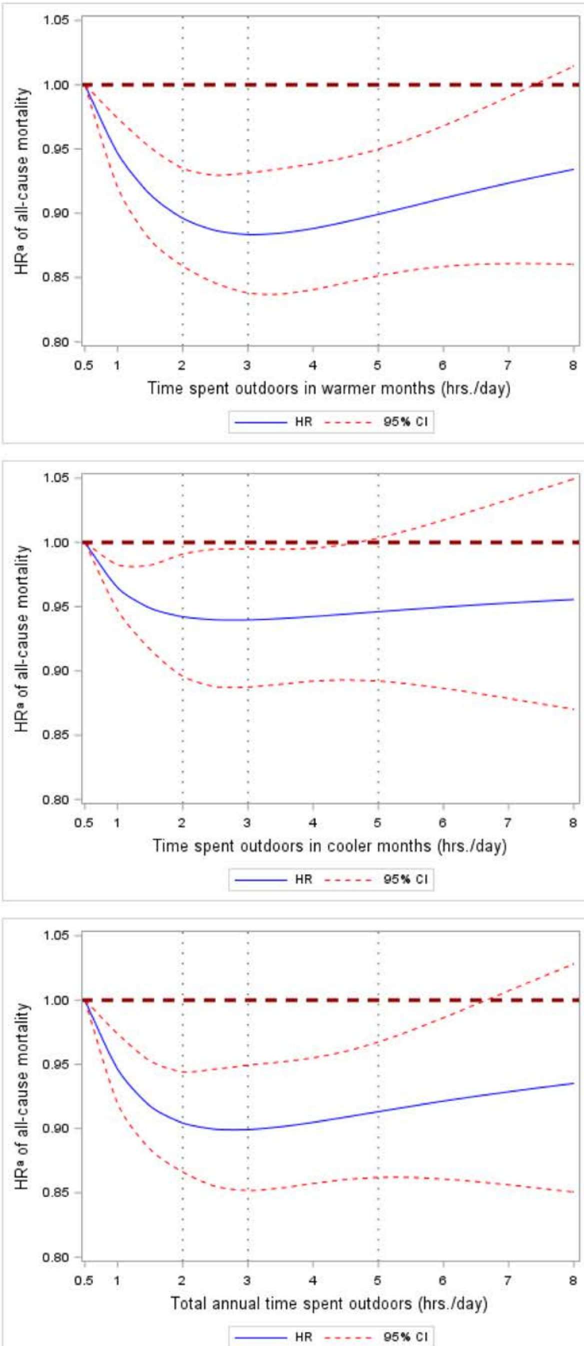

Figure 1. Adjusted hazard ratios of all-cause mortality by time spent outdoors from 9 AM to 5 PM compared with 30 minutes/day among 83,205 participants of the AHS-2 cohort. A, Time spent outdoors during daylight in warmer months. B, Time spent outdoors during daylight in cooler months. C, Total annual time spent outdoors during daylight. [a]HR: hazard ratio of all-cause mortality was calculated using Cox regression adjusted for sex, race/ethnicity, body mass index, exercise, smoking status, alcohol consumption (separate indicators for wine drinking and for beer and liquor drinking), dietary pattern, nut consumption, vitamin D intake from diets and supplements, dietary energy, educational attainment, marital status, female-centered variables (menopausal status and hormone replacement therapy use among menopausal women), household income, geographical regions, preexisting diseases: cancers, cardiovascular disease (ischemic heart disease, congestive heart failure treated in the past 12 months, and surgery [coronary bypass, stent]), stroke and carotid artery surgery combined variable, diabetes type II, hypertension, chronic obstructive pulmonary disease (asthma, bronchitis, and emphysema), high cholesterol, and aspirin use. Reference was defined as 30 min/day outdoors from 9 AM to 5 PM for all the models.

