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Original Contribution

Frequency of Leisure-Time Physical Activity and Serum 25-Hydroxyvitamin D Levels in the US Population: Results from the Third National Health and Nutrition Examination Survey

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The decline in vitamin D status among older people is probably due to decreased synthesis of vitamin D by sun-exposed skin and/or decreased outdoor activity. The authors examined the association between outdoor leisure physical activity and serum 25-hydroxyvitamin D in the Third National Health and Nutrition Examination Survey (1988–1994) ($n = 15,148$ aged $\geq$20 years). The mean 25-hydroxyvitamin D concentration declined with increasing age, with 79, 73, and 68 nmol/liter for persons aged 20–39, 40–59, and 60 or more years. The proportion that engaged in outdoor activity in the past month was 80% for persons aged 20–39 and 40–59 years but 71% for those aged 60 or more years. In contrast, the mean difference in 25-hydroxyvitamin D between those who participated in outdoor activities daily compared with those who did not participate in the past month was similar for the youngest and oldest age groups: 13 and 16 nmol/liter, respectively. Those persons aged 60 or more years who participated in daily outdoor activities had a mean 25-hydroxyvitamin D concentration similar to that of persons aged 20–39 years: 77 versus 79 nmol/liter, respectively. These nationally representative data suggest that persons aged 60 or more years can synthesize enough vitamin D from daily outdoor activities to maintain vitamin D levels similar to those of young adults.

aged; ethnic groups; exercise; vitamin D

Abbreviation: NHANES III, Third National Health and Nutrition Examination Survey.

Editor's note: *An invited commentary on this article appears on page 587, and the authors' response appears on page 590.*

Increasing evidence suggests that low vitamin D status is a risk factor for a range of diseases, including bone disease, infection, cancer, diabetes, and cardiovascular disease (1). A recent meta-analysis of 18 randomized trials including more than 57,000 participants demonstrated a significant reduction in all-cause mortality among older individuals assigned to vitamin D supplements (2). Sun exposure is the primary determinant of vitamin D status, but age and the degree of skin pigmentation are known to modify the effect of the sun on vitamin D synthesis (3).

Since the late 1970s, researchers have noted that body levels of vitamin D, as measured by serum 25-hydroxyvitamin D, decline with age (4, 5). This decline is due partly to a decreased capacity by the epidermis of the elderly to photosynthesize previtamin D, as compared with younger subjects (6), but the decline also may be due to decreased sun exposure because sun tanning and sun burning decrease with age (7, 8).

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Racial/ethnic variations in vitamin D status also occur, with lower levels observed in non-Hispanic Blacks and Mexican Americans compared with non-Hispanic Whites (9). Vitamin D insufficiency (serum 25-hydroxyvitamin D, <50 nmol/liter) is much more common among non-Hispanic Blacks (in winter ranging from 53 percent to 76 percent across the main age-sex subgroups) than in Mexican Americans (18–50 percent) and non-Hispanic Whites (8–33 percent) (9). Studies of vitamin D photosynthesis have shown that non-Whites have a similar capacity to synthesize vitamin D, but they require longer exposure to sunlight to achieve a similar vitamin D response because of their increased skin pigmentation (10, 11).

Outdoor activities increase body vitamin D levels through sun-induced synthesis of vitamin D. Previous studies have shown a positive association between physical activity, in general, and vitamin D status. Blood levels of 25-hydroxyvitamin D have been observed to be higher in weightlifters and track athletes than matched sedentary controls in some studies (12, 13) but not all (14, 15). The cited studies had small sample sizes ($n < 60$) that may have decreased power to detect an association between physical activity and 25-hydroxyvitamin D.

