NIH Public Access
Author Manuscript

Photochem Photobiol. Author manuscript; available in PMC 2014 March 26.

Published in final edited form as:
Photochem Photobiol. 2008 ; 84(3): 713–718. doi:10.1111/j.1751-1097.2007.00236.x.

Agreement Between Diary Records of Time Spent Outdoors and Personal Ultraviolet Radiation Dose Measurements

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Abstract

Little is known about the validity of self-recorded sun exposure and time spent outdoors for epidemiological research. The aims of the current study were to assess how well participants' self-recorded time outdoors compared to objective measurements of personal UVR doses. We enrolled 124 volunteers aged 40 and above who were identified from targeted subgroups of US radiologic technologists. Each volunteer was instructed to wear a polysulfone (PS) dosimeter to measure UVR on their left shoulder and to complete a daily activity diary, listing all activities undertaken in each 30 min interval between 9:00 A.M. and 5:00 P.M. during a 7 day period. In a linear regression model, self-recorded daily time spent outdoors was associated with an increase of 8.2% (95% CI: 7.3–9.2%) in the personal UVR exposure with every hour spent outdoors. The amount of self-recorded total daily time spent outdoors was better correlated with the personal daily UVR dose for activities conducted near noon time compared to activities conducted in the morning or late afternoon, and for activities often performed in the sun (*e.g.* gardening or recreation activities) compared to other outdoor activities (*e.g.* driving) in which the participant is usually shaded from the sun. Our results demonstrated a significant correlation between diary records of time spent outdoors with objective personal UVR dose measurements.

INTRODUCTION

Exposure to sunlight has been the subject of substantially increased epidemiological efforts in recent years, both for its potentially adverse (1) and beneficial (2) influence on the risk of cancer. A fundamental step in understanding the etiology of potentially sun-related cancers is accurate estimation of individual exposure to solar UVR. The most frequently used method to assess UVR exposure has been self-reported time spent outdoors using questionnaires or personal diaries (3–5). Yet, findings from epidemiological studies that

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have used these methods have been inconsistent. The inconsistencies have been ascribed to the difficulty participants have in accurately estimating time spent outdoors (6).

Little, however, is known about the degree to which self-recorded total daily time outdoors, as an estimate of sun exposure, actually corresponds to measured UVR exposure. Most previous epidemiological studies that have attempted to assess the relationship between self-recorded personal time outdoors and objective estimates of sun exposure obtained from polysulfone (PS) badges, which directly measure UVR exposure, were limited to children and adolescents (7–9) or indoor workers from Denmark (10) where ambient UVR doses are relatively low (11).

This study was designed to extend the earlier scientific research, by investigating the relationship between self-recorded total daily time outdoors (in a daily diary) and personal measured UVR exposure in a group of middle-aged and older men and women who are primarily indoor workers from northern and southern regions of the United States. In addition, the study examined the degree to which self-recorded outdoor time of day and specific daily activities were related to personal measured UVR exposure.

STUDY SUBJECTS AND METHODS

Study subjects

Study subjects were selected from a nationwide cohort of radiologic technologists participating in the US Radiologic Technologists cohort study, an ongoing collaboration of the U.S. National Cancer Institute, University of Minnesota, and the American Registry of Radiologic Technologists (12,13). To be eligible for this measurement study of UVR from sunlight exposure, subjects had to have completed a short baseline questionnaire on lifetime sun exposure during the summer of 2004, and one or more work history questionnaires during earlier surveys of the US Radiologic Technologist cohort in 1983–1989 or 1994–1998. The targeted population from which volunteers were sought for assessment of UVR exposure were radiologic technologists residing in proximity to the greater Minneapolis region and neighboring Wisconsin (northern latitudes) and to the Research Triangle Park/Raleigh/Durham/Chapel Hill region of North Carolina and Georgia (southern latitudes). The rationale for selecting these two regions was the availability of study staff who were responsible for measuring ambient (area) UVR daily during the entire study period. Sampling was performed to enroll approximately 120 volunteers. In each of the two regions, volunteers were selected so that the study population included similar proportions of women and men, and workers aged 40 to $<$60 years and $\geq$60. Of the 300 individuals randomly selected for a recruitment phone call, 127 agreed to participate (42% recruitment rate), and 124 subjects completed all aspects of the study (98% participation rate). For one subject, only the daily diary was available for analysis. Most (88.3%) of the 60 subjects aged 40 to $<$60 years were working at the time of the study, compared to only 34.3% of the subjects aged 60 or above.

