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Associations between objective and self-reported physical activity and vitamin D serum levels in the US population

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Abstract

Purpose

Both low levels of vitamin D and of physical activity are associated with all-cause, cancer and cardiovascular disease mortality. There is some evidence based on self-reported activity levels that physically more active individuals have higher vitamin D serum levels. The aim was to investigate associations between objectively measured and self-reported physical activity, respectively, and vitamin D serum concentrations in the US population.

Methods

Data from NHANES 2003-06 (n=6370, aged≥18 years) were analyzed using multiple regression analyses. 6370 individuals aged 18 years and older with valid data on vitamin D serum levels and physical activity were included. Objective physical activity was assessed using accelerometers, self-reported physical activity was based on the NHANES physical activity questionnaire.

Results

An increase of 10 minutes of objectively measured and self-reported moderate-to-vigorous activities per day was associated with an increase in circulating vitamin D of 0.32 ng/ml (95% CI 0.17, 0.48) and of 0.18 ng/ml (95% CI 0.12, 0.23), respectively. The odds ratio for being vitamin D deficient (<20ng/ml) if being insufficiently active compared to being sufficiently active was 1.32 (1.11, 1.57). Associations were not stronger for self-reported outdoor activities compared with indoor activities.

Conclusions

Physical activity may be a way to achieve higher vitamin D serum levels in the population. Factors other than sun exposure that may be responsible for higher vitamin D levels in more active individuals need further investigation.

Key words:

25-hydrodxyvitamin D, accelerometers, NHANES, physical activity, USA

Introduction

Several studies have shown associations between low vitamin D levels and adverse health outcomes: Associations with all-cause [1-6], cancer [7, 5, 6] and cardiovascular disease [5, 3, 4, 6] mortality were reported. Furthermore, associations between low vitamin D levels and morbidity were described for some types of cancer [8, 9], cardiovascular disease [10] and type 2 diabetes [11, 12]. Some of the studies regarding vitamin D and mortality [13, 3-5] as well as other outcomes [10, 14, 12] were based on data of the National Health and Nutrition Examination Survey (NHANES).

At the same time, it is well recognized that physical activity has positive effects on health [15, 16]. Lower mortality rates in more active individuals have also been reported in the NHANES population [17, 18]. These studies were based on self-reported physical activity. Objective physical activity data from NHANES have mostly been analyzed regarding prevalence and patterns of physical activity [19-22].

There are some studies that investigated physical activity as correlates or predictors of vitamin D status [23-28]. Scragg & Camargo (2008) reported associations between the frequency of leisure-time physical activity and vitamin D levels in NHANES III based on self-reported physical activity [23]. Specifically, they reported higher vitamin D levels for the same amount of outdoor compared to indoor activities, suggesting that sun exposure may trigger higher vitamin D levels in more active individuals. However, vitamin D levels also increased for higher amounts of indoor activity. In postmenopausal women, recreational physical activity was a predictor for higher vitamin D levels [27]. However, associations were attenuated (but still significant) when adjusting for covariates such as sun exposure, season, vitamin D intake, and waist circumference [24]. Physical inactivity, among other factors such as obesity and low vitamin D dietary and supplement intake, was reported as a major modifiable predictor of low vitamin D status in the US [25]. Another study including participants from around the world reported vigorous physical activity to be positively correlated with vitamin D levels [26]. In African-American men, who are known to suffer more often from low vitamin D levels than white men, vitamin D concentrations increased with more recreational physical activity [28].

To our knowledge, the present study is the first to use objective physical activity data in combination with vitamin D levels. Furthermore, while Scragg & Camargo (2008) used self-reported physical activity data from NHANES III, we analyzed more recent and more detailed self-reported physical activity data from NHANES 2003-06 which also includes information on the average duration in addition to the frequency and intensity.

The aim of this study was to investigate associations between objectively measured as well as self-reported physical activity and vitamin D levels in a large sample of US adults adjusting for a number of potential confounders. Furthermore, stratified analyses according to sex, age, ethnicity, body mass index (BMI), vitamin D supplement intake and season/region will shed light on potentially different associations in these sub groups.

Materials and Methods

Study population

The study is based on data from the National Health and Nutrition Examination Survey (NHANES) 2003-2006, two cross-sectional survey cycles (2003/04 and 2005/06, respectively) representative of the US civilian non-institutionalized population carried out by the National Center for Health Statistics of the Centers for Disease Control and Prevention. A multistage probability sampling is used to recruit participants. The National Center for Health Statistics Institutional Review Board has reviewed and approved the survey protocol and written informed consent was obtained from all participants. A detailed description of the surveys has been published elsewhere [29].

For the present analyses, data on serum vitamin D levels were available from blood samples; objective physical activity data were available from accelerometer measures included in the physical examinations. Data of more than 20’000 individuals are available for NHANES 2003-2006. We included 11’183 individuals aged 18 years and older. Of these, 546 individuals were excluded because they only participated in the interview part but not in the mobile examination center part of NHANES. A further 606 individuals were excluded due to missing data on vitamin D serum levels (N=10’031). Finally 3661 individuals were excluded because they had not sufficient valid objective physical activity data (see below), leaving 6370 individuals for analyses.