Few epidemiologic studies have examined the relation between leisure-time physical activity and vitamin D status in the general population. In the early 1990s, a cross-sectional survey of middle-aged men in New Zealand found that men who engaged in weekly leisure-time aerobic activities (indoor and outdoor combined) had significantly increased plasma levels of 25-hydroxyvitamin D compared with inactive men after adjustment for weekly hours of sunshine exposure, especially in winter (16). In a healthy workforce sample, also in New Zealand, the mean level of serum 25-hydroxyvitamin D_3, the vitamin D metabolite formed mainly from sun exposure and which comprises the major portion of body vitamin D (1), was higher in people engaging in vigorous (aerobic) leisure physical activities compared with those who were inactive, after adjustment for age, sex, ethnicity, and time of year (17); moreover, serum 25-hydroxyvitamin D_3 was 11–13 nmol/liter higher in those who participated in outdoor versus indoor activities. Recent reports have confirmed these earlier findings. Analyses of male US health professionals showed that participants in the highest quintile of leisure-time physical activity had a 13.5 nmol/liter higher level of plasma 25-hydroxyvitamin D than those in the lowest activity quintile (18). A cross-sectional survey in Florida found that osteoporosis patients who reported participating in outdoor exercise were 47 percent less likely to have hypovitaminosis D (25-hydroxyvitamin D, $\leq$30 ng/ml or 75 nmol/liter) than were nonoutdoor exercisers (19). Finally, Dutch studies of older people living in the community have observed a positive association between the level of physical activity and serum 25-hydroxyvitamin D (20) and reported that serum 25-hydroxyvitamin D increased by 1.8 nmol/liter for each hour per day of outdoor activity (21).

The Third National Health and Nutrition Examination Survey (NHANES III) involved a representative sample of the US civilian population, who were interviewed during 1988–1994. With serum 25-hydroxyvitamin D measurements from over 19,000 participants, NHANES III offers a unique opportunity to examine the association between leisure-time physical activity and vitamin D status, as well as whether the observed association varies with place of activity (outdoor or indoor), type of activity (vigorous or moderate), age, race/ethnicity, and time of year.

MATERIALS AND METHODS

A cross-sectional survey representative of the US civilian noninstitutionalized population (NHANES III) was carried out during 1988–1994 by the National Center for Health Statistics. A stratified, multistage sampling design was used to recruit participants from household clusters, with oversampling of non-Hispanic Blacks and Mexican Americans. After an initial interview at home, participants visited mobile centers where they had an extensive physical examination. Full details of all survey methods, including sampling, interview, examination and laboratory measurement of blood samples, ethical approval, and informed consent, have been published (22).

A total of 23,258 adults, aged 20 or more years, were invited to take part in the survey. Of these, 18,825 were interviewed at home, 16,573 of whom attended mobile examination centers. In the home interview, information was collected on a wide range of variables including age, sex, and race/ethnicity (self-assigned as non-Hispanic White, non-Hispanic Black, Mexican American, other). Participants were asked about frequency and type of food intake over the past month. For milk consumption, participants were asked how often they had milk to drink or on cereal. The four questions on frequency of consumption of breakfast cereal, generally fortified with 40–50 IU of vitamin D per 28-g serving (23), covered the major brands for cold cereals plus cooked, hot cereals. Information on the intake of vitamin D supplements in the past month came from a general question asking, ‘‘Have you taken any vitamins or minerals in the past month?’’ Samples of each supplement were checked for their content when participants attended the mobile examination centers. Further details about the questions on food and vitamin D intake have been published (23).

The frequency of leisure-time activities in the past month was assessed from questions on nine common activities and up to four other activities (24). The common activities were walking a mile or more ($\geq$1.6 km) without stopping, jogging/running, bicycling (including exercise bicycle), swimming, aerobics, other dancing, calisthenics, gardening, and weights. These activities, and those listed in appendix 2 of the documentation for the NHANES III adult data set (25), were categorized as outdoor (e.g., walking, jogging, gardening) or indoor (e.g., aerobics, weights) by the first author (R. S.). Activities that could have been indoor or outdoor (e.g., bicycling including exercise bike, swimming, basketball) were classified as indoor. From the metabolic equivalents assigned for each physical activity, participants aged 60 or more years were classified as engaging in moderate or vigorous activities if the metabolic equivalent for any activity was 3.0 or more or 6.0 or more, respectively, while those aged 20–59 years were

TABLE 1. Proportion of NHANES III* participants doing outdoor or indoor leisure physical activity in the past month, by level of demographic variable and month of year, weighted to the US civilian population, 1988–1994