Daily activity diaries

All study participants were asked to contemporaneously record their activities in a diary every 30 min between 9:00 A.M. and 5:00 P.M. for seven consecutive days between 1 September and 5 October 2004. The participants were asked to record the major outdoor or indoor activities carried out during each 30 min interval, the specific type of activity, and whether they were in the shade, what sun protective clothing they wore and whether they had applied sunscreen. If multiple activities occurred during the 30 min time blocks, we assumed that each activity took an equal amount of time during the 30 min time block.

Personal UVR exposure measurements

The personal solar UVR exposure was measured using PS film dosimeters, which relate the change of optical absorbance at 330 nm in J m^{-2}. PS film badges were developed specifically by one of us (M.G.K.) for the current study. The film dosimeter was constructed by dissolving PS (Sigma Aldrich) in chloroform, for 12 h. The dissolved PS was poured onto a piece of optically ground flat glass, and then spread by a speed and height regulated blade. During the film casting process, the casting equipment was placed in a fume cupboard for drying. The badge surface was cleaned with ethanol prior to the preoptical and postoptical absorbance at 330 nm which was measured in a UV–VIS spectrophotometer (Beckman DUV 65) using a custom adaptor to insure reproducibility of the PS badge with respect to the position of the beam (14). The optical absorbency of the dosimeters as measured at four locations over each dosimeter and the average of the four measurements was calculated. The PS badges were calibrated for each location used in this study. Irradiances from UVB Monitoring Stations of the U.S. Department of Agriculture were compared to a series of PS badges exposed to the same sunlight. Calibration curves were obtained for each locale and then applied to the PS badge measurements from each site, giving calibrated UVR values. The error associated with UVR measurements using PS film was estimated to be of the order of 10% (15). The PS badges were worn by each participant on their left shoulder attached to the outside of their clothing between 9:00 A.M. and 5:00 P.M. Eastern Daylight Time. Each participant placed a new PS dosimeter on their left shoulder each day during the 7 day period, allowing for the daily exposure to be measured. All study participants were contacted by phone at the end of the first day of the study to verify participation and to answer questions that the participant might have about procedures for wearing the PS dosimeter and for completing the daily diary.

Ambient UVR measurements

To assess the total available UVR exposure for that particular day, PS dosimeters were exposed continuously to sunlight in open fields in both study regions (Research Triangle, NC, and Minneapolis, MN). The specific method used to calculate maximum daily ambient UVR was to expose two new dosimeters to the sun from 9:00 A.M. to 5:00 P.M. each day throughout the study period and they were then placed in a light-proof envelope. For both regions, the midpoint of the reading of the two dosimeters was considered to be the maximal daily ambient UVR. The percentage of ambient UVR exposure was then defined as the total personal UVR dose divided by the maximal daily UVR exposure for the same date and region multiplied by 100%.

Quality control

To examine the reproducibility of the personal PS dosimeters, we asked 14 individuals to wear a second dosimeter placed next to the first dosimeter during the 7 day period. Eight subjects had readings of two PS dosimeters for the entire 7 day period and for six subjects, these data were available for 1–6 days, with a total of 82 simultaneous measurements. When the readings of the two dosimeters measurements were compared, a high level of correlation (Pearson $r = 0.92$, $P < 0.001$) was obtained.

Statistical analysis

Comparisons of the self-recorded total daily time spent outdoor between 9:00 A.M. and 5:00 P.M., personal daily UVR exposure and the personal percentage of ambient UVR dose were performed using the Mann–Whitney test, a distribution-free, nonparametric test (16). The time spent outdoors for weekdays *vs* weekend days (Table 1) were compared using the Kruskal–Wallis nonparametric test (16). We used Spearman correlations and multiple linear regression modeling to compare personal daily UVR dose with self-recorded total daily time spent outdoors after logarithmic transformation. The multiple linear regression model included the following variables: gender, age (40 to <60, ≥60 years), weekend day or weekday, North or South United States, ambient UVR in participant's geographic region and total time spent outdoors derived from the personal daily diaries. To adjust for within-individual variation in the repeated measures, we also included participants' identifying number in the model.