Measurements

Physical Activity (exposure)

Objective physical activity was measured in 2003/04 and 2005/06 using the ActiGraph 7164 accelerometer (ActiGraph, Shalimar, FL). This accelerometer has been validated in earlier studies [30-32]. At the medical examination center (MEC), participants aged 6 years and older were asked to wear an accelerometer on their right hip for 7 consecutive days following the examination. An epoch time of 1 minute was used. Individuals were included in the analyses if they had at least 4 days of physical activity data with at least 10 hours per day of accelerometer wear time [20]. For sensitivity analyses, we also analyzed data of individuals with at least 1 day of physical activity data with at least 8 valid hours per day (N=8178).

The units of measurement of the ActiGraph accelerometer are "counts", filtered accelerometer values summed over a specified epoch time such as one minute. The value of the counts varies based on the frequency and intensity of the raw acceleration. In order to quantify the duration of physical activity in different intensity levels, the following cut points were used: sedentary (<100 counts/min) [21], light (100-759 counts/min), lifestyle (760-2019 counts/min) [33], moderate (2020-5998 counts/min) and vigorous (≥5999 counts/min) [19]. Counts/minute, minutes spent in moderate-to-vigorous physical activity per day, and physical activity category (achieving ≥150 minutes per week of moderate-to-vigorous activities versus less corresponding to sufficiently active versus insufficiently active) were used as exposure variables in the regression models. There is no information regarding where the physical activity took place (indoor/outdoor).

Self-reported physical activity was based on the NHANES physical activity questionnaire and included the individual activity questions. To our knowledge, this questionnaire is not validated. Only leisure-time physical activity (but not transport-related activity and household activity) was used as these activities correlated best with objectively measured physical activity (data not shown). Participants stating that they engaged in moderate or vigorous leisure-time physical activities reported individual activities including the intensity level, the frequency during the past 30 days and the average duration. Examples of moderate activities are brisk walking and gardening, examples of vigorous activities running and fast bicycling. Minutes per day were calculated for total leisure-time activities, and for moderate and vigorous activities separately. Furthermore, individual activities were categorized as "indoor" and "outdoor" based on discussion with experts that are familiar with the physical activity habits in the US. Minutes per day spent in indoor and outdoor leisure-time activities were calculated.

Vitamin D (outcome)

Serum 25-hydroxyvitamin D concentrations were measured at the National Center for Environmental Health using a radioimmunoassay kit (Diasorin Corporation, Stillwater, MN) [34, 35]. A level of <20 ng/ml was used to define vitamin D deficiency [36].

Other variables

Socio-demographic variables (education [36], race/ethnicity [37, 36], gender [37], age [37], marital status, and poverty income ratio (PIR)) were considered as potential confounders. Education was dichotomized into post secondary education (college or higher) versus lower. Ethnicity was categorized as non-Hispanic White, non-Hispanic Black, Mexican-American, and other. Marital status included living together versus single (including widowed, separated, divorced and never married). As a measure of socio-economic status, PIR was categorized as at or above poverty versus below poverty. Season was taken into account based on the time of assessment, as higher-latitude regions in the northern states tended to be sampled during the summer months, whereas lower-latitude regions in the south tended to be sampled in the winter months (northern states/summer: May-October; southern states/winter: November-April [4, 3]). There is no more precise variable available for season in NHANES.

Self-reported smoking (current smoker versus current non-smoker) and alcohol intake (no drinks, ≤1 drink per week, and >1 drink per week) were used to reflect other health behaviors. Furthermore, milk consumption (daily versus less than daily) with respect to fortification of milk with vitamin D in the US [36, 38] and the intake of vitamin D supplements (mcg/day) based on detailed information on supplement intake and ingredient information were included.

Regarding health-related variables, BMI [37, 36, 39], general health status [36], hypertension [36, 40], cholesterol [36], and diabetes [11, 12] were taken into account. BMI was based on measured height and weight and categorized as normal weight ($BMI<25kg/m^2$), overweight ($25\ g/m^2 \leq BMI<30kg/m^2$) and obese ($BMI \geq 30kg/m^2$). General health status was derived from questionnaire data and coded as excellent/very good, good, and not so good/poor. Self-reported hypertension was coded as yes if a participant had ever been told to have high blood pressure/hypertension or was taking any prescribed medicine for hypertension. Self-reported hypercholesterolemia was coded as yes if a person had been told by a doctor to have a high cholesterol level or was taking any prescribed medicine to lower blood cholesterol. Self-reported diabetes was coded as yes if an individual was told by a doctor to have diabetes, or was taking insulin or diabetic pills to lower blood sugar.