Variable and level	No. of participants	Outdoor activity, % (SE*)	Indoor activity, % (SE)	Outdoor and/or indoor activity, % (SE)
Age, years				
20–39	6,182	80 (1)	68 (1)	89 (1)
40–59	4,071	80 (1)	52 (1)	86 (1)
≥60	4,895	71 (1)	37 (1)	78 (1)
p value†		<0.0001	<0.0001	<0.0001
Sex				
Male	7,144	84 (1)	57 (1)	90 (1)
Female	8,004	72 (1)	54 (1)	82 (1)
p value		<0.0001	0.022	<0.0001
Race/ethnicity				
Non-Hispanic White	6,562	80 (1)	57 (1)	87 (1)
Mexican American	4,285	63 (2)	46 (1)	74 (1)
Non-Hispanic Black	4,301	67 (1)	53 (1)	78 (1)
p value		<0.0001	<0.0001	<0.0001
Month of year				
January-February	2,509	65 (2)	48 (3)	76 (2)
March-April	2,913	72 (2)	51 (2)	82 (2)
May-June	2,559	82 (1)	56 (2)	88 (1)
July-August	2,466	84 (1)	63 (2)	91 (1)
September-October	2,381	78 (1)	58 (4)	86 (1)
November-December	2,320	76 (1)	51 (4)	84 (2)
p value		<0.0001	<0.0001	<0.0001
Total sample	15,148	78 (1)	56 (1)	86 (1)

* NHANES III, Third National Health and Nutrition Examination Survey; SE, standard error.

† *p* value showing significance of variation in percentages among subgroups, from the log-likelihood chi-square value.

similarly classified if the metabolic equivalent for any activity was 3.5 or more or 7.0 or more, respectively (26).

At the mobile examination centers, participants were dressed in underpants, disposable light clothing, and slippers while being weighed in kilograms, to two decimal places, on electronic scales. Height was measured to the nearest millimeter with a fixed stadiometer (27). Body mass index was calculated as weight (kg)/height (m)^2. The date of the interview was used to classify people by calendar month.

Blood samples collected during the examination were centrifuged, aliquoted, and frozen to −70°C on site, before being shipped on dry ice to central laboratories where they were stored at −70°C until analysis (28). Serum 25-hydroxyvitamin D was measured by a radioimmunoassay kit after extraction with acetonitrile (DiaSorin, Inc., Stillwater, Minnesota) by the National Center for Environmental Health in Atlanta, Georgia (29). Serum 25-hydroxyvitamin D concentrations ranged from 8.7 to 243.6 nmol/liter after one person with a 25-hydroxyvitamin D value of 400.1 nmol/liter was excluded.

Data in this report are restricted to non-Hispanic White, non-Hispanic Black, and Mexican-American adults, aged 20 or more years, who attended the mobile examination centers ($n = 15{,}148$) after excluding those who had missing 25-hydroxyvitamin D measurements ($n = 790$), the one person with a very high outlying 25-hydroxyvitamin D value of 400.1 nmol/liter, and those who were of "other" race/ethnicity ($n = 634$).

Statistical analyses were carried out with SUDAAN, version 9.0.0, software (SUDAAN Statistical Software Center, Research Triangle Park, North Carolina), by using the sampling weights from the mobile examination centers to adjust for oversampling of non-Hispanic Blacks and Mexican Americans and to correct standard errors for any design effect arising from clustered sampling. Statistical significance was two sided.

RESULTS

The (weighted) proportion of all participants who did some type of outdoor physical activity in the last month was 78 percent; some type of indoor activity, 56 percent; and either, 86 percent (table 1). The proportion who engaged

TABLE 2. Mean (SE*) 25-hydroxyvitamin D concentration by level of demographic and lifestyle variable and month of year, adjusted for all the other variables in the table, for NHANES III* participants weighted to the US civilian population, 1988–1994

Variable and level	No. of participants	Mean 25-hydroxyvitamin D, nmol/liter (SE)	*p* value (*t* test)
Age, years			
20–39	6,182	79 (1)	Referent
40–59	4,071	73 (1)	$<$0.0001
$\geq$60	4,895	68 (1)	$<$0.0001
Sex			
Male	7,144	78 (1)	Referent
Female	8,004	72 (1)	$<$0.0001
Race/ethnicity			
Non-Hispanic White	6,562	78 (1)	Referent
Mexican American	4,285	68 (1)	$<$0.0001
Non-Hispanic Black	4,301	51 (1)	$<$0.0001
Body mass index, kg/m^2 (quintile)			
$\leq$22.4	3,037	79 (1)	Referent
22.5–25.0	2,993	78 (1)	0.10
25.1–27.6	3,085	74 (1)	$<$0.0001
27.7–31.1	2,961	72 (1)	$<$0.0001
$\geq$31.2	3,038	67 (1)	$<$0.0001
Month of year			
January-February	2,509	68 (2)	Referent
March-April	2,913	67 (1)	0.44
May-June	2,559	72 (2)	0.13
July-August	2,466	80 (1)	$<$0.0001
September-October	2,381	80 (1)	$<$0.0001
November-December	2,320	72 (1)	0.15
Milk intake, times in last month			
0	2,447	70 (1)	Referent
1–12	4,374	72 (1)	0.048
13–30	6,693	76 (1)	$<$0.0001
$\geq$31	1,600	80 (1)	$<$0.0001
Cereal intake, times in last month			
0	2,643	75 (1)	Referent
1–12	5,780	74 (1)	0.29
13–30	4,968	75 (1)	0.84
$\geq$31	1,714	74 (1)	0.37
Vitamin D supplements, IU/day			
0	11,631	73 (1)	Referent
$>$0–$<$200	627	76 (2)	0.11
200–$<$400	307	77 (2)	0.09
$\geq$400	2,583	78 (1)	$<$0.0001
Leisure-time physical activity, times in last month			
0	3,329	69 (1)	Referent
1–4	2,527	72 (1)	0.01
5–12	2,204	73 (1)	$<$0.0001
13–30	3,260	76 (1)	$<$0.0001
$\geq$31	3,828	79 (1)	$<$0.0001
Total sample	15,148		

