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ORIGINAL ARTICLE

Cross-sectional study on different characteristics of physical activity as determinants of vitamin D status; inadequate in half of the population

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BACKGROUND/OBJECTIVES: Physical activity (PA) may have an impact on vitamin D status. The aim of the present study is to assess the contribution of different characteristics of PA (duration, intensity as estimated by energy expenditure, location) to vitamin D status.
SUBJECTS/METHODS: The study was conducted in 1255 community-dwelling older men and women of the Longitudinal Aging Study Amsterdam (LASA). Cross-sectional relationships between PA and serum 25-hydroxyvitamin D (25(OH)D) concentrations were examined.
RESULTS: Total PA, both indoor and outdoor PA, expressed in kcal/d was positively associated with 25(OH)D in women ($P<0.05$) but not in men. The total time spent on these activities was not associated. As compared with the lowest tertile, both men and women in the highest tertile of cycling activity ($\geqslant$6.4 min/d or 34.7 kcal/d) had a $\sim$6 nmol/l higher 25(OH)D ($P<0.05$). For men and women in the highest tertile of gardening ($\geqslant$8.6 min/d or 87.6 kcal/d), these levels were 14.2 nmol/l ($P<0.001$) and 5.8 nmol/l 25(OH)D ($P<0.05$), respectively. Walking showed no association.
CONCLUSIONS: Daily time spent on total PA is often included when studying the association between sum of PA and 25(OH)D, while our study showed that energy expenditure might be a better unit. Individual types of outdoor PA with a high intensity, such as gardening and cycling, were associated with 25(OH)D.

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Keywords: physical activity; outdoor; energy expenditure; vitamin D; aged

INTRODUCTION

As reviewed by Pfeifer *et al.*,[1] treatment with vitamin D in vitamin D-deficient states is associated with an increase in muscle strength. However, the reverse, an increase in serum 25-hydroxyvitamin D (25(OH)D) after muscle strengthening exercise is also possible. This effect was confirmed in intervention and cohort studies.[2,3] It was suggested that both skeletal muscle and physical activity (PA) may influence the synthesis, absorption or metabolism of vitamin D.[3] The PA-induced increase in 1,25-dihydroxyvitamin D3 concentrations[4,5] might be mediated through an increased plasma insulin-like growth factor-I level.[6,7] Therefore, on the one hand, PA may directly affect vitamin D concentrations via changes in hormone levels.[8] On the other hand, the effect of PA on vitamin D concentrations may be indirect such as via sunlight exposure during activities performed outdoor[9] or changes in body mass index (BMI).[3,10]

Whether the impact of PA on vitamin D status is dependent on time spent on PA, intensity, location or type of PA needs to be studied to be able to optimize the advice to older individuals, who are at high risk for vitamin D deficiency.[11] Furthermore, this knowledge is of importance to epidemiological studies, in which PA is often included in the analyses as the time spent on the sum of all activities. Therefore, the aim of the present study is to assess which characteristics of PA (duration, intensity as estimated by energy expenditure, location, type of outdoor PA) are contributing to vitamin D status.

SUBJECTS AND METHODS

Subjects

Data for this study were collected within the framework of the Longitudinal Aging Study Amsterdam (LASA) in older people in the Netherlands. The sampling, data collection procedures and non-response have been described in detail elsewhere.[12] In summary, a random sample, stratified according to age, gender, degree of urbanization and expected 5-year mortalitywas drawn from the population registers of 11 municipalities in three geographical areas in the Netherlands.[12] After baseline examination in 1992-1993, every following three years another cycle of data collection took place. For the current study, data of the second cycle were used. The study sample comprised 1509 persons (97.7% Caucasian) with complete and partial medical interviews, aged $\geqslant$65 years as of 1 January 1996. Participants who did not provide a blood sample or whose sample was insufficient ($n=189$), who were bed-ridden or in a wheelchair ($n=22$), whose data on PA were missing ($n=36$) or who had missing values for one of the confounders ($n=7$) were excluded. The statistical analyses were performed using data of 1255 participants. All participants provided written informed consent, and the study was

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approved by the Ethics Committee of VU University Medical Center Amsterdam.

PA

PA was measured using the validated LASA Physical Activity Questionnaire (LAPAQ),[13] an interviewer-administered questionnaire which estimates the frequency and duration of participation in activities in the previous 2 weeks. The LAPAQ correlated with both the 7-day diary ($r = 0.68$, $P < 0.001$) and the pedometer ($r = 0.56$, $P < 0.001$).[13] Total PA was defined as the sum of activities such as outdoor walking, cycling (both non-sporting activities), light (for example, doing dishes and dusting) and heavy household work (for example, washing and scrubbing the floor) and sport activities. The most frequently recorded and generally known indoor or outdoor sport activities were selected to include in the sum of total outdoor and indoor PA. Outdoor PA was the sum of distance and non-sporting walking and cycling. Total indoor PA was the sum of household work, gymnastics and home training. Besides the sum of total (outdoor and indoor) PA, individual outdoor activities such as non-sporting walking, cycling and gardening were also studied. As data on gardening were missing for 450 participants, gardening was not included in the total PA scores.