To examine the effect of time of day on the association between amount of time spent outdoors and personal UVR dose, we summed the self-reported time spent outdoors for each of the 8 h between 9:00 A.M. and 5:00 P.M., which was then included in a multiple linear regression model as a dummy variable. The calculated regression coefficients for self-recorded time spent outdoors during each hour were plotted together with a curvilinear function.

Finally, to examine whether the correlation between self-recorded time spent outdoors from the diary and daily UVR dose were higher for certain activities, we first entered all outdoor activities verbatim from the daily diary into the analysis data set. These activities were then cataloged according to key words, using a factor analysis. We used the American Time Use Survey (17) and the National Human Activity Pattern Survey (18) as guides to form grouped activities into categories. The categorized outdoor activities were further reduced into seven distinct groups— leisure (*e.g.* relaxing outside, eating or cooking outside), gardening, house repair (outside home maintenance such as remodeling, painting or car maintenance), walking with pets, water activity (fishing, swimming, sailing, boating, canoeing or sunbathing), recreation (outdoor recreation such as playing golf, soccer, biking, hiking, running, jogging, or moderate to heavy exercise) and driving (driving such as driving to errands, shopping, commuting) (19). The duration of these types of outdoor activities was then applied to a multivariate linear regression for internal comparison of their regression coefficients.

RESULTS

Time spent outdoors

During the study period, personal activity diaries were obtained from 125 participants covering 869 days. The mean daily time spent outdoors between 9:00 A.M. and 5:00 P.M. during weekend days (2.22 h) was significantly ($P < 0.001$) longer compared to weekdays (1.37 h). Driving was the most frequent activity outdoor activity between 9:00 A.M. and 5:00 P.M. both during weekdays (0.48 h) and weekend days (0.67 h) while water activity was the least frequent. Similar results were observed in men and women in both regions (Table 1).

Personal UVR exposure

Personal UVR doses were available for 124 subjects covering 846 days. There were no available UVR dose readings for 22 days (2.5% of total study days) because of technical difficulties. The average of the daily ambient UVR dose in the northern and southern regions was 2250 (range: 250, 5150) and 2200 J m^{-2} (range: 700, 3850), respectively. The average daily time spent outdoors, the personal daily UVR dose and the percentage of ambient UVR dose according to region, age, and gender are given in Table 2. Compared to women, men reported significantly ($P < 0.01$) longer time outdoors between 9:00 A.M. and 5:00 P.M. (2.03 h for men *vs* 1.23 h for women), had higher personal cumulative daily UVR doses (170.4 J m^{-2} *vs* 101.9 J m^{-2}) and were exposed to higher personal percentage of the ambient UVR dose (8.3% *vs* 5.2%). Higher average personal doses (J m^{-2}) were measured during weekend days compared with weekdays both in the northern region (119.0 *vs* 59.4, $P = 0.04$) and in the southern region (236.8 *vs* 175.0, $P = 0.01$).

Comparison between time spent outdoors recorded in daily diaries and personal UVR dose measurements

Correlation between personal UVR dose measurements and contemporaneously recorded daily time spent outdoors as recorded in diary—As depicted in Fig. 1 the calculated Pearson correlation coefficient for the contemporaneously recorded time spent outdoors between 9:00 A.M. and 5:00 P.M. and personal daily UVR dose was higher in northern regions (0.69, $P < 0.001$) compared with southern regions (0.57, $P < 0.001$). In multivariate linear regression, total time spent outdoors was significantly ($P < 0.001$) associated with the personal daily UVR doses with a regression coefficient of 0.082 (Table 3), which reflects an increase of 8.2% in the personal UVR exposure with every hour spent outdoors. Maximal ambient UVR dose was associated significantly with personal UVR dose ($P < 0.01$). After adjusting for ambient UVR dose and time spent outdoors, there was no statistically significant association between age, gender, region or type of day and personal UVR dose.

Differences in the regression coefficients between hours during the day— When the time of day spent outdoors was introduced into the model, higher regression coefficients were calculated for activities conducted around noon. The regression coefficient for amount of time spent outdoors between 12:00 P.M. and 1:00 P.M. (0.25, 95% CI: 0.21–0.29%) was significantly higher ($P < 0.05$) compared with the regression coefficients for the amount of time spent outdoors between 3:00 P.M. and 4:00 P.M. (0.18) or between 4:00 P.M. and 5:00 P.M. (0.13). Figure 2 presents the actual and the fitted linear regression coefficients, according to time of activity.