Table continues

TABLE 2. Continued

* SE, standard error; NHANES III, Third National Health and Nutrition Examination Survey.

in outdoor leisure activity in the past month was similar for those aged 20–39 and 40–59 years (each with 80 percent) but lower for those aged 60 or more years (71 percent). There was even greater variation with age in the proportion engaging in indoor activity, from 68 percent in the youngest age group down to 37 percent in the oldest group. Males were more likely than females to participate in outdoor and indoor activities. With regard to race/ethnicity, non-Hispanic Whites were most likely to engage in both outdoor and indoor activities and Mexican Americans least likely. The proportion engaging in outdoor and indoor activity also varied by month, being lowest in January-February and increasing to a peak in July-August before declining again.

The adjusted mean serum 25-hydroxyvitamin D concentrations varied between levels of demographic and lifestyle variables (table 2). The vitamin D level decreased with increasing age, particularly between the ages of 20–39 and 40–49 years, and was lower in women than men. For race/ethnicity, vitamin D was highest in non-Hispanic Whites, intermediate in Mexican Americans, and lowest in non-Hispanic Blacks. Vitamin D levels were inversely associated with body mass index. The expected seasonal variation in 25-hydroxyvitamin D was present, with levels being lowest in March-April and highest in July-October, adjusting for covariates.

Vitamin D concentrations were also related to lifestyle, being positively associated with frequency of milk intake in the last month and with daily amount of vitamin D supplement intake, but not with cereal intake. With regard to leisure physical activity, the adjusted mean serum 25-hydroxyvitamin D concentrations were lowest in participants who had no leisure-time physical activity during the previous month, compared with those who were physically active, and increased in a stepwise fashion with increasing frequency of activity.

Table 3 shows the association between serum 25-hydroxyvitamin D and the place (outdoor/indoor) and intensity (aerobic/nonaerobic) of leisure physical activity. Compared with that of inactive participants, the mean difference

TABLE 3. Mean difference in serum 25-hydroxyvitamin D, by place, intensity, and frequency of leisure-time physical activity, compared with inactive participants, for NHANES III* participants weighted to the US civilian population, 1988–1994

Type and frequency of leisure activity, times/month	No. of participants	Adjusted for covariates†			Adjusted for covariates† and both other activity variables		
		Difference in serum 25-hydroxyvitamin D, nmol/liter		*p* value‡	Difference in serum 25-hydroxyvitamin D, nmol/liter		*p* value‡
		Mean	95% confidence interval		Mean	95% confidence interval	
Outdoor							
None	4,654	0		<0.0001	0		0.0005
1–4	3,393	4.2	2.0, 6.4		3.3	0.2, 6.4	
5–12	2,202	4.5	2.8, 6.3		3.5	1.1, 6.0	
13–30	3,126	7.9	5.9, 9.9		6.1	2.8, 9.3	
≥31	1,773	11.5	8.4, 14.6		9.6	5.4, 13.7	
Indoor							
None	8,105	0		0.0028	0		0.40
1–4	2,215	1.0	−1.0, 3.0		0.1	−2.1, 2.3	
5–12	1,427	1.7	−0.8, 4.1		0.0	−2.9, 2.9	
13–30	2,098	4.0	1.9, 6.1		1.8	−0.7, 4.4	
≥31	1,303	4.4	0.4, 8.3		1.6	−3.2, 6.4	
Intensity							
Inactive	3,371	0		<0.0001	0		0.42
Moderate							
1–11	4,231	4.1	2.0, 6.1		1.2	−1.7, 4.1	
≥12	5,227	8.7	6.7, 10.7		2.5	−1.1, 6.1	
Vigorous							
1–11	1,504	6.5	3.7, 9.3		0.6	−3.2, 4.3	
≥12	815	10.7	7.8, 13.7		2.3	−2.6, 7.2	

* NHANES III, Third National Health and Nutrition Examination Survey.