Statistical analyses

Weighted means and proportions were used for descriptive statistics. Linear regression was used to model the association between physical activity and continuous vitamin D levels. Objective physical activity was expressed as mean counts/minute, minutes/day spent in moderate-to-vigorous activities, and physical activity categories (≥150 min/week of moderate-to-vigorous activities versus less). Self-reported leisure-time physical activity was expressed as minutes per day in different intensities (moderate, vigorous) as well as indoor/outdoor categories. Logistic regression analysis was used to model the odds ratio (OR) of having a vitamin D deficiency based on the physical activity category. Models 1 present the unadjusted results, models 2 are adjusted for sex, age, ethnicity, PIR, education, marital status, and season/region. Finally models 3 were additionally adjusted for alcohol intake, smoking, BMI, general health status, daily milk intake, vitamin D supplement intake, hypertension, hypercholesterolemia, and diabetes. For self-reported physical activity as exposure, only the fully adjusted models are presented, these also include adjustment for other physical activities (e.g. for outdoor activities when indoor activities are used in the analyses).

For objective physical activity, adjusted means were calculated by quartiles of physical activity levels (counts/minute, mean minutes spent in moderate and vigorous activities) and by physical activity categories (insufficiently active, sufficiently active). Linear hypothesis testing was used to look at the trends of the adjusted means by physical activity level.

The regression analyses were also stratified individually by sex, age category (18-39 years, 40-64 years, ≥65 years), ethnicity, BMI category, vitamin D supplement intake (yes/no) and season/region (data assessed in northern states during summer, in southern states during winter) while adjusting for the other variables. Interactions between the physical activity variables and these variables were tested in order to investigate whether associations between physical activity and vitamin D levels are different in the respective stratification groups. All analyses were weighted according to the NHANES guidelines [29] in order to account for the complex survey design, survey non-response, and post-stratification. A two-sided $P<0.05$ was considered as statistically significant. The analyses were performed using STATA version 12 (Stata Corporation, College Station, TX, USA).

Results

The mean age was 47.7 years and the proportion of women was 51.6%. Table 1 shows the characteristics of the study participants by physical activity category. Women were more likely to be insufficiently active. Mean age, BMI and waist circumference were higher in insufficiently active individuals compared to sufficiently active ones. More sufficiently active individuals had a post-secondary education. Vitamin D serum levels were higher in sufficiently active individuals. Obviously, all physical activity variables were higher in sufficiently active individuals. Sufficiently active individuals were more likely to drink more than one alcoholic drink per week, had a better health status and were less likely to have hypertension, hypercholesterolemia and diabetes.

Table 2 displays the results of the linear regression analyses for objectively measured mean minutes spent in moderate-to-vigorous activities per day stratified by sex, age group, ethnicity, weight status, vitamin D supplement intake and season/region. According to the fully adjusted models, an increase of 10 minutes of moderate-to-vigorous activities per day was associated with a significant increase in circulating vitamin D of 0.32 ng/ml (95% CI 0.17, 0.48). According to the fully adjusted models, an increase of 100 counts/minute was associated with a statistically significant increase in vitamin D concentration of 0.75 ng/ml (95% CI 0.53, 0.96) (Electronic Supplementary Material Table 1). Compared to being insufficiently active, individuals categorized as sufficiently active had on average 1.29 ng/ml (95% CI 0.62, 1.96) higher vitamin D levels (Electronic Supplementary Material 1). According to the stratified analyses and the statistically significant interaction terms for these analyses, the associations were stronger in women than in men. There also seemed to be some effect modification for different ethnicities. However, there were no indications for effect modification by age group, weight status, and season/region. Stratified by intake of vitamin D supplements (yes/no), there were significant associations between physical activity and vitamin D serum levels only for individuals not taking any vitamin D supplement with indications for effect modification depending on the physical activity variables (Table 2, Electronic Supplementary Material Table 1).

Using physical activity data of those individuals having at least one day of accelerometer data with at least 8 valid hours for sensitivity analyses (N=8178) did not considerably change the results (data not shown). The associations were generally slightly weaker (exposure less precise) and confidence intervals slightly smaller (larger sample size).

Table 2 presents the OR of being vitamin D deficient when being insufficiently active. Being insufficiently active was associated with a significant OR of 1.32 (95% CI 1.11, 1.57) for having vitamin D deficiency. Again, the associations were statistically significant for individuals not taking any vitamin D supplements but not for those taking these supplements with indications for effect modification.

Mean vitamin D serum levels in individuals with different physical activity levels according to accelerometer data are displayed in Fig. 1. Adjusted means were higher in the third and fourth quartile of mean counts/minute and minutes spent in moderate-to-vigorous physical activity compared to the first quartile. Linear hypothesis testing revealed highly significant trends for vitamin D levels by physical activity level ($P<0.001$ for all three physical activity variables).

