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Association between leisure-time aerobic physical activity and vitamin D concentrations among US older adults: the NHANES 2007–2012

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Abstract

Background Although previous studies have described a positive correlation between physical activity and 25-hydroxyvitamin D concentrations (25(OH)D), there have been inconsistent results in regard to the frequency or intensity of physical activity needed to achieve adequate 25(OH)D status.

Aims To examine the relationship between self-reported leisure-time physical activity and $25(OH)D_3$ and 25(OHD) concentrations among US adults aged 60 years and older.

Methods The present analysis was based on data from participants in the National Health and Nutrition Examination Survey 2007–2012. Moderate or vigorous leisure-time physical activity was calculated by min/week or metabolic equivalent task scores-minutes/week and defined according to the 2008 Physical Activity Guidelines for Americans. General linear models adjusted for confounders were created to compare mean 25(OH)D and $25(OH)_3$ concentrations across physical activity status.

Results A total of 4764 adults with a mean age of 69.7 years comprised the study sample. Overall, 33.3% men and 23.1% women were defined as physically active and participants' mean 25(OH)D and $25(OH)D_3$ concentration was 75.0 and 68.8 nmol/L, respectively. Older adults physically active had 8.1 and 7.1 nmol/L higher 25(OH)D and $25(OH)_3$ levels than those physically inactive, respectively. Moreover, higher $25(OH)D_3$ and 25(OH)D concentrations were consistently seen during the summer and autumn months. In contrast, sedentary older adults had on average 25(OH)D levels < 75 nmol/L irrespective of the 6-month study period examined.

Conclusions Leisure-time physical activity appears to be an effective manner of maintaining adequate vitamin D concentrations later in life. Therefore, promoting physical activity in older adults should be a national public health priority.

Keywords Leisure-time physical activity · Older adults · Vitamin D levels · NHANES survey

Introduction

The main source of vitamin D is the endogenous production of 25-hydroxyvitamin D_3 ($25(OH)D_3$) in the skin from 7-dehydrocholesterol upon exposure to sunlight [1]. In general, older adults are at increased risk of developing vitamin D deficiency as result of inadequate dietary vitamin D intake and decreased outdoor activities [2]. Moreover, aging reduces the concentration of 7-dehydrocholesterol in the epidermis and the total production of previtamin D_3 after exposure to solar ultraviolet B radiation [3].

Numerous studies have described that physical activity positively correlates with 25-hydroxyvitamin D (25(OD)D) concentrations [4–12]. However, there have been inconsistent results in regard to the frequency or intensity of leisure-time physical activity needed to achieve adequate 25(OH)D status [4, 5, 8, 10–12, 19]. Moreover, there is paucity of data about the effect of physical activity on $25(OH)D_3$ concentrations, particularly among older adults. Previously, Scragg et al. among participants in the National Health and Nutrition Examination Survey (NHANES) during 1988–1994 demonstrated that the mean 25(OH)D concentration difference between those who engaged in outdoor physical activities compared with those physically inactive was similar for subjects aged 20–39 and 60 years and older suggesting that US older adults who participate in daily outdoor physical activity may potentially prevent the age-related decline in vitamin D status [11]. Since that latter study, the 2008

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Physical Activity Guidelines for Americans were issued by the Federal government to inform policy makers, physical educators, health providers, and the public on the amount, types, and intensity of physical activity needed to achieve many health benefits for Americans across the life span [13]. In this context, the present study aimed to examine the association between leisure-time physical activity status and $25(OH)D_3$ and $25(OH)D$ concentrations in a nationally representative sample of US older adults.

Materials and methods

The NHANES is a biannual cross-sectional study conducted by National Center for Health Statistics of the Centers for Disease Control and Prevention. The purpose of the NHANES is to collect data about the health, nutritional status, and health behaviors of the noninstitutionalized civilian resident population of the United States (US). The NHANES data were obtained using a complex, multistage probability sampling design to select a sample representative of the US civilian noninstitutionalized household population [14]. For this analysis, the NHANES data for subjects aged 60 years and older for the cycles 2007–2012 ($n = 6018$) were selected. Those participants who were only interviewed ($n = 281$) and had missing data on physical activity ($n = 2$), BMI ($n = 106$), dietary vitamin D intake ($n = 286$), and $25(OH)D$ concentrations ($n = 577$) were excluded, leaving a total sample size of 4764 participants. In general, participants with missing data were more likely to be women, non-hispanic white, had less than high school education, were physically inactive, self-reported fair to poor health.