† Covariates: age, sex, race/ethnicity, body mass index, month of year, and intakes of milk, cereal, and vitamin D supplements.

‡ *p* value for the adjusted *F* statistic based on the Wald chi-square value.

in serum 25-hydroxyvitamin D level increased with the frequency of both outdoor and indoor activities, with adjustment for demographic and lifestyle variables, but the difference in vitamin D was twice as high for outdoor activities as for indoor activities. The intensity of physical activity was associated with a difference in vitamin D similar to that with outdoor activity, with vitamin D being 10.7 nmol/liter higher in people engaging in daily vigorous activities and 11.5 nmol/liter higher in people engaging in daily outdoor activities compared with inactive people. However, when all three categories of physical activity were entered in the same model, only outdoor activity remained significantly associated with a higher serum 25-hydroxyvitamin D level compared with inactive people ($p = 0.0005$).

We examined the differences in vitamin D by frequency of outdoor activities to see if the differences varied by demographic variable and time of year. Figure 1 shows that the mean difference in 25-hydroxyvitamin D level between those who engaged in outdoor activities compared with those who engaged in none in the past month was similar for those aged 20–39 and 60 or more years (13 vs. 16 nmol/liter, respectively). The mean vitamin D differences for frequency of outdoor activity were similar for men and women and did not vary greatly by time of year (data not shown). In contrast, the mean vitamin D difference by frequency of outdoor activity varied with race/ethnicity, being higher at all activity frequency levels in non-Hispanic Whites compared with both Mexican Americans and non-Hispanic Blacks (figure 2).

The adjusted mean serum 25-hydroxyvitamin D concentrations for outdoor activity frequency groups are shown in table 4 according to demographic variables and time of year. With regard to age, participants aged 60 or more years had lower vitamin D levels in all activity frequency groups. However, the mean 25-hydroxyvitamin D concentration for participants aged 60 or more years who engaged in daily outdoor activities (77 nmol/liter) was similar to the mean for participants aged 20–39 years who were inactive or engaged