Table 3 presents the associations between self-reported indoor, outdoor and total leisure-time physical activity and vitamin D serum concentration. A table for self-reported moderate- and vigorous-intensity leisure-time physical activity is shown in Electronic Supplementary Material Table 2. The associations for self-reported total leisure-time physical activity (Table 3) were smaller than for objectively measured physical activity (Table 2). Furthermore, there were some differences when looking at the stratified analyses. Indications for effect modification were present for ethnicity, but not for sex, age and vitamin D supplement intake. Unexpectedly, associations were not stronger for outdoor compared to indoor leisure-time activities in the fully adjusted models for the total sample and for most sub groups (Table 3).

Discussion

In the present analyses based on US nationally representative data findings indicate that physical activity is associated with higher levels of serum vitamin D. The associations were stronger for objectively measured than for self-reported physical activity. Interestingly, the associations were not stronger for self-reported outdoor compared to indoor physical activity. Statistically significant associations were observed in some sub groups while non-significant tendencies were observed in the other sub groups. According to objective physical activity, the associations disappeared for individuals taking vitamin D supplements. There are some indications that the associations were stronger in women according to objective physical activity data.

An important determinant of the associations between physical activity and circulating vitamin D concentration is sun exposure during outdoor physical activity. Kluczynski et al. came to the conclusion that these associations largely reflect the effect of sunlight exposure during outdoor physical activity because they found significant associations only for summer/fall, but not for winter/spring [24]. However, the fact that in the present study the associations were not stronger for self-reported outdoor compared to indoor physical activity indicates that other effects independent of sun exposure may play a role. This is supported by a French study reporting an association between physical activity and vitamin D even after adjustment for sun exposure and practice of outdoor hobbies or sports [41]. The study found 15% higher vitamin D concentrations in individuals practicing at least 1 hour per day walking equivalent compared to irregular physical activity. Furthermore, the correlation between indoor and outdoor physical activity of 0.29 indicates that active people are usually active both inside and outside. A review reported elevated levels of vitamin D metabolites in athletes [42] and hypothesized that factors other than sun exposure that are known to be altered by physical activity could contribute to the observed associations. Firstly, a decrease in serum phosphate (phosphate suppresses the production of activated vitamin D via a negative feedback system [43]) [42]. Secondly, a decrease in ionized calcium during exercise may stimulate parathyroid hormone secretion and thereby activate renal calcitriol synthesis (active form of vitamin D) [42]. In the present study, misclassification of indoor and outdoor activities may also play a role, but it is unlikely that misclassification alone accounted for the unexpected results regarding indoor and outdoor activities. Furthermore, indoor physical activity may be more structured and therefore easier to recall, leading to smaller measurement errors for indoor than for outdoor activities.

The stronger associations observed for objectively measured compared to self-report physical activity may be due to measurement error in the self-report instrument which attenuates the true association. Furthermore, accelerometers are especially useful for measuring ambulatory activity such as walking and jogging [44], activities that may be performed outside to a large extent. Therefore, physical activity measured by accelerometers may to a larger part reflect outdoor activity than self-reported physical activity.

Similar to our results, Scragg and Camargo reported associations between self-reported physical activity and vitamin D [23]. These analyses based on NHANES III data showed stronger associations for outdoor than for indoor activities, which was not replicated in our analyses using more recent NHANES data. However, the slightly stronger associations observed for vigorous- compared to moderate-intensity activities (Electronic Supplementary Material Table 2) was comparable. Furthermore, both studies reported associations between physical activity and vitamin D also in older individuals, even though the capacity to synthesize vitamin D from sun exposure decreases with age [45] (but is still present and effective). This supports the indication that effects of physical activity other than sun exposure may also play a role. For objective physical activity, we also found associations with vitamin D for the different ethnicities, even though the capacity to synthesize vitamin D depends on skin color [46]. For self-reported physical activity, the associations were not significant for non-Hispanic Blacks and Mexican Americans with the exception of indoor activity for non-Hispanic Blacks and for vigorous physical activity in Mexican Americans in our study. Although

Scragg and Camargo also reported associations between physical activity and circulating vitamin D concentration for different ethnicities, the levels of vitamin D were much lower in Mexican Americans and non-Hispanic Blacks compared to non-Hispanic Whites [23].

Our study is also in line with other studies reporting correlations between physical activity and vitamin D [24, 25]. While these studies did not distinguish between different intensities of physical activity and indoor/outdoor activity, Kluczynski et al. included self-reported sunlight exposure as a confounder in the analyses [24]. Although the inclusion of this confounder weakened the association between physical activity and vitamin D, it was still significant. An Australian study reported that physical activity contributed 4% to the explained variance in 25-hydroxyvitamin D (compared to 17% for season, 7% for vitamin D supplement intake and 27% for the proportion of skin covered by clothing) [47].

For objective physical activity, associations stratified by vitamin D supplement intake were only statistically significant for individuals not taking any vitamin D supplements. In those taking supplements, the additional effect of physical activity on circulating vitamin D concentrations was probably not strong enough to reach statistical significance. Interestingly, the impact of supplementation was not observed in the analyses using self-reported physical activity data.