Demographic characteristics of participants

All participants who completed a household interview record were included in the demographics file. The 6-month time period when the examination was performed (November 1st through April 30th and May 1st through October 31st), age, gender, race/ethnicity (Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and other race) education (< high school, high school/GED equivalent, some college or AA degree, college graduate or above), and the ratio of family income to poverty threshold as a measure of socioeconomic status were reported. In the mobile examination center, the body mass index (BMI) was calculated as body weight (kg) divided by height (m^2) and subjects were classified as underweight or normal weight (< 25.0 kg/m^2), overweight (25.0–29.9 kg/m^2), or obese (≥ 30 kg/m^2). Participants also reported their smoking status and were classified as current, former, and never smokers. Moreover, self-reported general health condition was grouped as good to excellent or fair to poor.

Leisure-time aerobic physical activity status

The Physical Activity Questionnaire is based on the Global Physical Activity Questionnaire (GPAQ). Participants were considered to perform vigorous LTPA if they responded affirmatively to the question "Do you do any sports, fitness, or recreational activities that cause large increases in breathing or heart rate like running or basketball for at least 10 min continuously?". Likewise, subjects were considered to engage in moderate recreational activities if they affirmatively responded to the question "Do you do any moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate such as brisk walking, bicycling, swimming, or golf for at least 10 min continuously?". The reported number of days and time in minutes spent performing vigorous or moderate leisure-time physical activity in the previous week were calculated. Based on the 2008 Physical Activity Guidelines for Americans, respondents who engaged in ≥ 150 min/week of moderate-intensity aerobic activity, ≥ 75 min/week of vigorous-intensity aerobic activity, or an equivalent combination of moderate-intensity and vigorous-intensity physical activity (1 min of vigorous-intensity physical activity is equivalent to 2 min of moderate intensity physical activity) totaling at least 150 min/week were defined as meeting the guidelines [13]. For the present analysis, three levels of physical activity were created: (1) participants who engaged in ≥ 150 min/week of moderate activity, or ≥ 75 min/week of vigorous activity, or ≥ 150 min/week of an equivalent combination were defined as physically active; (2) insufficiently active were considered those who reported some physical activity, but not enough to meet the active definition (> 0 to < 150 min/week); inactive if they reported no physical activity [15]. To quantify the energy expenditure of physical activity, metabolic equivalent task (MET) scores based on the NHANES recommendations for vigorous (8.0 MET) and moderate (4.0 MET) leisure-time physical activity were used to calculate MET-minutes per week (MET-min/week). As previously described, participants were classified as inactive (0 MET-min/week), insufficiently active (< 750 MET-min/week), and sufficiently active (≥ 750 MET-min/week) [16].

Total daily vitamin D intake

The NHANES dietary intake data were used to estimate the types and amounts of foods and beverages consumed during the 24-h period prior to the interview, and to estimate intakes of energy, nutrients, and other food components from those foods and beverages. Since 2007–2008,

vitamin D has been added to the list of nutrients. The vitamin D values in this dataset reflect the sum of ergocalciferol and cholecalciferol content of foods reported by survey participants. The 24-h dietary supplement interview was collected following the 24-h dietary recall. All NHANES examinees responding to the dietary recall interview were eligible for the dietary supplement and antacid use questions. Information was obtained on all vitamins, minerals, herbals and other dietary supplements that were consumed during a 24-h time period, including the name and the amount of dietary supplement taken. Since 2007–2008, vitamin D supplements (ergocalciferol and cholecalciferol) were reported to estimate participants' consumption of vitamin D supplements during the 24-h period. For the present analysis, vitamin D intake from the dietary and supplement component was combined to estimate the total daily dietary intake of vitamin D [17].