Activity-related differences in the correlation between personal UVR doses and contemporaneously recorded time spent outdoors—When the type of activity was introduced into the multivariate model, significantly higher coefficients were calculated for activities often performed in the sun (*e.g.* recreation and gardening) compared with activities in which the participant is often shaded (such as driving and house repair) (20). For example, there was an increase of 17.6% (95% CI: 15.2–20.0%) in the measured UVR exposure with every recorded hour the volunteers spent in outdoor recreational activities. In contrast, there was an increase of only 3.9% (2.1–5.7%) in the measured UVR exposure with each recorded hour the subjects spent driving. The regression coefficients for different activities are given in Table 4.

DISCUSSION

Analyses of data collected in our indoor workers' study provide evidence that self-recorded time spent outdoors has good validity when compared with objective personal UVR dose measurements. The results showed a significant correlation between the amount of recorded time spent outdoors and personal UVR dose measurements, and even better correlation between time spent outdoors and UVR dose during the noon hours or for activities that are frequently performed in the sun, such as recreation (21) and gardening (22).

Our results agree with the findings of a previous study that examined the correlation between individual UVR dose measurements and self-recorded exposure using daily diaries among Danish indoor workers (10). For working day periods both studies found comparable UVR exposure (4% of the total ambient UVR), similar correlation coefficient ($r \geq 0.33$) between total daily time outdoors and UVR dose, and stronger correlation coefficients for outdoor exposure around noon. Other studies that compared personal UVR exposures using PS dosimeters and those calculated from diary or questionnaire entries among schoolchildren (7,9) and volunteers recruited from recreation organizations and sporting clubs (21) also reported reasonably good correlations between these two measures. In contrast, investigators found a poor correlation between personal UVR doses measurements and reported time spent outdoors for young children and their mothers (23). The authors interpreted the results as the result of lack of data on type of activities performed throughout the day as well as by their data gathering method which was based on recall at the end of the 4 day study period.

Our study strengths include a relatively large sample size, high compliance rate and data collected from subjects living in two distinct geographic regions. Nevertheless, some limitations of the study should be considered. The participants were radiologic technologists selected from among those who had responded to at least two previous questionnaires; hence, they may not reflect the general population. Nonetheless, a similarly high subject compliance rate was reported in a previous study (24) that examined diary records and UV dosimeter readings on a daily basis among children and adults. Also, we assessed time outdoors during a single 1 week period, which may not represent the usual behavior patterns throughout the year (25). The weather during the study period was relatively temperate for outdoor activity. During the study period the mean maximum and minimum temperatures in Raleigh, NC, and Minneapolis, MN, areas, ranged from 62 to 80°F and from 45 to 65°F, respectively; and the respective monthly precipitation was 4.5 and 4.2 in with less than seven rainy days within the 5 week study period (26,27). Different weather conditions and amount of daily sunshine could potentially affect the time spent outdoors and in turn, the calculated validity. In addition, UVR exposure was measured using PS badges on the shoulder, which may be higher compared with other body parts (21). PS dosimeters provide a simple, compact and inexpensive means of providing cumulative UVR exposure continuously; however, overall measurement uncertainties of 20% have been reported (28).

The findings from our assessment of the validity of self-recorded total daily time outdoors from a 7 day diary with objective personal UVR dose measurements obtained simultaneously does not necessarily reflect the validity of retrospective questionnaires regarding long-term or lifetime sun exposure, which is frequently assessed in case–control studies or cohort studies asking about previous exposures. The validity of these questionnaires depend on subjects' recall and is made difficult due to the large variability in amount and frequency of sun exposure over time and due to the generally low perceived importance of sun exposure compared to other carcinogens (29). However, the study results do support the use of daily diaries and outdoor activity logs for contemporaneous sun exposure assessments over relatively short periods (22,30). The study results also indicate that the paper-and-pencil daily diary is efficient and acceptable to subjects, yielded a negligible amount of missing data, provided relatively good estimates of the individual time spent outdoors, and can be used in future prospective and cross sectional studies. In summary, the results of our investigation of indoor workers, the first such study conducted in the United States, showed a significant correlation between the total self-recorded total daily time spent outdoors with objective personal UVR dose measurements, and support the use of personal daily diaries as a reliable tool to collect information on outdoor sun exposure.