The strengths of our study are the large sample size representative of the US population and the use of both objective and self-reported physical activity data that could be categorized as indoor and outdoor activities. Furthermore, a variety of socio-demographic, behavioral and health-related variables were included as potential confounders. The study has also some limitations. The design is cross-sectional and, thus, no inference about cause and effect is possible. However, it is rather unlikely that individuals participate in less physical activity because they have low vitamin D serum levels. We had no measure of sun exposure and no detailed information on where people lived. As sun exposure is an important determinant of vitamin D serum levels, the lack of a precise measure of sun exposure is a major limitation of this and other studies. Furthermore, measurement error particularly regarding the self-reported physical activity data and the classification of indoor and outdoor is likely to be present. Several activities can be performed both indoor and outdoor and it is likely that this also depends on where people live (e.g. outdoor swimming in the south and in coastal regions, indoor swimming in the north). Accelerometers had to be taken off during water-based activities such as swimming which can result in an underestimation of true activity.

In conclusion, physical activity has several positive effects on human health. This paper adds evidence that one of the positive effects is a higher level of serum vitamin D. This association was observed in several sub groups according to age, sex, ethnicity, and BMI status. The findings in the present analyses that associations for outdoor leisure-time physical activities were not stronger than for indoor activities needs further investigation.

Conflict of interest

The authors declare that they have no conflict of interest.

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Table 1. Characteristics of Participants, by Objectively Measured Physical Activity Category (Weighted According to the NHANES Guidelines), NHANES 2003-2006

	Insufficiently active[a)]	Sufficiently active[b)]
N (unweighted)	3924	2446
Proportion [%]	61.6	38.4
Gender [%]		
Men	37.9	62.9
Women	62.1	37.1
Age [years], mean (SE)	52.6 (0.57)	41.0 (0.44)
Ethnicity [%]		
Non-Hispanic White	74.7	73.2
Non-Hispanic Black	10.2	9.0
Mexican American	6.5	9.6
Other	8.6	8.2
Marital status [%]		
Married/living together	66.2	67.9
Single (widowed, separated, divorced)	33.7	32.1
Missing information	0.1	0.0
Poverty index ratio [%]		
Below poverty	9.9	8.6
At or above poverty	85.0	88.8
Missing information	5.1	2.6
Education [%]		
High school or lower	44.6	34.4
Post secondary (college or higher)	54.1	62.0
Missing information	1.3	3.6
Body Mass Index [kg/m^2], mean (SE)	29.3 (0.18)	26.9 (0.18)
Waist circumference [cm], mean (SE)	99.9 (0.42)	93.8 (0.42)
BMI category [%]		
Normal weight	28.2	39.3
Overweight	32.5	37.4
Obese	38.1	23.1
Missing information	1.2	0.2
Vitamin D serum level [ng/ml], mean (SE)	22.8 (0.35)	25.2 (0.50)
Vitamin D supplement intake		
Mean intake [mcg/d], mean (SE)	1.2 (0.07)	0.7 (0.06)
Taking any [%]	14.7	11.0
Objective physical activity, mean (SE)		
Mean total [counts/min]	232 (2.03)	440 (2.93)
Moderate and vigorous [min/d]	9.0 (0.15)	43.4 (0.49)
Self-reported physical activity, mean (SE)		
Total leisure-time [min/d]	19.0 (0.79)	38.6 (1.22)
Moderate leisure-time [min/d]	14.2 (0.68)	23.8 (0.89)

Vigorous leisure-time [min/d]	4.9 (0.32)	14.8 (0.68)
Leisure-time indoor [min/d]	6.8 (0.33)	13.6 (0.82)
Leisure-time outdoor [min/d]	12.3 (0.73)	24.9 (0.89)
Smoking status [%]		
Current non-smoker	78.8	79.1
Current smoker	21.2	20.9
Alcohol intake [%]		
No drinks	40.5	28.6
≤1 drink/week	33.9	28.4
>1 drink/week	25.6	43.0
Milk consumption past 30 days [%]		
Less than daily	55.6	55.3
Daily	44.4	44.7
Health status [%]		
Excellent or very good	39.4	55.3
Good	37.0	31.5
Not so good or bad	18.7	8.5
Missing information	4.9	4.7
Hypertension [%]		
No hypertension	60.5	81.4
Hypertension	39.0	18.2
Missing information	0.5	0.4
Hypercholesterolemia [%]		
No hypercholesterolemia	42.3	40.4
Hypercholesterolemia	34.9	24.3
Never checked or missing	22.7	35.3
Diabetes [%]		
No diabetes	88.7	97.1
Diabetes	11.3	2.9

[a)] achieving <150 minutes per week of moderate-to-vigorous activities

[b)] achieving ≥150 minutes per week of moderate-to-vigorous activities

Table 2. Associations Between Objectively Measured Physical Activity and Vitamin D Serum, by Sex, Age Category, Ethnicity, Weight Status, Vitamin D Supplement Intake and Season/Region; NHANES 2003-2006