The minutes spent per activity per day were summed to a total time or energy spent on activity per day. For example, a participant who walks outdoor for 70 min two times per 2 weeks ($2 \times 70/14 = 10$) and does light household work for 30 min per day ($14 \times 30/14 = 30$) spent on average 40 min per day on PA. To take the intensity of the activities into account, metabolic equivalent (MET) scores were assigned to each activity based on the published MET score lists.[14,15] One MET unit is equal to one kcal per kg body weight per hour. The daily amount of energy spent during a specific activity was calculated by multiplying the MET score with body weight (kg) and time spent on an activity (min/day) divided by 60 min.

Serum 25(OH)D

Blood samples were obtained and centrifuged in the morning. Subjects were allowed to have tea and toast but no dairy products. The serum samples were stored at $-20\,^{\circ}$C until assays were performed in 1997–1998. The serum 25(OH)D concentration was determined using a competitive binding protein assay (Nichols Institute Diagnostics, San Juan Capistrano, CA, USA), with an inter-assay coefficient of variation of 11% on average levels of 27 and 141 nmol/l.

Potential effect modifiers

Sex and BMI were examined as potential effect modifiers. Previous studies have shown that higher BMI[16] is associated with lower vitamin D status and may result in less engagement in moderate or greater intensity activity.[17] As vigorous but not non-vigorous PA is a predictor of vitamin D status,[18] the association between time spent on PA and 25(OH)D may differ according to BMI. BMI was dichotomized using the cutoff of 25.0 kg/m^2.

Potential confounders

The following potential confounders, measured in 1995–1996, were examined: age, BMI, level of education, degree of urbanization, alcohol consumption, smoking status, number of chronic diseases, season of blood collection, dairy intake, use of calcium/multivitamin tablets (yes/no) and serum creatinine. BMI was calculated as weight (kilograms)/height (meters)^2. The participants were asked about the highest level of education they had achieved. The score was dichotomized into low level ($\leqslant 9$ year) versus high level (> 9 year) of education.[19] Degree of urbanization was assessed by applying a postal code rubrication system designed by Statistics Netherlands (CBS, Heerlen/Voorburg, the Netherlands), which links the postal codes to five categories, based on the number of addresses per square kilometre.[20] The alcohol consumption index was used to classify alcohol drinkers into four categories based on the number of days alcohol was consumed and the number of drinks consumed each time.[21] Information on smoking status was based on self-report and was classified as never smoked, former smoker or current smoker. The selection of seven major chronic diseases was based on their prevalence ($> 5\%$) in the 55+ years age group in the Netherlands.[22] These were: chronic obstructive pulmonary disease, cardiac disease, peripheral arterial disease, stroke, diabetes mellitus, rheumatoid arthritis/osteoarthritis and cancer. Information about the diseases was based on self-report.[23] The season for blood collection was dichotomized into winter (October–March) and summer (April–September). In LASA, calcium intake was not assessed by a validated food questionnaire, and therefore a question on consumption of milk products from age 50 years on, was used as a proxy for calcium intake.[24] Serum creatinine level was measured using the Jaffe alkaline picrate reaction with a Hitachi 747 analyzer (Roche Diagnostics, Almere, the Netherlands), and was included as a marker for renal function.

Statistical analyses

For clarity reasons, baseline characteristics are shown for total PA after dichotomization using the median of 135 min/d. Differences in baseline characteristics for more or less time spent on total PA were tested using analysis of variance for normally distributed continuous variables and Chi-squared tests for categorical variables. Linear regression analysis was performed for analyses with 25(OH)D concentrations as the dependent variable and daily time or energy spent on total PA, indoor/outdoor PA, gardening, cycling or walking as independent variable. First, linearity was tested by adding dummies of daily time or energy spent on sum of total PA to the model. If the regression coefficients of the dummies did not decrease or increase linearly, the association was considered non-linear. None of the PA scores were linear, and therefore they were analyzed as categorical variables. Interaction was studied by adding a product term to the regression analyses on time spent on total PA. The analyses were stratified according to the effect modifier (sex or BMI) that was significant in the total group ($P < 0.05$). Subsequently, within each stratum, the other potential effect modifier was tested in the regression analyses on time spent on total PA or gardening and 25(OH)D. A $P < 0.1$ for the interaction term was considered significant.

All models were adjusted for age, and further adjusted for potential confounding factors that changed the regression coefficients of at least two quartiles of total PA by $\geqslant 10\%$ when added to the linear regression model.

All reported P values were two-sided, and P values < 0.05 were considered statistically significant. All analyses were conducted using SPSS software version 15.0.2 (SPSS, Chicago, IL).