25(OH)D and 25(OH)$_3$ concentrations

The CDC standardized liquid chromatography-tandem mass spectrometry (LC–MS/MS) method was used for measurement of 25(OH)D for NHANES 2007–2010, which allows laboratories and surveys to compare 25(OH)D measurements. The CDC decided to develop a LC–MS/MS method traceable to the NIST-reference materials for NHANES, and used this method starting with NHANES 2007–2008 to measure 25(OH)D$_3$, 25(OH)D$_2$, and the C3 epimer of 25(OH)D$_3$. For the CDC LC–MS/MS method, total 25(OH)D (in SI units of nmol/L) was defined as the sum of 25(OH)D$_3$ and 25(OH)D$_2$ and excluded the C3 epimer of 25(OH)D$_3$. However, due to rounding, the sum of 25(OH)D$_3$ and 25(OH)D$_2$ will not necessarily be equal to the 25(OH)D. The CDC recommends using the total 25(OH)D in SI units (nmol/L) measured directly by LC–MS/MS and converting this quantity to conventional units (1 nmol/L = 0.4066 ng/mL), if needed. This method has better analytical specificity and sensitivity compared to immunoassay methods, and fixed analytical goals for imprecision ($\leq 10\%$) and bias ($\leq 5\%$) [18].

Statistical analysis

The descriptive characteristic of the study population was reported as proportions and mean values with their respective standard errors. The Chi-squared and ANOVA tests for categorical and continues variables were used to compare demographic and behavioral characteristics of the participants across physical activity status (inactive, insufficiently active, and sufficiently active), respectively. General linear models were created to examine the associations between physical activity status and mean 25(OH)D and 25(OH)D$_3$ concentrations. The following potential confounders were

included in the model: 6-month study period, age, gender, race/ethnicity, education, ratio of family income to poverty threshold, BMI, smoking status, self-reported health, and total daily vitamin D intake. Similarly, the association between physical activity status and vitamin D concentrations was examined according to the 6-month study period, as a surrogate for seasons (November 1st through April 30th and May 1st through October 31st), race/ethnicity, and BMI categories. Statistical analyses were performed using SPSS Complex Sample software, V.17 (SPSS Inc, Chicago, IL, USA) to incorporate constructed weights for the combined survey cycles and obtain unbiased, national estimates representative of the US population [19].

Results

A total of 4764 participants with a mean age of 69.7 (SE 0.1) comprised the study sample, representing an estimated 46 million older adults in the US during the study period. Table 1 shows the demographic characteristics of the participants stratified by physical activity status. Overall, 33.3% men and 23.1% women aged 60 years and older were defined as physically active. Overall, the mean 25(OH)D concentration among older adults was 75.0 (0.93) nmol/L. However, higher 25(OH)D concentrations were found in women 76.9 (1.2) nmol/L than those in men 72.7 (0.98). In general, older non-Hispanic white, college graduate or above, higher socioeconomic status, and a self-reported good to excellent health were characteristics of the participants associated with a higher prevalence of physical activity. In contrast, physical activity status did not differ by the 6-month study period. Likewise, daily vitamin D intake was not significantly associated with physical activity. As shown in Fig. 1, a strong dose–response relationship was seen between minutes of physical activity per week and 25(OH)D$_3$ and 25(OH)D concentrations. For instance, older adults who engaged in 250 min or more of recreational physical activity had 14.2 and 14.0 nmol/L higher mean concentration of 25(OH) and 25(OH)D$_3$ compared with their physically inactive counterparts, respectively. Moreover, even participants who participated between 50 and 99 min per week of physical activity had adequate 25(OH)D concentrations.

As shown in Table 2, 25(OH)D$_3$ concentrations were significantly higher among those physically active than those sedentary according to the 6-month study period. Notably, similar 25(OH)D$_3$ levels were seen irrespective of the reported frequency or intensity of physical activity per week. However, 25(OH)D$_3$ levels differed by study period among older adults physically active. Indeed, participants physically active between May 1st through October 31st had on average 5.4 nmol/L higher 25(OH)D$_3$ concentrations than their counterparts examined between November 1st through April

Table 1 Characteristics of US older adults according to leisure-time physical activity status