	Mean minutes per day spent in moderate-to-vigorous activities versus Vitamin D Serum (continuous variables)			Odds ratio (OR) of being vitamin D deficient (<20ng/ml) if being insufficiently active (<150 minutes of moderate-to-vigorous physical activity per week)		
	beta[a)]	95% CI	*P* interaction	OR	95% CI	*P* interaction
Total sample	0.032	0.017, 0.048		1.32	1.11, 1.57	
Men	0.031	0.016, 0.046		1.30	1.06, 1.59	
Women	0.047	0.020, 0.074	0.003	1.37	1.02, 1.85	0.125
18-39 years	0.051	0.032, 0.070		1.55	1.11, 2.18	
40-64 years	0.020	-0.001, 0.041	0.450	1.27	1.01, 1.60	0.744
≥65 years	0.058	0.032, 0.084	0.067	1.04	0.73, 1.47	0.318
Non-Hispanic White	0.031	0.010, 0.052		1.22	0.99, 1.50	
Non-Hispanic Black	0.031	0.010, 0.052	0.029	1.70	1.13, 2.55	0.103
Mexican-American	0.022	0.002, 0.041	0.070	1.46	1.07, 1.98	0.946
Other	0.022	-0.013, 0.057	0.361	1.06	0.65, 1.73	0.647
Normal weight	0.043	0.020, 0.066		1.27	0.90, 1.78	
Overweight	0.025	0.007, 0.044	0.917	1.11	0.83, 1.48	0.943
Obese	0.033	0.011, 0.054	0.296	1.68	1.26, 2.23	0.067
Vitamin D supplement intake	0.016	-0.028, 0.060		0.72	0.34, 1.53	
No vitamin D supplement intake	0.034	0.017, 0.052	0.086	1.38	1.18, 1.62	0.020
Winter (=southern states)	0.046	0.023-0.068		1.46	1.12, 1.90	
Summer (=northern states)	0.021	0.002-0.040	0.399	1.21	0.94, 1.54	0.452

All analyses adjusted for sex, age, ethnicity, poverty income ratio, education, marital status, season, alcohol intake, smoking, weight status, general health status, daily milk intake, vitamin d supplement intake, hypertension, hypercholesterolemia, and diabetes

[a)] beta from linear regression analyses is interpreted as the increase in circulating vitamin D concentration (ng/ml) per additional minute/day of physical activity

Table 3. Associations Between Self-Reported Indoor, Outdoor and Total Leisure-Time Physical Activity and Vitamin D Serum, by Sex, Age Category, Ethnicity, Weight Status, Vitamin D Supplement Intake and Season/Region; NHANES 2003-2006