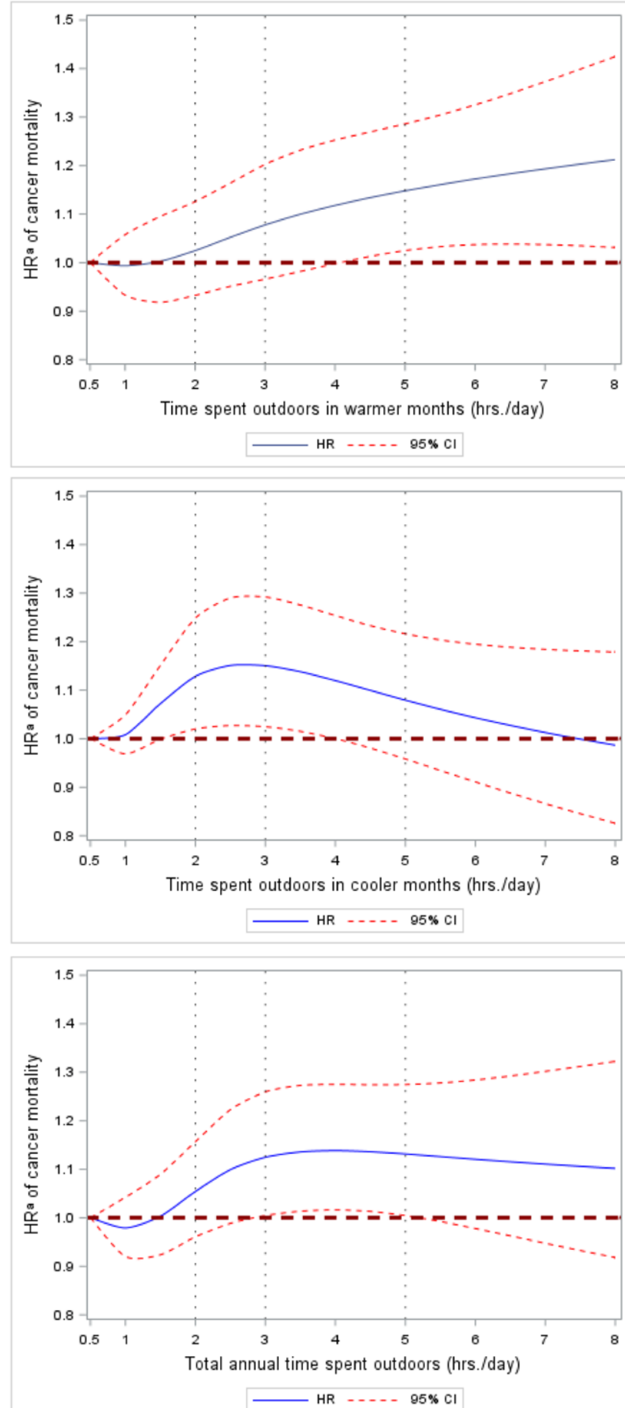

Figure 2. Adjusted hazard ratios of cancer mortality, CVD mortality, and noncancer non-CVD mortality by hours spent outdoors from 9 AM to 5 PM compared with 30 minutes/day among 83,205 participants of the Adventist Health Study 2, 2002–2015. 1. Cancer mortality: time spent outdoors during daylight in warmer months (A), time spent outdoors during daylight in cooler months (B), total annual time spent outdoors during daylight (C); 2. Cardiovascular disease mortality: time spent outdoors during daylight in warmer months (A), time spent outdoors during daylight in cooler months (B), total annual time spent outdoors during daylight (C); 3. Noncancer noncardiovascular disease mortality: time spent outdoors during daylight in warmer months (A), time spent outdoors during daylight in cooler months (B), total annual time spent outdoors during daylight (C). [a]Hazard ratio of cancer mortality was calculated using Cox regression, adjusting for sex, race, body mass index, exercise, smoking status, alcohol consumption (separate indicators for wine drinking and for beer and liquor drinking), dietary pattern, nut intake, vitamin D