	n	Inactive	< 150 min/week	≥ 150 min/week
Six-month time period, % (SE)				
Nov 1st to April 30th	2064	58.0 (1.5)	14.4 (1.1)	27.6 (1.5)
May 1st to Oct 31st	2700	57.2 (2.0)	15.0 (0.8)	27.8 (1.7)
Age (years), mean (SE)	4764	70.4 (0.2)	68.6 (0.3)	68.6 (0.2)*
Gender, % (SE)				
Male	2366	53.0 (1.4)	13.7 (0.9)	33.3 (1.1)*
Female	2398	61.3 (1.9)	15.6 (0.9)	23.1 (1.7)
Race/ethnicity, % (SE)				
Mexican-American	552	71.9 (2.0)	9.4 (1.3)	18.7 (1.6)*
Other Hispanics	464	71.7 (3.5)	13.9 (1.9)	14.4 (2.6)
Non-Hispanic white	2573	55.6 (1.6)	14.7 (0.8)	29.6 (1.4)
Non-Hispanic black	938	67.3 (2.2)	14.5 (1.1)	18.2 (1.7)
Other race	237	52.5 (5.5)	20.8 (3.9)	26.7 (4.6)
BMI (kg/m^2), mean (SE)	4764	29.9 (0.2)	28.3 (0.3)	27.3 (0.2)*
Education, % (SE)				
Less than high school	1589	80.2 (1.2)	9.5 (0.7)	10.4 (0.9)*
High school graduate/GED	1108	62.8 (2.2)	14.1 (1.2)	23.1 (1.9)
Some college or AA degree	1145	56.1 (2.2)	14.9 (1.5)	29.0 (1.7)
College graduate or above	914	34.9 (2.0)	19.8 (1.6)	45.3 (2.3)
Income to poverty ratio < 1.00, % (SE)				
Yes	709	79.3 (1.8)	9.7 (1.2)	11.0 (1.6)*
No	3623	54.9 (1.6)	15.1 (0.8)	30.1 (1.4)
Smoking status, % (SE)				
Never	2316	56.3 (1.9)	15.2 (1.0)	28.5 (1.7)*
Former	1865	54.1 (1.8)	15.3 (1.1)	30.7 (1.8)
Current	581	76.2 (2.0)	10.8 (1.7)	13.0 (2.2)
Self-reported health, % (SE)				
Good to excellent	3278	50.9 (1.6)	16.1 (0.9)	33.0 (1.4)*
Fair to poor	1485	81.4 (1.4)	9.9 (1.1)	8.7 (0.8)
Vitamin D intake (μg), mean (SE)	4764	19.4 (2.0)	21.7 (2.4)	25.0 (2.7)
25(OH)D (nmol/L), mean (SE)	4764	70.4 (0.9)	77.3 (1.7)	83.3 (1.6)*
25(OH)D$_3$ (nmol/L), mean (SE)	4764	64.7 (0.9)	68.8 (1.5)	77.2 (1.8)*

*$P < 0.0001$

30th. Similarly, 25(OH)D concentrations were significantly higher among older adults physically active compared with those inactive, irrespective of the 6-month study period. Notably, the highest 25(OH)D concentration was seen among older adults who reported physical activity between May 1st through October 31st. In contrast, sedentary older adults had consistently 25(OH)D concentrations < 75 nmol/L throughout the year.

In the fully adjusted model including the 6-month study periods, 25(OH)$_3$ and 25(OH)D concentrations among physically active participants were on average 7.1 and 8.1 nmol/L higher than those physically inactive, respectively. Similarly, older adults defined as physically active according to MET-min/week had increased 25(OH)D$_3$ and 25(OH)D concentrations compared with their physically inactive counterparts.

Notably, 25(OH)D$_3$ concentrations among physically active participants accounted for 92% of 25(OH)D levels.