Acknowledgments

The study was funded by the National Cancer Institute, National Institutes of Health and U.S. Public Health Service.

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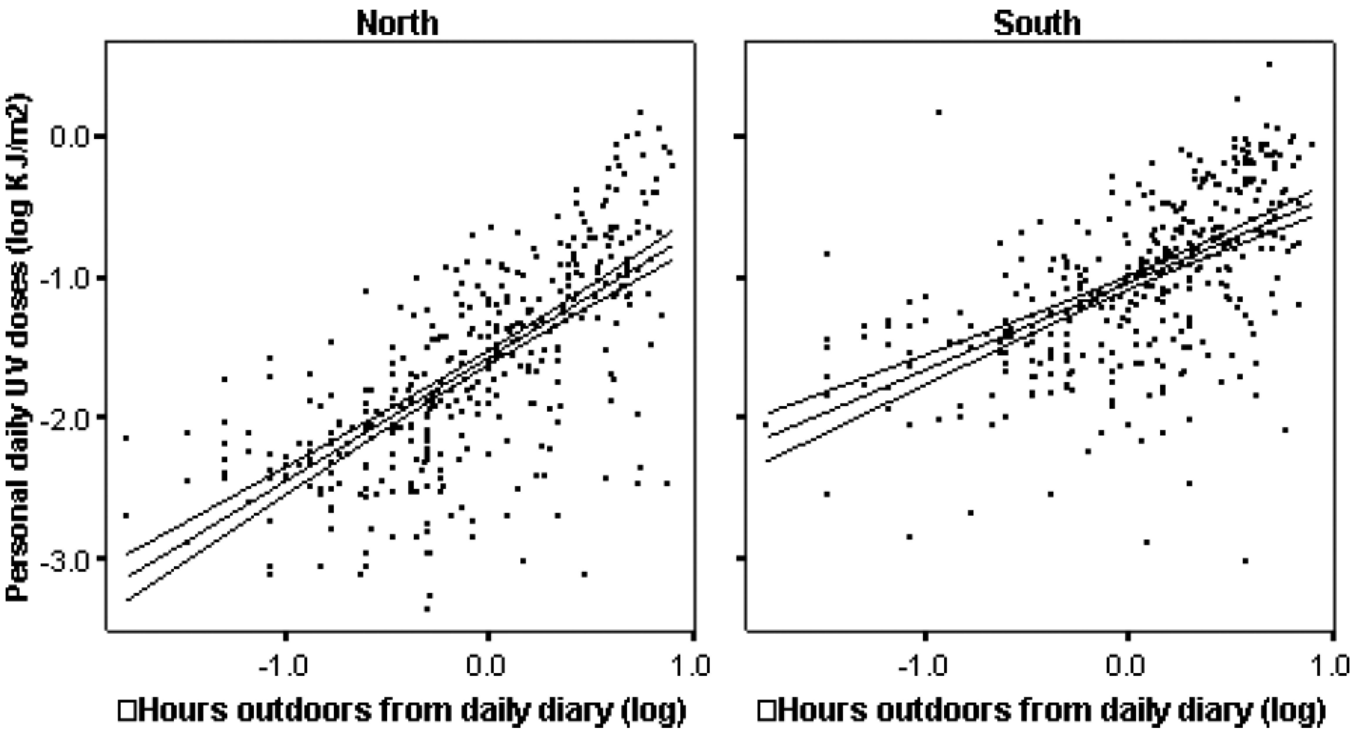

Figure 1.

Correlation coefficients and 95% CI boundaries between daily time spent outdoors and daily personal UVR dose. Spearman's rho correlation coefficients—south (0.63, $P < 0.001$), north (0.72, $P < 0.001$).