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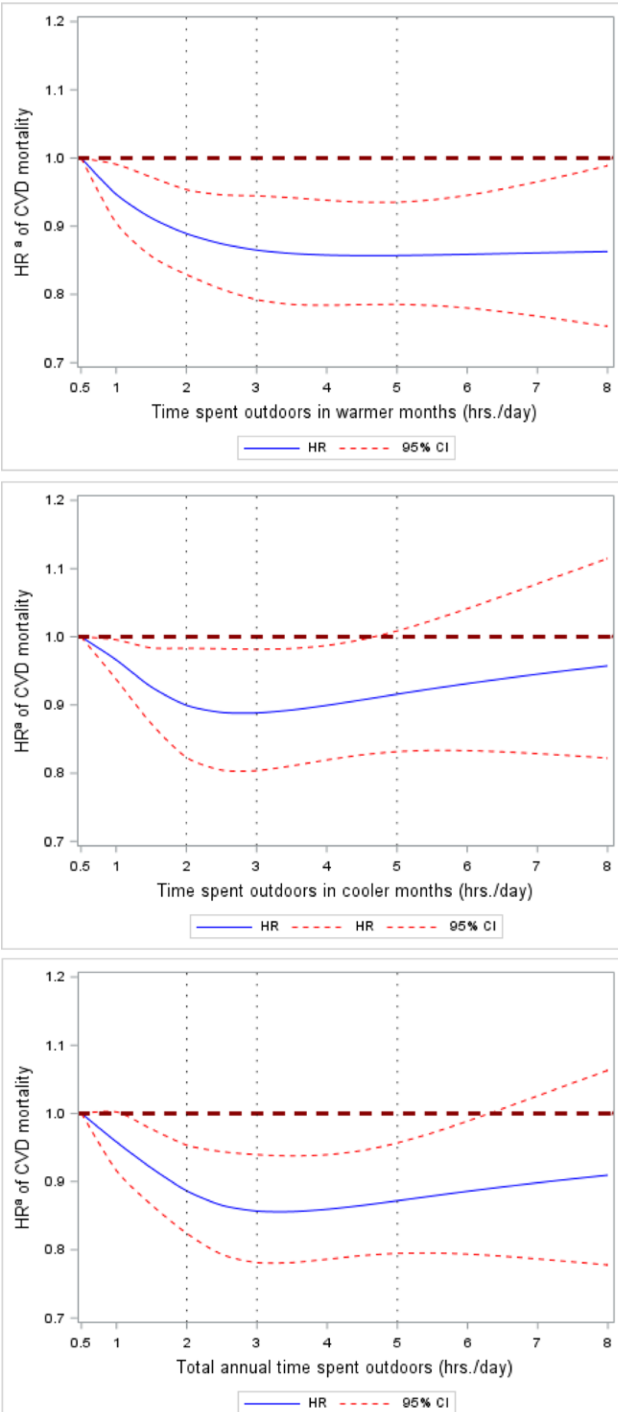

Figure 2. Continued

intake from diets and supplements, dietary energy, educational attainment, marital status, female-centered variables (menopausal status and hormone replacement therapy use among menopausal women), household income, geographical regions, preexisting diseases including cancers (not including nonmelanoma skin cancer), cardiovascular disease (ischemic heart disease, congestive heart failure treated in the past 12 months, and surgeries [coronary bypass, stent]), stroke and carotid artery surgery combined variable, diabetes type II, hypertension, chronic obstructive pulmonary diseases (asthma, bronchitis, and emphysema), high cholesterol, and aspirin use.