As shown in Fig. 2, higher adjusted mean 25(OH)D$_3$ concentrations were seen among non-Hispanic whites as compared with other racial/ethnic groups. Of interest, non-Hispanic blacks had considerably lower 25(OH)D$_3$ concentrations regardless their physical activity status. Notably, physically inactive non-Hispanic blacks had 25(OH)$_3$ concentrations < 50 nmol/L. As shown in Fig. 3, obese older adults had also lower 25(OH)$_3$ concentrations compared with their normal weight counterparts. This difference was most evident among participants defined as physically active. However, obese older adults were able to synthesize 25(OH)D$_3$ while performing physical activity. For instance, a mean absolute 25(OH)D$_3$ concentration difference of
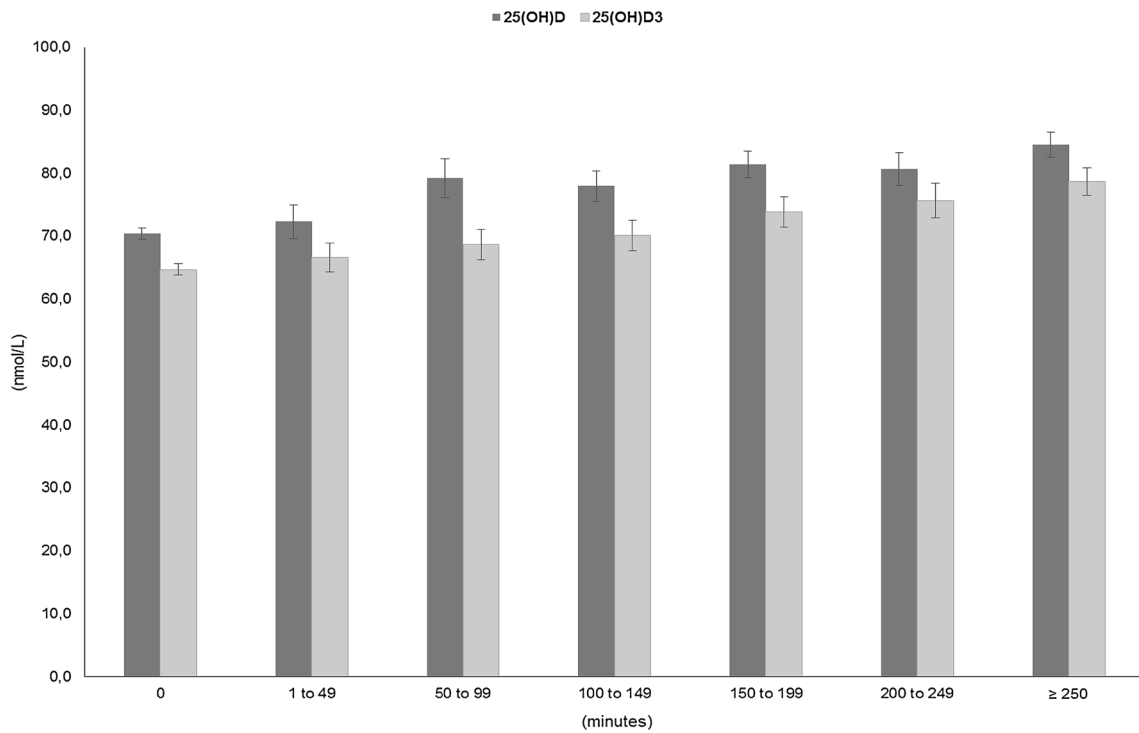
Fig. 1 Vitamin D concentrations according to minutes per week of physical activity

Table 2 Association between leisure-time physical activity status and vitamin D concentrations among US older adults

Physical activity	Min/week		MET-min/week	
	Mean 25(OH)D$_3$ (nmol/L)	Mean 25(OH)D (nmol/L)	Mean 25(OH)D$_3$ (nmol/L)	Mean 25(OH)D (nmol/L)
November 1st through April 30th				
Inactive ($n=1194$)	63.0 (1.4)	68.4 (1.4)	63.0 (1.4)	68.5 (1.4)
Insufficient ($n=248$)	67.1 (3.2)	72.9 (2.9)	68.8 (2.8)	74.4 (2.8)
Sufficient ($n=422$)	70.7 (1.9)*	77.4 (1.7)**	70.1 (1.7)*	77.2 (1.6)**
May 1st through October 31st				
Inactive ($n=1510$)	68.0 (1.1)	74.1 (1.1)	67.5 (1.1)	74.1 (1.1)
Insufficient ($n=353$)	67.8 (2.2)	78.1 (2.1)	69.2 (1.7)	78.1 (1.7)
Sufficient ($n=596$)	76.1 (1.9)*	82.3 (1.9)**	79.4 (2.4)**	83.2 (2.4)**
Total study period[a]				
Inactive ($n=2704$)	66.8 (0.9)	72.2 (0.9)	66.8 (0.9)	72.2 (0.9)
Insufficient ($n=601$)	67.2 (1.6)	75.8 (1.5)	68.2 (1.2)	76.6 (1.2)
Sufficient ($n=1018$)	73.9 (1.7)**	80.3 (1.3)**	74.6 (1.8)**	80.6 (1.5)**

The adjusted mean 25(OH)D$_3$ and 25(OH)D concentrations are significantly different from participants physically inactive (*$P<0.005$, **$P<0.0001$)

Model adjusted for age, gender, race/ethnicity, BMI, education, ratio family income to poverty, smoking status, self-reported health, and total daily vitamin D intake