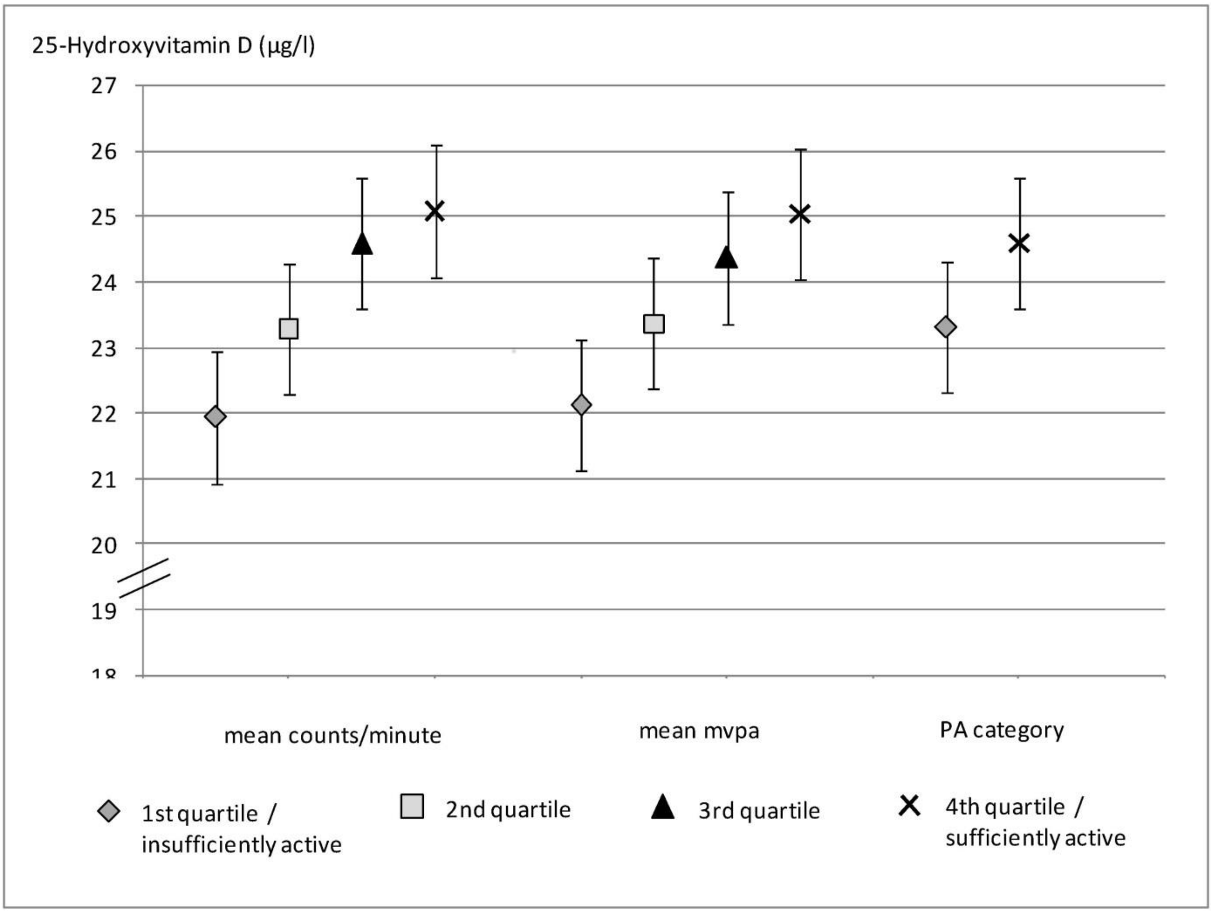
	Indoor LTPA			Outdoor LTPA			Total LTPA		
	beta[a)]	95% CI	*P* interaction	beta[a)]	95% CI	*P* interaction	beta[a)]	95% CI	*P* interaction
Self-reported leisure-time indoor activities, min/day									
Total sample	0.020	0.010-0.031		0.017	0.010-0.023		0.018	0.012-0.023	
Men	0.026	0.016-0.037		0.017	0.009-0.025		0.020	0.013-0.026	
Women	0.014	-0.007-0.035	0.898	0.015	0.002-0.028	0.646	0.015	0.004-0.026	0.650
18-39 years	0.014	-0.003-0.031		0.010	-0.003-0.022		0.011	0.004-0.019	
40-64 years	0.028	-0.000-0.056	0.486	0.021	0.008-0.034	0.279	0.022	0.009-0.035	0.248
≥65 years	0.027	0.015-0.039	0.179	0.014	-0.003-0.030	0.507	0.019	0.007-0.030	0.262
Non-Hispanic White	0.024	0.012-0.036		0.019	0.010-0.029		0.021	0.013-0.029	
Non-Hispanic Black	0.023	0.007-0.038	0.030	-0.007	-0.015-0.000	<0.001	0.002	-0.007-0.011	0.001
Mexican-American	0.005	-0.017-0.028	0.043	-0.003	-0.025-0.019	0.012	0.000	-0.016-0.016	0.003
Other	0.005	-0.024-0.034	0.282	0.030	0.009-0.051	0.679	0.023	0.004-0.041	0.843
Normal weight	0.021	0.006-0.037		0.006	-0.005-0.017		0.011	0.003-0.019	
Overweight	0.017	-0.005-0.040	0.952	0.025	0.011-0.039	0.065	0.022	0.011-0.033	0.090
Obese	0.011	-0.015-0.037	0.588	0.025	0.008-0.042	0.050	0.021	0.007-0.035	0.165
Vitamin D supplement intake	0.042	0.011-0.073		0.018	-0.004-0.039		0.025	0.008-0.043	
No vitamin D supplement intake	0.017	0.007-0.028	0.376	0.016	0.010-0.023	0.872	0.017	0.011-0.022	0.677
Winter (=southern states)	0.015	-0.005-0.035		0.017	0.004-0.031		0.017	0.006-0.027	
Summer (=northern states)	0.023	0.009-0.036	0.434	0.016	0.009-0.023	0.949	0.018	0.012-0.023	0.694

LTPA, leisure-time physical activity

Models adjusted for sex, age, ethnicity, poverty income ratio, education, marital status, season, alcohol intake, smoking, weight status, general health status, daily milk intake, vitamin d supplement intake, hypertension, hypercholesterolemia, diabetes and for other physical activity variable (indoor LTPA for outdoor LTPA; outdoor LTPA for indoor LTPA)

[a)] beta from linear regression analyses is interpreted as the increase in circulating vitamin D concentration (ng/ml) per additional minute/day of physical activity

Fig. 1 Adjusted Means of 25-Hydroxyvitamin D by Objectively Measured Physical Activity Levels



PA, physical activity; mvpa, moderate-to-vigorous physical activity.

Mean mvpa in minutes per day.

PA categories: insufficiently active, <150 minutes per week of moderate-to-vigorous activities; sufficiently active, ≥150 minutes per week of moderate-to-vigorous activities.