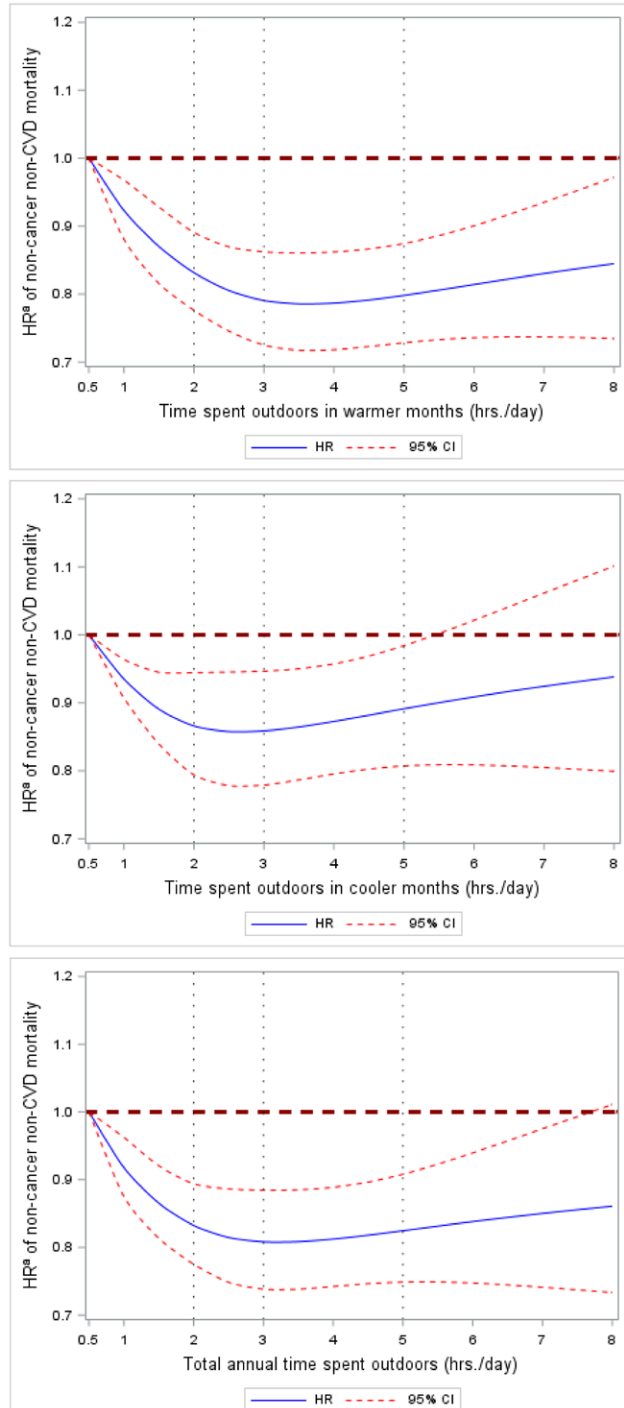

Figure 2. Continued

more likely to be men, to be more physically active, to have lower education attainment and household income, to be non-vegetarian, to have ever smoked tobacco, and to have higher all-cause mortality and cancer mortality, but less likely to have used sunscreen than participants in the lower sun exposure groups. Regardless of the exposure groups, the mean vitamin D intake (from diet and supplements) was low for the entire cohort (Q4:5.5 [SD: 23.5], Q3:5.4 [22.6], Q2:5.0 [21.1], Q1:5.22 [24.1] in μg/day).

We evaluated the correlation between time spent outdoors in warmer and cooler months and found it to be high (Pearson correlation coefficient of 0.75, $P < 0.001$). The correlation between time outdoors in daylight and physical activity was low (Pearson correlation coefficient was 0.09 for warmer and 0.10 for cooler months, $P < 0.001$).

Time spent outdoors during daylight and all-cause mortality

Table 2 presents the multivariable-adjusted HRs of all-cause mortality by daytime hours spent outdoors in warmer months, cooler months, and total annual time oudoors in daylight. Regardless of the season, there were nonlinear (reverse J-shaped) associations between time spent outdoors during daylight and all-cause mortality, and these associations were strongest in warmer months. Compared with spending 30 minutes per day outdoors in daylight during warmer months, spending 2 hours per day was associated with an approximately 10% lower risk of mortality (HR: 0.90; 95% confidence interval (CI) = 0.86, 0.93). This inverse association between time spent outdoors in warmer months and mortality weakened as the time spent outdoors exceeded a certain limit (Table 2 and Figure 1). In winter, the HRs of all-cause mortality by spending 2, 3, and 5 hours per day vs. 30 minutes per day were 0.94 (0.90, 0.99), 0.94 (0.89, 0.99), and 0.95 (0.89, 1.00), respectively.

Time spent outdoors during daylight and cause-specific mortality

Time spent outdoors in daylight in warmer months and total annual hours were associated with lower risks of CVD mortality and noncancer non-CVD mortality (Table 3 and Figure 2). The associations appeared to be nonlinear (reverse J-shaped) and stronger with noncancer non-CVD mortality. The HR of noncancer non-CVD mortality by spending 2 hours per day outdoors in warmer months was 0.83 (95% CI = 0.78, 0.89); 3 hours per day was 0.79 (0.72, 0.86); and 5 hours per day was 0.80 (0.73, 0.87), compared with spending 30 minutes per day outdoors. Spending 2, 3, and 5 hours vs. 30 minutes per day outdoors in warmer months were associated with a lower risk of CVD mortality ([HR: 0.89; 95% CI = 0.83, 0.95], [0.87; 0.79, 0.94], and [0.86; 0.79, 0.94], respectively). Weaker associations were observed between the time spent outdoors in cooler months and both outcomes. The HRs of cancer mortalities by spending 2, 3, and 5 hours per day outdoors in warmer months' daylight were 1.02 (95% CI = 0.93, 1.13), 1.08 (0.97, 1.20), and 1.15 (1.02, 1.29), respectively, compared with 30 minutes per day (Table 3 and Figure 2A).