Parenthesis represents standard errors or the estimates

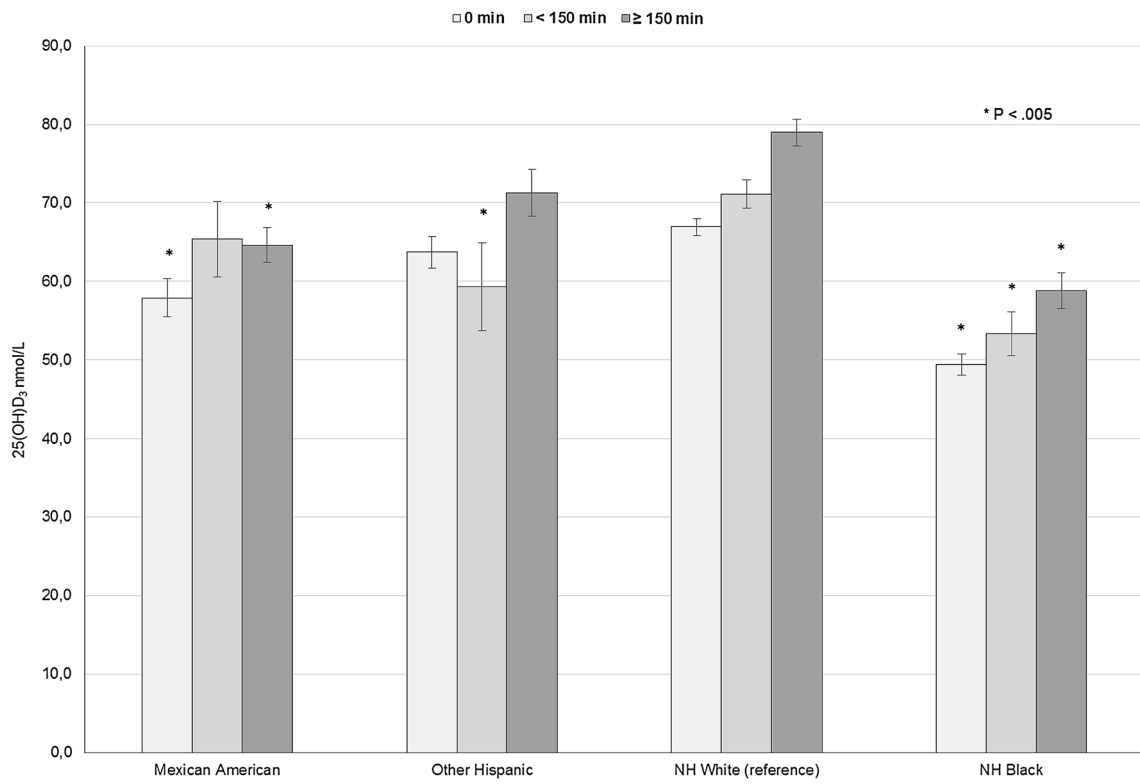[a]Total study period was also adjusted by 6-month study periods