Associations between objective and self-reported physical activity and vitamin D serum levels in the US population

Cancer Causes and Control

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Electronic Supplementary Material Table 1. Associations Between Objectively Measured Physical Activity (Counts/Minute and Being Sufficiently Active)) and Vitamin D Serum, by Sex, Age Category, Ethnicity, Weight Status, Vitamin D Supplement Intake and Season/Region; NHANES 2003-2006

	Mean counts/minute			PA category (achieving ≥150 minutes of moderate-to-vigorous physical activity per week versus less)		
	beta[a)]	95% CI	*P* interaction	beta[a)]	95% CI	*P* interaction
Total sample	0.007	0.005, 0.010		1.294	0.625, 1.963	
Men	0.007	0.005, 0.009		1.376	0.636, 2.116	
Women	0.008	0.005, 0.012	0.009	1.373	0.467, 2.278	0.030
18-39 years	0.011	0.008, 0.014		1.884	0.823, 2.945	
40-64 years	0.005	0.002, 0.008	0.097	0.999	0.057, 1.942	0.684
≥65 years	0.009	0.005, 0.013	0.763	1.351	0.236, 2.467	0.863
Non-Hispanic White	0.008	0.005, 0.010		1.096	0.160, 2.031	
Non-Hispanic Black	0.007	0.004, 0.010	0.012	1.457	0.313, 2.601	0.111
Mexican-American	0.004	0.001, 0.007	0.003	1.156	0.153, 2.159	0.473
Other	0.005	0.000, 0.010	0.108	0.657	-0.902, 2.216	0.543
Normal weight	0.009	0.005, 0.012		1.814	0.683, 2.946	
Overweight	0.007	0.004, 0.009	0.794	0.875	-0.170, 1.921	0.590
Obese	0.008	0.004, 0.012	0.345	1.233	0.422, 2.043	0.792
Vitamin D supplement intake	0.005	-0.001, 0.011		0.225	-1.464, 1.913	
No vitamin D supplement intake	0.008	0.006, 0.010	0.046	1.444	0.695, 2.192	0.041
Winter (=southern states)	0.009	0.006-0.013		1.499	0.311, 2.687	
Summer (=northern states)	0.006	0.004-0.008	0.722	1.020	0.318, 1.722	0.955

All analyses adjusted for sex, age, ethnicity, poverty income ratio, education, marital status, season, alcohol intake, smoking, weight status, general health status, daily milk intake, vitamin d supplement intake, hypertension, hypercholesterolemia, and diabetes

[a)] beta from linear regression analyses is interpreted as the increase in circulating vitamin D concentration (ng/ml) per additional count/minute of physical activity

Associations between objective and self-reported physical activity and vitamin D serum levels in the US population

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Electronic Supplementary Material Table 2. Associations Between Self-Reported Moderate and Vigorous Leisure-Time Physical Activity and Vitamin D Serum, by Sex, Age Category, Ethnicity, Weight Status, Vitamin D Supplement Intake and Season/Region; NHANES 2003-2006

	Moderate LTPA			Vigorous LTPA		
	beta[a)]	95% CI	*P* interaction	beta[a)]	95% CI	*P* interaction
Total sample	0.015	0.007-0.023		0.025	0.011-0.039	
Men	0.016	0.007-0.025		0.032	0.017-0.047	
Women	0.011	-0.006-0.028	0.968	0.021	-0.002-0.044	0.523
18-39 years	0.007	-0.003-0.017		0.020	0.000-0.040	
40-64 years	0.017	0.003-0.031	0.223	0.039	0.011-0.067	0.300
≥65 years	0.021	0.012-0.030	0.026	0.014	-0.016-0.045	0.889
Non-Hispanic White	0.022	0.011-0.033		0.018	0.002-0.035	
Non-Hispanic Black	-0.001	-0.011-0.009	0.006	0.013	-0.012-0.037	0.021
Mexican-American	-0.004	-0.020-0.011	0.001	0.022	0.002-0.041	0.511
Other	0.011	-0.007-0.029	0.350	0.058	0.012-0.104	0.215
Normal weight	0.006	-0.004-0.017		0.021	0.003-0.039	
Overweight	0.020	0.007-0.034	0.038	0.027	-0.002-0.056	0.505
Obese	0.021	0.007-0.036	0.058	0.021	-0.014-0.057	0.855
Vitamin D supplement intake	0.023	-0.004-0.050		0.029	0.001-0.056	
No vitamin D supplement intake	0.014	0.007-0.021	0.608	0.023	0.007-0.039	0.784
Winter (=southern states)	0.008	-0.001-0.018		0.049	0.020-0.078	
Summer (=northern states)	0.019	0.008-0.031	0.271	0.014	-0.002-0.031	0.193

LTPA, leisure-time physical activity

Models adjusted for sex, age, ethnicity, poverty income ratio, education, marital status, season, alcohol intake, smoking, weight status, general health status, daily milk intake, vitamin d supplement intake, hypertension, hypercholesterolemia, diabetes and for other physical activity variable (moderate LTPA for vigorous LTPA; vigorous LTPA for moderate LTPA)

[a)] beta from linear regression analyses is interpreted as the increase in circulating vitamin D concentration (ng/ml) per additional minute/day of physical activity