We tested the interaction between sunscreen use and time spent outdoors in daylight. The interaction was not significant for all mortality outcomes (data not shown).

Subgroup analysis by race and sex

Spending 2 hours per day outdoors from 9 AM to 5 PM in warmer months had inverse associations with all-cause, CVD, and noncancer non-CVD mortalities, compared with 30 minutes per day in subgroup analyses (not all associations were statistically significant) (Table 4). For cancer mortality, the associations were not significant in any of the subgroups.

Sensitivity analysis

When excluding selected prevalent chronic diseases, the HR of all-cause mortality, CVD mortality, and noncancer non-CVD mortality slightly weakened but were still significantly inverse (Supplementary Table S1 and S2; https://links.lww.com/EE/A351). We excluded the first 2 years of the follow-up to evaluate reverse causation by preclinical diseases. The exclusion did not consistently weaken our mortality risk estimates, and the HR of all-cause and noncancer mortalities was still significantly inverse (not reported). When adjusting for selected chronic diseases that varied by outcomes, the risks of our mortality outcomes were comparable to those in the fully adjusted models (Supplementary Table S3; https://links.lww.com/EE/A351).

Discussion

This study provided evidence that time spent outdoors from 9 AM to 5 PM in warmer months could be associated with a lower risk of all-cause mortality, CVD mortality, and noncancer non-CVD mortality (which had the strongest association). However, there was no strong evidence of an association with cancer mortality. All associations appeared to be weaker in cooler months. To our knowledge, this is the first study to investigate the impact of sun exposure on mortality using daytime hours spent outdoors during the warmer and cooler months. This measure can better reflect the overall impact of habitual exposure to sunlight than activities with intermittent high sun exposure.

Few epidemiological longitudinal studies have investigated the association between sun exposure and all-cause mortalities. In a longitudinal study of the "Melanoma in Southern Sweden" cohort, sun exposure was measured using the frequency of sunbathing in summer and winter, tanning bed use, and swimming and sunbathing during holidays. The group with the highest sun exposure had a lower risk of all-cause mortality (HR: 0.66; 95% CI = 0.5, 0.8).[14] In the Swedish Women's Lifestyle and Health cohort study, the annual number of weeks spent on sunbathing vacations over three decades (from age 10 to 39 years) was used to represent the cumulative sun exposure.[15] Women who spent ≥1 week/year on sunbathing vacations at these ages had a lower risk of all-cause mortality (HR: 0.7; 95% CI = 0.6, 0.9) than those with no sunbathing vacations. In the 12-year National Institutes of Health–American Association of Retired Persons Diet and Health Study, the yearly average measurements of ambient UVR in July were linked to participants' residential addresses at baseline and were associated with an increased risk of all-cause mortality (highest quartile [253.7–289.5 biological damage/m^2 vs. lowest quartile]: HR: 1.06; 95% CI = 1.03, 1.09).[16] In contrast, a higher annual average shortwave radiation exposure of 2000 kJ/m^2 based on the participants' geographical locations was associated with a significantly reduced risk of all-cause mortality in the UK Biobank study (HR: 0.85; 95% CI = 0.78, 0.89). Important indicators of sun exposure,

Table 2.

Adjusted hazard ratios of all-cause mortality by time spent outdoors from 9 AM to 5 PM among 83,205 participants of the Adventist Health Study 2, North America, 2002–2015

Hours spent outdoors in daylight (hour/day)	All-cause mortality (number of cases = 11,515) HR[a] (95% CI)
In warmer months	
0.5	Ref
2	0.90 (0.86, 0.93)
3	0.88 (0.84, 0.93)
5	0.90 (0.85, 0.95)
In cooler months	
0.5	Ref
2	0.94 (0.90, 0.99)
3	0.94 (0.89, 0.99)
5	0.95 (0.89, 1.00)
Total annual	
0.5	Ref
2	0.90 (0.87, 0.94)
3	0.90 (0.85, 0.95)
5	0.91 (0.86, 0.97)

[a]Calculated using Cox regression adjusting for sex, race/ethnicity, body mass index, exercise, smoking status, alcohol consumption (separate indicators for wine drinking and for beer and liquor drinking), dietary pattern, nut consumption, vitamin D intake from diets and supplements, dietary energy, educational attainment, marital status, female-centered variables (menopausal status and hormone replacement therapy use among menopausal women), household income, geographical region, preexisting diseases: cancers not including nonmelanoma skin cancer, cardiovascular disease (ischemic heart disease, congestive heart failure treated in the past 12 months, and surgery (coronary bypass, stent)), stroke and carotid artery surgery combined variable, diabetes type II, hypertension, chronic obstructive pulmonary disease, high cholesterol, and aspirin use.