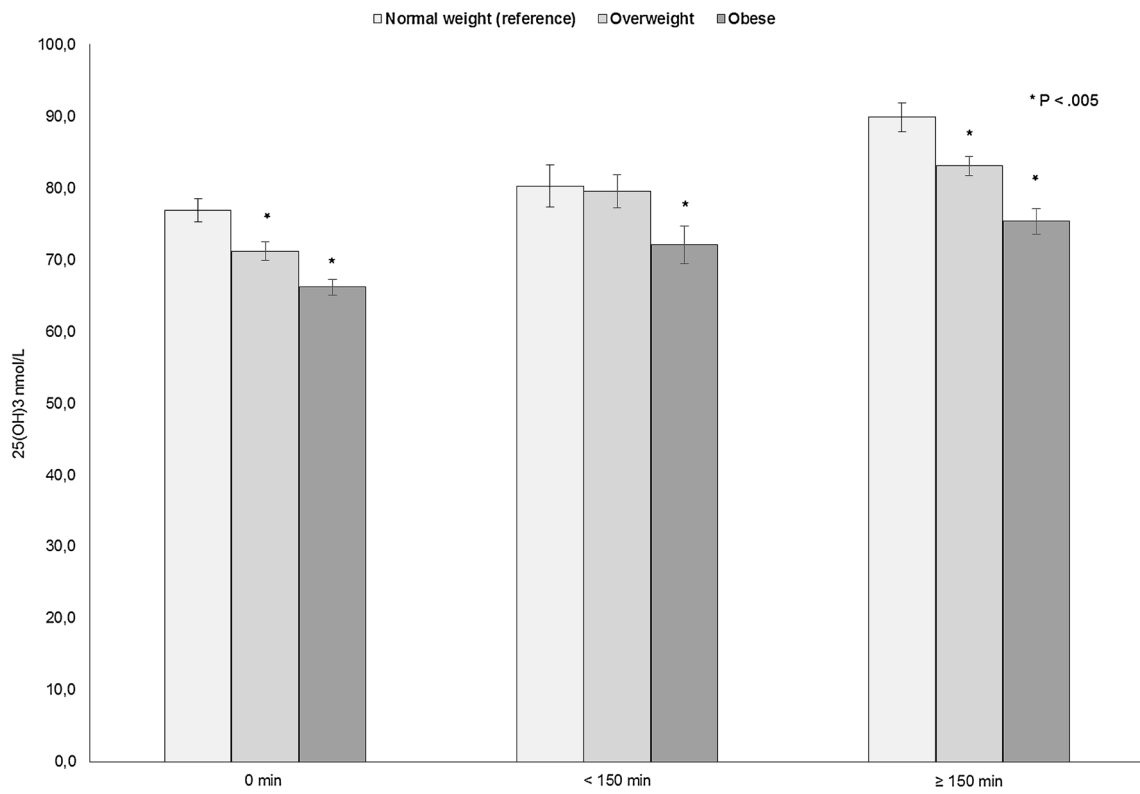**Fig. 2** 25(OH)D$_3$ concentrations according to race/ethnicity and physical activity status

Fig. 3 25(OH)D$_3$ concentrations according to BMI and physical activity status

9.2 nmol/L was seen between obese older adults physically active compared with their physically inactive counterparts.

Discussion

In a nationally representative sample of US older adults, physical activity was significantly associated with higher $25(OHD)_3$ and 25(OH)D concentrations. This strong relationship persisted irrespective of the frequency or intensity of leisure-time physical activity definition used to meet the 2008 Physical Activity Guidelines for Americans. Moreover, a strong linear dose–response relationship between minutes of physical activity and $25(OH)D_3$ concentrations was observed during the study period, suggesting that older adults are able to synthesize adequate $25(OH)D_3$ concentrations as a result of increasing sunlight exposure while participating in outdoor activity. For instance, among older US adults examined during the 6-month period between May 1st through October 31st, $25(OH)D_3$ concentrations account for 91.7%, 86.8%, and 92.4% of the total 25(OH)D concentrations in those physically inactive, insufficiently, and sufficiently active participants, respectively. Although the present study does not specifically assess participants' sun exposure, similar $25(OH)D_3$ concentrations according to physical activity status may be explained by greater sun exposure while performing other recreational outdoor activities, particularly in participants with sedentary lifestyle. However, the present findings are in agreement with published data suggesting that between 80 and 90% of vitamin D is obtained from endogenous synthesis of $25(OH)D_3$ [20].

Previous studies have concluded that the relationship between physical activity and circulating vitamin D concentrations mostly reflect the effect of sunlight exposure during outdoor physical activity [8, 11, 12]. Of note, a recent cross-sectional study among adults aged 60 years or older from Giessen, Germany (50°35′N) reported that habitual dietary vitamin D and calcium intakes have no independent effects on $25(OH)D_3$ in elderly subjects without vitamin D deficiency [21]. Although the present survey does not distinguish between participants indoor or outdoor physical activity, the increased $25(OH)D_3$ concentration seen among older adults physically active compared with those sedentary indicate that sunlight exposure is a major determinant of adequate $25(OH)_3$ concentrations and 25(OH)D status in older US adults. Of interest, Wanner et al. described that among participants aged 18 years and older in the NHANES 2003–2006, stronger associations between indoor physical activity and 25(OH)D levels even after controlling for potential confounders, which contrast with the present study findings [22]. Possible explanations for these contradictory results may be related

to differences in the age distribution of participants, comorbidities, vitamin D intake assessment, and misclassification bias. Previous research has suggested that physical activity may directly affect vitamin D concentrations through changes in hormone levels or changes in body mass index [10]. For instance, Bell et al. reported higher 25(OH)D concentrations in young adult white males who engaged regularly in muscle-building exercise for a year compared with controls [23]. In rat models, exercise also promoted a positive calcium and phosphorus balance and increased the skeletal mass, largely as a result of an increase in 1,25-dihydroxyvitamin D and an enhancement of the intestinal calcium absorption [24].