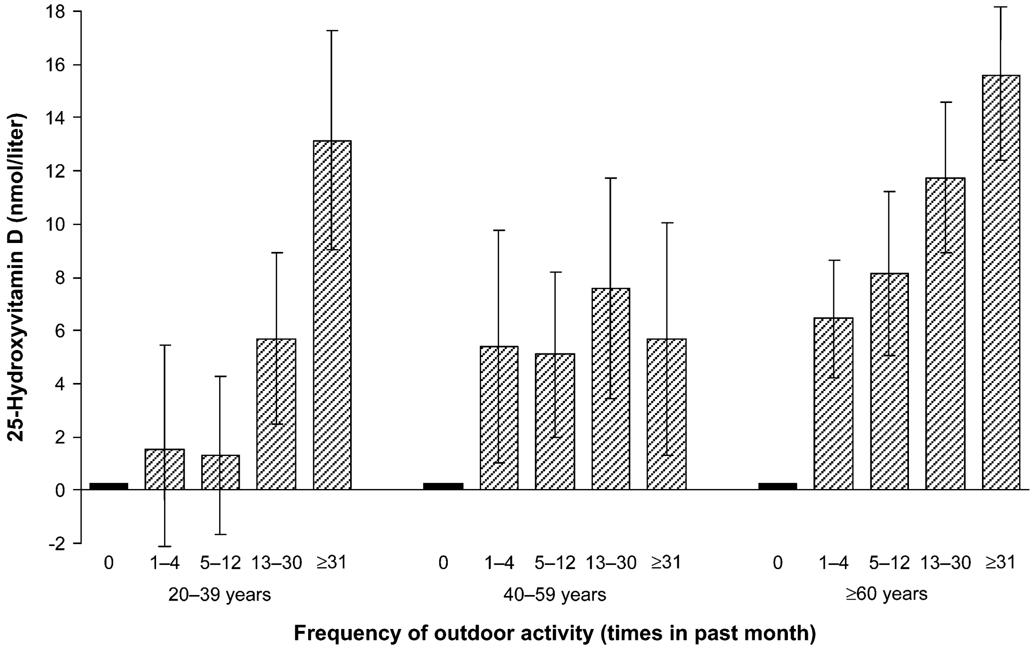

FIGURE 1. Mean (95% confidence interval) difference in serum 25-hydroxyvitamin D concentration associated with frequency of outdoor activity in the past month, compared with no outdoor activity, by age group, adjusted for sex, ethnicity, body mass index, month, milk, cereal, and vitamin D supplements, Third National Health and Nutrition Examination Survey, 1988–1994. Solid bars, reference; striped bars, mean difference.

in outdoor activities 1–4 and 5–12 times per month (76, 77, and 77 nmol/liter, respectively). Similarly, women who engaged in daily outdoor activities had a mean 25-hydroxyvitamin D level (79 nmol/liter) that was higher than or similar to those of men who were inactive (74 nmol/liter) or participated in outdoor activities less than daily (76, 77, and 81 nmol/liter for activity 1–4, 5–12, and 13–30 times per month, respectively). In contrast, race/ethnic differences

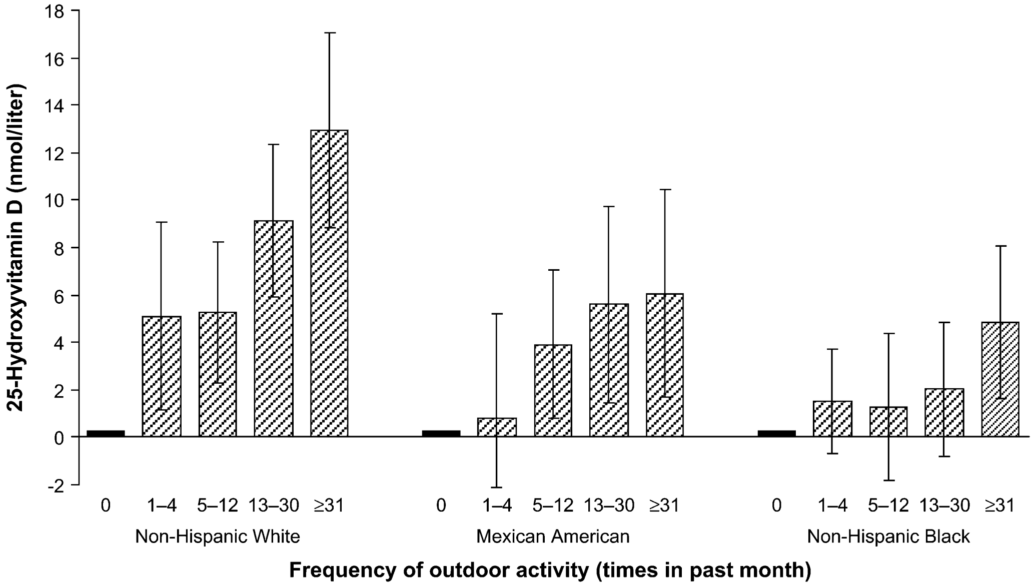

FIGURE 2. Mean (95% confidence interval) difference in serum 25-hydroxyvitamin D concentration associated with frequency of outdoor activity in the past month, compared with no outdoor activity, by ethnic group, adjusted for sex, age, body mass index, month, milk, cereal, and vitamin D supplements, Third National Health and Nutrition Examination Survey, 1988–1994. Solid bars, reference; striped bars, mean difference.

TABLE 4. Mean (SE*) serum 25-hydroxyvitamin D (nmol/liter) associated with frequency of outdoor leisure-time activities, by level of demographic variable and month of year, adjusted for all the variables in the table (as appropriate) plus covariates,† for NHANES III* participants weighted to the US civilian population, 1988–1994