Table 3.

Adjusted hazard ratios of cause-specific mortalities (cancer, CVD, and noncancer non-CVD) by time spent outdoors from 9 AM to 5 PM among 83,205 participants of the Adventist Health Study 2, North America, 2002–2015

	Cause-specific mortality		
Hours spent outdoors in daylight (hour/day)	Cancer (number of cases = 3018) HR[a] (95% CI)	CVD (4422) HR[a] (95% CI)	Noncancer non-CVD (4075) HR[a] (95% CI)
Warmer months			
0.5	Ref	Ref	Ref
2	1.02 (0.93, 1.13)	0.89 (0.83, 0.95)	0.83 (0.78, 0.89)
3	1.08 (0.97, 1.20)	0.87 (0.79, 0.94)	0.79 (0.72, 0.86)
5	1.15 (1.02, 1.29)	0.86 (0.79, 0.94)	0.80 (0.73, 0.87)
Cooler months			
0.5	Ref	Ref	Ref
2	1.13 (1.02, 1.25)	0.90 (0.82, 0.98)	0.87 (0.79, 0.94)
3	1.15 (1.02, 1.29)	0.89 (0.80, 0.98)	0.86 (0.78, 0.95)
5	1.08 (0.96, 1.22)	0.92 (0.83, 1.01)	0.89 (0.81, 0.98)
Total annual			
0.5	Ref	Ref	Ref
2	1.05 (0.96, 1.16)	0.89 (0.82, 0.95)	0.83 (0.78, 0.89)
3	1.12 (1.00, 1.26)	0.86 (0.78, 0.94)	0.81 (0.74, 0.88)
5	1.13 (1.00, 1.27)	0.87 (0.79, 0.96)	0.82 (0.75, 0.91)

[a]Cox models were adjusted for sex, race/ethnicity, body mass index, exercise, smoking status, alcohol consumption (separate indicators for wine consumption and for beer and liquor consumption), dietary pattern, nut intake, vitamin D intake from diets and supplements, dietary energy, educational attainment, marital status, female-centered variables (menopausal status and hormone replacement therapy use among menopausal women), household income, geographical regions, preexisting chronic diseases: cancers (not including nonmelanoma skin cancer), cardiovascular disease (ischemic heart disease, congestive heart failure treated in the past 12 months, and surgeries (coronary bypass, stent)), stroke and carotid artery surgery combined, diabetes type II and related medications, hypertension, chronic obstructive pulmonary diseases (asthma, bronchitis, and emphysema), high blood cholesterol and cholesterol lowering medications, and aspirin use.

Table 4.

Subgroup analysis examining the association of spending 2 hours/day vs. 30 minutes/day from 9 AM to 5 PM in warmer months with all-cause and cause-specific mortalities (cancer, CVD, and noncancer non-CVD mortality) by sex and race among 83,205 participants of the Adventist Health Study 2, North America, 2002–2015

Variables	Number of cases	HR (95% CI)
All-cause mortality[a]		
Men	4757	0.91 (0.83, 1.00)
Women	6758	0.88 (0.83, 0.93)
Blacks	2042	0.88 (0.79, 0.98)
Nonblacks	9473	0.90 (0.86, 0.94)
Cancer mortality[a]		
Men	1227	1.11 (0.87, 1.41)
Women	1791	1.01 (0.90, 1.12)
Blacks	613	1.05 (0.85, 1.30)
Nonblacks	2405	1.02 (0.92, 1.13)
CVD mortality[a]		
Men	1859	0.94 (0.80, 1.09)
Women	2563	0.85 (0.78, 0.93)
Blacks	720	0.80 (0.68, 0.95)
Nonblacks	3702	0.91 (0.85, 0.99)
Noncancer non-CVD mortality[a]		
Men	1671	0.79 (0.68, 0.92)
Women	2404	0.83 (0.76, 0.91)
Blacks	709	0.86 (0.73, 1.03)
Nonblacks	3366	0.82 (0.76, 0.89)