Notably, physically active older adults who completed a MEC examination from May 1st through October 31st had on average 11.7% higher $25(OH)D_3$ concentrations than their physically inactive counterparts. Similarly, 12.2% higher $25(OH)_3$ concentrations were found among physically active subjects examined between November 1st through April 30th. Moreover, $25(OH)_3$ concentrations were 7.6% higher among physically active participants examined during summer and autumn months than those during winter and spring months. This association remained unchanged even if leisure-time physical activity was defined by MET-min/week. Although the 6-month period examination used in the continuous NHANES does not precisely define seasons, the present findings are consistent with results from previous studies which have demonstrated that season significantly modify the associations between physical activity and 25(OH)D concentrations [4, 8, 10, 11]. For instance, among older adults in Southern Germany (latitude: 48.4°N), objectively measured walking was positively correlated with 25(OH)D levels in all seasons, but not in summer. This unexpected finding was explained by increasing sunlight exposure among participants through other activities such as sitting or lying during summer months [25].

Population-based studies have consistently demonstrated that sunlight exposure, season, latitude, and physical activity are important determinants of adequate 25(OH)D status [9, 26, 27]. For instance, van Dam et al. reported that among adults aged 60–87 years in the Netherlands, more time spent on outdoor physical activity was associated with adequate vitamin D status. In fact, 25(OH)D concentrations increased by 1.8 nmol/L for each hour of outdoor activity [9]. Likewise, among older survivors of the Framingham Heart Study, sunlight exposure variables such as season, residing in sunny states for 3 or more months during the year, and stay outdoors most of the day were major determinant of 25(OH)D concentrations [27]. Reid et al. also demonstrated that sunlight exposure for at least 30 min daily leads to a substantial increase in 25(OH)D levels in elderly subjects [28]. As expected, obese older adults had

significantly lower $25(OH)_3$ concentrations compared with their normal weight counterparts. Of relevance, among obese participants, those defined as physically active were able to synthesize higher $25(OH)D_3$ concentrations than those physically inactive. This inverse association between low vitamin D status and obesity has been explained by decreased bioavailability of vitamin D as a result of sequestration of vitamin D by the adipose tissue, dilution of vitamin D in the large fat mass of obese people, and reduced sun exposure [29]. Likewise, regardless of their physical activity status, non-Hispanic blacks had significantly lower $25(OH)D_3$ concentrations than non-Hispanic whites. Notably, the lowest $25(OH)D_3$ concentrations by race/ethnicity was seen among non-Hispanic blacks with sedentary lifestyle. Scragg et al. previously reported similar racial/ethnic $25(OH)D$ concentration differences according to the frequency of outdoor activity among participants in the NHANES during 1988–1994 [4]. Since the capacity to synthesize $25(OH)D_3$ from sun exposure, is inversely related to the degree of skin pigmentation, non-Hispanic blacks, particularly those with sedentary lifestyle should be offered vitamin D supplements [30]. Despite the significant relationship between physical activity and $25(OH)D$ concentrations found in the present and previous studies, only 33% of men and 23% of women aged 60 years and older met the 2008 Physical Activity Guidelines for Americans, which is consistent with recent national estimates among older adults [31].

The present study has several limitations. First, because of the NHANES survey cross-sectional design, the present results do not infer causation. Second, participants self-reported their physical activity, which may have been subject to recall bias and the individual type of physical activity was not assessed in the NHANES during 2007–2012. Third, subject's sunlight exposure or use of sunscreen was not evaluated in the present study. Finally, the effect of latitude on participants' vitamin D concentration was unknown. Despite these limitations, the present findings indicate that leisure-time physical activity was positively and significantly correlated with $25(OH)D_3$ and $25(OH)D$ concentrations among older adults in the US.

In conclusion, physical activity appears to be an effective manner of maintaining adequate vitamin D concentrations later in life. However, a small proportion of US older adults participate regularly in recreational physical activity. Therefore, promoting physical activity should be a national public health priority.

Compliance with ethical standards

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