Variable and level	Frequency of outdoor activity in the past month					p value‡
	None	1–4	5–12	13–30	≥31	
Age, years						
20–39	76 (1)	77 (2)	77 (1)	81 (2)	89 (2)	<0.0001
40–59	67 (1)	73 (1)	72 (1)	75 (1)	73 (2)	0.01
≥60	61 (1)	68 (1)	70 (1)	73 (1)	77 (1)	<0.0001
Sex						
Male	74 (1)	76 (1)	77 (1)	81 (1)	84 (2)	0.0001
Female	66 (1)	71 (1)	71 (1)	74 (1)	79 (2)	<0.0001
Race/ethnicity						
Non-Hispanic White	73 (1)	78 (1)	78 (1)	82 (1)	86 (2)	<0.0001
Mexican American	60 (1)	61 (1)	64 (1)	66 (1)	66 (2)	<0.0001
Non-Hispanic Black	47 (1)	48 (1)	48 (1)	49 (1)	52 (1)	0.0001
Month of year						
January-February	62 (2)	62 (2)	64 (2)	67 (3)	72 (4)	0.02
March-April	62 (2)	64 (2)	65 (1)	68 (3)	74 (3)	0.005
May-June	69 (2)	74 (2)	73 (1)	75 (3)	78 (3)	0.0495
July-August	77 (1)	79 (3)	81 (2)	86 (2)	91 (3)	<0.0001
September-October	72 (2)	79 (1)	83 (2)	82 (1)	83 (2)	<0.0001
November-December	64 (2)	73 (2)	68 (1)	74 (2)	76 (3)	<0.0001

* SE, standard error; NHANES III, Third National Health and Nutrition Examination Survey.

† Covariates: body mass index and intakes of milk, cereal, and vitamin D supplements.

‡ *p* value for the adjusted *F* statistic based on the Wald chi-square value.

in the serum 25-hydroxyvitamin D level were so large that vitamin D levels for non-Hispanic Blacks and Mexican Americans engaging in daily outdoor activities (52 and 66 nmol/liter, respectively) were lower than that for inactive non-Hispanic Whites (73 nmol/liter).

DISCUSSION

These findings from a nationally representative US sample indicate that regular outdoor physical activity is associated with higher levels of serum 25-hydroxyvitamin D. In particular, consistent with previous research (17), it is the place of physical activity (outdoor rather than indoor) and the frequency of activity rather than the intensity that are related to vitamin D status (table 3).

Previous research has shown that the capacity to synthesize vitamin D from solar ultraviolet B exposure decreases with age (6). A somewhat surprising observation in the present study was that the 25-hydroxyvitamin D increase with daily outdoor activity in people aged 60 or more years was as great as that in people aged 20–39 years (figure 1). One explanation is that older people, who are mostly retired, may spend more time outside each time they participate in physical activity than younger and middle-aged people who are mostly working. Another explanation is that adults aged less than 60 years, who are mostly working, are less able to do physical activity in the middle of the day when ultraviolet radiation from the sun is strongest (30). The elevated serum 25-hydroxyvitamin D level in people aged 60 or more years who participated in daily outdoor physical activity indicates that this activity pattern can minimize and potentially prevent the age-related decline in body vitamin D status. This finding is consistent with that of a recent survey of people aged 60–87 years who were living in a Dutch town (i.e., that outdoor activities were associated with significantly higher plasma 25-hydroxyvitamin D levels) (21).

The increase in serum 25-hydroxyvitamin D with daily outdoor physical activity occurred in all seasons (table 4). This result was also surprising because solar radiation is strongest in summer and weakest in winter when prolonged sun exposure (>4 hours) is required for skin to synthesize vitamin D at latitudes above 25 degrees, particularly above 42 degrees North where no synthesis takes place (30, 31). However, interviews in NHANES III were carried out mainly in the southern states during winter and in the northern states during summer to ensure optimal weather conditions for interviewing (9). Thus, the NHANES III sample will have overestimated solar radiation exposure in winter and underestimated it in summer, since the intensity of solar radiation is inversely associated with latitude (30).

The greater increase in 25-hydroxyvitamin D with daily outdoor activity in non-Hispanic Whites, compared with

Mexican Americans and non-Hispanic Blacks, was expected because the capacity to synthesize vitamin D from sun exposure is inversely related to the degree of skin pigmentation (10, 11). The maximum mean level of serum 25-hydroxyvitamin D of 52 nmol/liter in non-Hispanic Blacks observed among those who engaged in daily outdoor activity (table 4) is of concern, given recent evidence suggesting that serum 25-hydroxyvitamin D levels need to be above 75 nmol/liter for optimum health (32). Other strategies, such as vitamin D supplementation or fortification of food, as already occurs with milk, are required to elevate 25-hydroxyvitamin D in African Americans to the above desired level during winter months at higher latitudes. The lack of an association between cereal consumption and serum 25-hydroxyvitamin D (table 2) contrasts with results for African American and White women aged 15–49 years from the same study that showed significantly higher unadjusted vitamin D levels for women in the highest cereal consumption category, although the significant association between serum 25-hydroxyvitamin D and cereals remained only in Black women after adjusting for covariates that included milk consumption (23). In our analyses, there was a significant positive association ($p < 0.001$) between the frequency of cereal intake and serum 25-hydroxyvitamin D when milk was excluded from the model (data not shown), indicating that milk consumption was a positive confounder. Thus, cereal consumption in the United States during 1988–1994 may have been associated with vitamin D status in subgroups such as young Black women (23), but not in the total population.