[a]Subgroup analyses by sex was calculated using Cox regression and adjusted for race, body mass index, exercise, smoking status, alcohol consumption (separate indicators for wine drinking and for beer and liquor drinking), dietary pattern, nut intake, vitamin D intake from diets and supplements, dietary energy, educational attainment, marital status, female-centered variables (menopausal status and hormone replacement therapy use among menopausal women), household income, geographical region, preexisting diseases, cancers (not including nonmelanoma skin cancers), cardiovascular disease (ischemic heart disease, congestive heart failure treated in the past 12 months, and surgeries (coronary bypass, stent)), and stroke and carotid artery surgery combined variable, diabetes type II, hypertension, chronic obstructive pulmonary diseases (asthma, bronchitis, and emphysema), high cholesterol, and aspirin use. Subgroup analysis by race was additionally adjusted for sex, but not race.

such as time spent outdoors in daylight and sunscreen use, were not considered.

Epidemiological investigations on the association between sun exposure and cause-specific mortality have mostly focused on cancer mortality. Ecological studies suggested an inverse association between different measures of solar UVR and mortality from multiple cancers, such as female cancers (breast, ovarian, and corpus uterus) and prostate, esophageal, stomach, colon, rectal, pancreas, non-Hodgkin lymphoma, bladder, kidney, and lung cancers.[9,10,22,23] Important individual-level confounders and risk modifiers were not controlled for. Prospective studies on sun/solar UVR exposure and cause-specific mortality have reported mixed findings. For instance, the Swedish Women's Lifestyle and Health study found that spending ≥1 week/year on sunbathing vacations from age 10 to 39 years was associated with a lower risk of CVD mortality (HR: 0.5; 95% CI = 0.3, 0.8) but had a nonsignificant association with cancer mortality (HR: 0.9; 95% CI = 0.7, 1.2).[15] Lower risks of CVD mortality and cancer mortality were observed with higher average UV radiation of 2000 kJ/m^2 in the UK biobank study ([HR: 0.77; 95% CI = 0.66, 0.91] and [0.88; 0.77, 0.99], respectively).[17] The US National Institutes of Health–American Association of Retired Persons Diet and Health Study observed a positive association between the highest quartile of the Total Ozone Mapping Spectrometer average UV measures in July and CVD mortality (HR: 1.06; 95% CI = 1.00, 1.12), cancer mortality (1.06; 1.02, 1.11), respiratory disease mortality (1.37; 1.21, 1.55), and stroke mortality (1.16; 1.01, 1.33) compared with the lower quartile of ambient UV measures.

In line with our findings, Lindqvist et al.[13] found that avoiders of sun exposure had a higher risk of CVD mortality than those with moderate exposure (subdistribution HR: 1.4; 95% CI = 1.01, 1.8) and high exposure (2.2; 1.5, 3.2), and a higher risk of noncancer non-CVD deaths ([1.6; 1.2, 2.1] and [2.1; 1.5, 2.9] compared with moderate and high exposure, respectively), but in a dose-response manner. This study also reported a nonsignificant difference in cancer mortality according to sun exposure. In our study, time spent outdoors during daylight in warmer months was associated with a lower risk of CVD mortality and noncancer non-CVD mortality.

Different indicators of sun exposure might explain these results. In this study, the benefit from sun exposure in terms of all-cause mortality, CVD mortality, and noncancer non-CVD mortality appeared nonlinear, in that health benefits decreased as time spent outdoors exceeded certain limits. Although there is strong evidence of a positive association between sun exposure and skin cancer, the most common type of skin cancer, nonmelanoma skin cancer, is rarely fatal. Previous studies have reported a nonlinear relationship between time outdoors in daylight and diseases. A nonlinear J-shaped association was observed between outdoor light exposure and incident heart failure in a UK Biobank cohort study.[24] Compared with individuals with an average outdoor light duration of 1–2.5 hours per day, those with <1 hour per day and those with >2.5 hours per day had a higher risk of incident heart failure ([HR: 1.10; 95% CI = 1.03, 1.18] and [1.07; 1.03, 1.11], respectively). Other studies have also found nonlinear J-shaped associations between outdoor light exposure and the risks of depression and dementia,[25,26] which were lower among individuals with an average of 1.5 hours per day outdoor light exposure than those with higher or lower exposure.