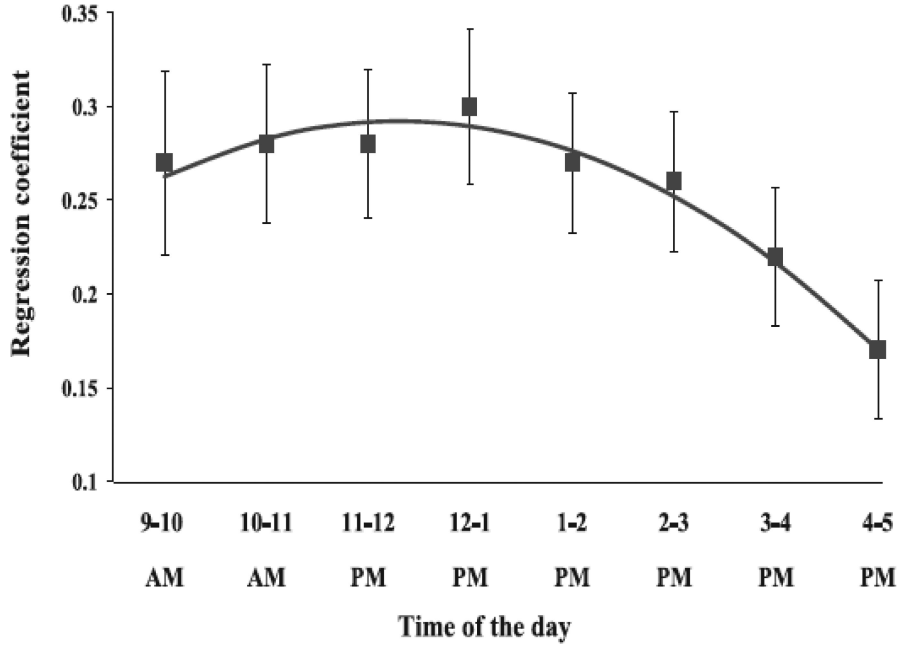

Figure 2.

Multivariate linear regression coefficient for self-recorded time outdoors (per hour) and measured personal UVR dose, according to the time of the day for which the outdoor time was reported. Other variables included in the regression: age, gender, type of day (weekend or weekday), region (southern or northern United States) and local terrestrial UVR dose. Curvilinear fit equation = −0.473 + 0.130 × hour of day (24 h) – 0.006 × hour of day (24 h)^2.

Table 1

Self-recorded daily (9:00 A.M.–5:00 P.M.) outdoor time (h) among indoor workers aged 40 or above, by gender, region in weekdays and weekend days.

	North			South		
	Weekdays	**Weekend days**	***P*** *	**Weekdays**	**Weekend days**	***P*** *
Men						
Overall recorded time in diary	7.76 (75.57–7.94)	7.80 (7.55–8.00)	NS	7.95 (7.85–8.00)	7.99 (7.98–8.00)	NS
Outdoors, overall	1.49 (1.19–1.80)	3.15 (2.16–3.70)	< 0.001	1.95 (1.64–2.25)	2.49 (2.04–2.94)	0.01
Driving	0.43 (0.31–0.54)	0.76 (0.49–1.03)	0.04	0.59 (0.48–0.71)	0.85 (0.60–1.10)	0.09
Leisure	0.45 (0.25–0.65)	0.63 (0.33–0.94)	NS	0.38 (0.23–0.52)	0.60 (0.32–0.88)	NS
Gardening	0.17 (0.10–0.24)	0.73 (0.43–1.03)	< 0.001	0.49 (0.28–0.70)	0.36 (0.16–0.56)	NS
Recreation	0.06 (0.00–0.14)	0.24 (0.00–0.49)	0.26	0.10 (0.01–0.18)	0.11 (0.00–0.27)	NS
House repair	0.20 (0.07–0.32)	0.31 (0.03–0.60)	NS	0.08 (0.01–0.15)	0.11 (0.01–0.21)	0.03
Walking the pet	0.04 (0.01–0.07)	0.17 (0.06–0.17)	0.002	0.11 (0.06–0.16)	0.22 (0.11–0.33)	0.03
Water activity	0.04 (0.00–0.10)	0.12 (0.01–0.22)	0.01	0.04 (0.00–0.10)	0.08 (0.00–0.17)	0.04
Women						
Overall recorded time in diary	7.88 (7.78–7.97)	7.93 (7.85–8.00)	NS	7.80 (7.63–7.97)	7.81 (7.54–8.00)	NS
Outdoors, overall	0.94 (0.77–1.10)	1.56 (1.19–1.94)	0.006	1.17 (0.96–1.38)	1.80 (1.32–2.27)	0.08
Driving	0.44 (0.34–0.53)	0.64 (0.45–0.83)	0.11	0.48 (0.35–0.62)	0.42 (0.24–0.60)	NS
Leisure	0.16 (0.11–0.21)	0.39 (0.23–0.55)	0.01	0.27 (0.18–0.35)	0.48 (0.25–0.71)	NS
Gardening	0.12 (0.05–0.19)	0.18 (0.07–0.29)	0.19	0.12 (0.07–0.18)	0.25 (0.09–0.41)	0.20
Walking the pet	0.07 (0.04–0.10)	0.10 (0.03–0.16)	NS	0.13 (0.09–0.17)	0.18 (0.08–0.28)	NS
Recreation	0.06 (0.01–0.10)	0.10 (0.01–0.18)	NS	0.07 (0.01–0.13)	0.31 (0.04–0.58)	NS
House repair	0.04 (0.00–0.09)	0.09 (0.01–0.18)	0.004	0.01 (0.00–0.03)	0.02 (0.00–0.05)	NS
Water activity	0.00 (0.00–0.00)	0.00 (0.00–0.39)	NS	0.01 (0.00–0.03)	0.01 (0.00–0.02)	NS