Daily outdoor physical activity was associated with an increase in 25-hydroxyvitamin D similar to that of daily consumption of milk, both about 10 nmol/liter (table 2), indicating that both are likely to be effective strategies for modest increases in body levels of vitamin D. Daily consumption of at least 400 IU of vitamin D supplements was associated with a smaller increase in 25-hydroxyvitamin D of about 5 nmol/liter (table 2), a little lower than the reported increase of 1.75 nmol/liter per 100 IU of vitamin D_3 or 7 nmol/liter per 400 IU supplement (33). A possible explanation is that many participants may have used vitamin D_2 that does not increase 25-hydroxyvitamin D levels as much as vitamin D_3 (34). More importantly, recent studies indicate that much higher levels (e.g., 4,000 IU per day) are required to increase serum 25-hydroxyvitamin D levels up to 100 nmol/liter (35). These and other data (33, 36) suggest that the larger-dosed vitamin D supplements would assist individuals living at higher latitudes to have optimal levels of 25-hydroxyvitamin D.

The finding of a strong association between outdoor physical activity and vitamin D status has implications for public health. The data in table 1 show that 22 percent of all US adults did not participate in any outdoor physical activity in the past month at the time NHANES III was carried out. Of concern, those groups with the lowest vitamin D levels—the elderly, Mexican Americans, and non-Hispanic Blacks—were least likely to have reported engaging in any outdoor physical activity in the past month. Public health interventions supporting outdoor activities probably would improve the vitamin D status of these communities. Previous research suggests that a 10 nmol/liter increase in 25-hydroxyvitamin D from daily outdoor physical activity (table 3) could result in modest but important reductions in disease rates. For example, a recent meta-analysis of randomized clinical trials has shown that a weighted vitamin D dose of 528 IU/day, estimated to have increased 25-hydroxyvitamin D by 1.75 nmol/liter per 100 IU (33) or about 9 nmol/liter, reduced total mortality by 7 percent (2). A cohort study of US health professionals observed that a 25 nmol/liter increase in predicted plasma 25-hydroxyvitamin D was associated with a 17 percent reduction in total cancer incidence (37), equivalent to a 7 percent reduction for a 10 nmol/liter increase in 25-hydroxyvitamin D. The association between outdoor physical activity and vitamin D status provides another mechanism for how physical activity may lower chronic disease risk. The well-documented inverse association between physical activity and various diseases, such as coronary heart disease, diabetes, and breast and colon cancers (38), may partly be due to increased vitamin D levels arising from outdoor physical activity, since epidemiologic evidence suggests that low vitamin D status increases the risk of these diseases after controlling for physical activity (39–41).

This study has a few limitations. Its cross-sectional design precludes determination of cause and effect. Moreover, measurement error is likely to be present, particularly with regard to physical activity measures. For example, the place of physical activity (outdoor or indoor) was not recorded during the interview and had to be inferred from the type of activity. Information was collected only on the frequency of physical activity and not on the time participating in activity or the time of day when it was carried out. Both of the latter are likely to have influenced serum 25-hydroxyvitamin D levels. Further, the determination of vitamin D status from a single measure of serum 25-hydroxyvitamin D also is likely to have contributed to measurement error. If this measurement error was random, it may have weakened the observed association between outdoor physical activity and vitamin D, in which case, the true effect of outdoor physical activity on vitamin D status maybe stronger than what is reported in this paper.

In summary, nationally representative data demonstrate a strong association between the frequency of outdoor physical activity and serum levels of 25-hydroxyvitamin D in the US population. Daily outdoor activities may be able to redress the differences in vitamin D status associated with age and sex, but not those associated with race/ethnicity. Public health strategies that support daily outdoor activities that are safe (e.g., by avoiding sun burn) probably will increase the vitamin D status of the general population. However, additional strategies, such as higher-dosed vitamin D supplements, are required for African Americans in order to achieve optimal vitamin D levels.

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