This study demonstrated that the association between time spent outdoors in daylight and all-cause mortality was comparable between Blacks and non-Blacks. It is well known that individuals with lighter skin tones are at a greater risk of solar UV radiation and skin cancers from prolonged exposure to the sun than those with darker skin tones. We could not compare these results with those of previous prospective studies because they only included non-Blacks or did not provide information on race.[13–16]

Subgroup analysis based on sex revealed comparable results between women and men. While most previous studies were conducted among women.[13–15] Lin et al.[16] (2013) evaluated the interaction between ambient UVR and sex, reported similar positive associations with all-cause, CVD, and respiratory disease mortality between women and men. However, the association was significantly positive for cancer mortality only in men.

The health effects of sun exposure are not yet fully understood. Sun exposure plays a significant role in the photosynthesis of vitamin D. The active metabolite of vitamin D, 1,25 $(OH)_2$, has important anti-inflammatory and immunomodulatory effects[27–30] and exhibits anticancer properties, such as inhibiting cellular proliferation and tumor angiogenesis, inducing cellular differentiation, and decreasing tumor invasion and metastasis.[31] A recent systematic review of 84 studies reported that circulating 25-hydroxyvitamin D was associated with a lower mortality risk in most epidemiological studies, and the association was not linear (plateaued at higher serum vitamin D levels).[32] Aside from vitamin D, early day exposure to visible sunlight helps regulate the circadian rhythm,[33] and sunlight has also been linked to better mental health.[34] Sunlight therapy and naturalistic light that resembles sunlight improve depression and daily function in poststroke patients.[35,36] Solar radiation might have cardiovascular benefits independent of vitamin D. Exposing healthy volunteers to a UVA irradiation dose equivalent to spending 30 minutes in sunlight at noon lowered their diastolic blood pressure.[5] This process likely involves the mobilization of NO stores from the skin into circulation.[5]

In contrast, prolonged exposure to solar radiation increases the risk of skin cancers, such as basal cell and squamous cell carcinomas. Prolonged time spent outdoors could have adverse health effects that are not related to skin cancer through hyperthermia, reducing brain production of the hormone melatonin, which could disrupt sleep and probably prolong exposure to environmental pollutants.[24–26]

Limitations

Data on daylight exposure were collected at baseline. Exposure might have changed throughout the study period owing to many factors, such as residential relocation, outdoor occupation, and changes in public health awareness. Residual confounding cannot be ruled out. People with underlying health problems could spend less time outdoors. However, when we excluded major chronic diseases, the risks of all-cause and noncancer mortalities were still significantly inversely related to time spent outdoors in daylight during warmer months. We also excluded the first 2 years of follow-up to evaluate reverse causation by preclinical diseases. That did not consistently weaken the risks of all-cause, CVD, and noncancer non-CVD mortalities. Additionally, it is not clear how residual confounding explains the stronger inverse associations observed in warmer months than in cooler months. This study measured sun exposure using a questionnaire, whereas the association between mortality and ambient UV irradiance by the residential location of participants could be different. We evaluated daylight exposure during adulthood; however, the exposure earlier in life (i.e., during childhood and adolescence) could have different associations. Additionally, sun exposure was measured throughout the day, with no specification for the time of the day, whereas a sun exposure variable that accounted for intensity would have been ideal. The increased health consciousness of the AHS-2 participants may limit the generalizability to populations whose lifestyles deviate from those of the Adventists. Finally, the vitamin D intake was low in the AHS-2 cohort. Thus, the study results may not be generalizable to individuals with a high vitamin D intake.

Conclusions

This study provided evidence that moderate time spent outdoors during daylight in warmer months could be associated with lower risks of all-cause, CVD, and noncancer non-CVD mortality. However, there was no strong evidence of an association with cancer mortality. Further epidemiological studies are required to investigate other associations like sunlight and mental health, and the balance between sunlight-related health benefits and risks, which could lead to better public health awareness.

Conflicts of interest statement

The authors declare that they have no conflicts of interest with regard to the content of this report.

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