NS = nonsignificant.

*Kruskal–Wallis test.

Table 2

Self-recorded daily outdoor time, personal erythemally weighted solar UVR dose and personal percentage of ambient erythemally weighted solar UVR doses* (September 2004) among 124 adults in the United States and from a previously published national study in the United States.

		Daily time spent outdoors (h)		Personal daily UVR dose (J m^{-2})		Personal ambient UVR exposure (%)†	
	Age (years)	Mean	95% CI	Mean	95% CI	Mean (%)	95% CI
North	41–59	1.95	1.52–2.39	139.4	90.5–188.4	6.3	4.1–8.5
	60+	1.97	1.61–2.34	84.3	48.6–120.0	3.7	2.6–1.9
South	41–59	1.74	1.43–2.04	211.9	152.7–271.1	10.7	8.0–13.5
	60+	2.48	2.09–2.86	242.2	165.1–319.4	12.2	8.1–16.4
North	41–59	1.14	0.88–1.40	37.9	24.3–51.4	1.8	1.2–2.4
	60+	1.11	0.90–1.32	48.2	33.5–62.9	2.9	1.5–3.2
South	41–59	1.28	0.97–1.58	135.8	97.8–173.8	7.4	5.1–9.7
	60+	1.41	1.14–1.68	183.1	158.7–227.3	9.1	6.8–11.5

*Using personal polysulfone badges.

†Calculated as the daily personal UVR dose from the corresponding daily ambient UVR dose.

Table 3

Multivariate linear regression model* with personal daily erythemally weighted solar UVR as the dependent variable.

Variable	**Regression coefficient**	**95% CI**	***t***	***P*-value**
Type of day (weekend day *vs* weekday)	–0.011	–0.039 to 0.017	–0.77	0.439
Gender (women *vs* men)	0.075	–0.070 to 0.220	1.021	0.308
Age (≥60 years *vs* 40–59 years)	–0.011	–0.146 to 0.124	–0.158	0.874
Region (south *vs* north)	0.062	–0.074 to 0.197	0.891	0.373
Ambient UVR (J m^{-2})	0.019	0.006–0.037	2.71	0.007
Total time spent outdoors (per hour)	0.082	0.073–0.092	17.182	< 0.001

*Adjusted for unique identity number for each participant (data not shown). The model adjusted R^2 was 0.46.

Table 4

Multivariate* regression coefficients for activities documented in daily diaries and erythemally weighted solar UVR dose measured using polysulfone dosimeters

Outdoor activity	Regression coefficient	95% CI	*t*	*P*-value
Recreation (per hour)	0.176	0.152–0.200	14.39	< 0.001
Gardening (per hour)	0.118	0.099–0.014	12.45	< 0.001
Walking with pet (per hour)	0.077	0.030–0.125	3.207	0.001
Water activity (per hour)	0.060	0.010–0.111	2.34	0.019
Leisure activities (per hour)	0.060	0.042–0.078	6.517	< 0.001
House repair (per hour)	0.043	0.016–0.071	3.098	0.002
Driving (per hour)	0.039	0.021–0.057	4.305	0.039

Adjusted R^2 = 0.51.

*Adjusted for age, gender, region, type of day (weekend or weekday) and unique identity number for each participant (data not shown).