RESULTS

The average 25(OH)D concentration among all participants was 53.7 nmol/l (s.d. = 24.2). Serum 25(OH)D in women was 49.1 (22.9) nmol/l and lower than in men (58.6 (24.5) nmol/l, $P < 0.001$). 47.9% of the participants were vitamin D deficient (< 50 nmol/l), 33.9% had a level between 50–75 nmol/l and 18.2% had a level $\geqslant 75$ nmol/l. Men spent significantly ($P < 0.001$) more daily time on non-sporting walking (median (interquartile range): 17.9 (5.0–38.6) versus 14.3 (2.7–30.0) min/d), non-sporting cycling (0.9 (0–15.0) versus 0 (0–8.6) min/d) and gardening (4.3 (0–30.0) versus 0 (0–6.4) min/d) and less time on light household work (median: 42.9 (15.0–75.0) versus 120.0 (60.0–180.0) min/d, $P < 0.001$) than women. Between men and women, no difference was found in time spent on heavy household work and sport activities. Daily time spent on total PA for men (105.0 (59.9–168.9) min/d) was significantly less than for women (162.9 (110.0–222.9) min/d). The prevalence of inactivity (0 min/day on total PA) was 14.1% in men and 19.8% in women. In all, 52.9% of men and 36.9% of women spent some time (> 0 min/d) on gardening. More women than men were inactive with regard to non-sporting cycling (58.1% versus 48.0%) and non-sporting walking (19.8% versus 14.1%). Table 1 shows baseline characteristics of the study population. When taken into consideration the total group, sex was a significant effect modifier of the association ($P = 0.03$ of the fourth quartile of total PA) between daily time spent on total PA and serum 25(OH)D concentration. Therefore, all analyses are presented for men and women separately.

Table 2 shows the association between daily time or energy spent on total, outdoor and indoor PA and 25(OH)D concentrations. In women, the second, third and fourth quartile of energy

Table 1. Characteristics of men and women with a total physical activity of less or more than 135 min/d

Total physical activity (min/d)	*Men*		P*	*Women*		P
	⩽135	*>135*		*⩽135*	*>135*	
No. of Subjects	384	226		249	396	
Serum 25(OH)D (nmol/l)[a]	56.4 (24.5)	62.2 (24.2)	**0.005**	44.1 (21.8)	52.2 (23.0)	**0.000**
Age (years)[a]	76.2 (6.5)	74.2 (6.4)	**0.000**	77.5 (6.7)	74.0 (6.0)	**0.000**
Body mass index (kg/m^2)[a]	26.1 (3.6)	26.2 (2.9)	0.795	27.5 (4.7)	27.6 (4.6)	0.936
No. of chronic disease (0–5)[b]	1.3 (1.1)	1.1 (1.0)	**0.026**	1.5 (1.2)	1.1 (1.0)	**0.000**
Users of calcium tablets (%)[b]	23 (6.0)	13 (5.8)	0.904	36 (14.5)	69 (17.4)	0.320
Smoking[b]			0.670			0.089
Never	39 (10.2)	25 (11.1)		162 (65.1)	224 (56.6)	
Past	248 (64.6)	151 (66.8)		59 (23.7)	122 (30.8)	
Current	97 (25.3)	50 (22.1)		28 (11.2)	50 (12.6)	
Alcohol use[b]			0.612			0.277
No	59 (15.4)	26 (11.5)		91 (36.5)	125 (31.6)	
Light	185 (48.2)	112 (49.6)		129 (51.8)	205 (51.8)	
Moderate	103 (26.8)	65 (28.8)		25 (10.0)	55 (13.9)	
(Very) excessive	37 (9.6)	23 (10.2)		4 (1.6)	11 (2.8)	
Season of vitamin D assessment[b]			0.916			0.339
% Summer (April–September)	175 (45.6)	102 (45.1)		103 (41.4)	179 (45.2)	
Consumption of milk products: from 50 years on[b]			0.788			0.745
About every meal	38 (9.9)	28 (12.4)		50 (20.1)	70 (17.7)	
Every day but not every meal	249 (64.8)	143 (63.3)		156 (62.7)	253 (63.9)	
Every week but not every day	57 (14.8)	34 (15.0)		27 (10.8)	51 (12.9)	
Less than once a week	40 (10.4)	21 (9.3)		16 (6.4)	22 (5.6)	

Abbreviation: 25(OH)D, 25-hydroxyvitamin D. *P = P-value (in bold, $P < 0.05$). [a]Values are mean (s.d.). [b]Values are number (%);

expenditure (but not for daily time) on total activity was associated with at least 4.8 nmol/l higher 25(OH)D as compared with the lowest quartile (<292.1 kcal/d), after adjustment for confounding. Also, a significant association was found for the highest quartile of energy expenditure on both indoor as outdoor PA. In men, for total PA scores no significant associations were found after adjustment for confounding.

Table 3 shows no consistent difference between the unit of PA (total energy expenditure and total time spent) in the association between a certain types of outdoor PA and 25(OH)D. More time spent on cycling and gardening was associated with higher 25(OH)D levels in both men and women. Walking was not associated with 25(OH)D levels in either sex. Table 3 shows regarding a certain type of outdoor PA there is no consistent difference between the unit of PA (total energy expenditure or total time spent) in the association with 25(OH)D.

BMI was an effect modifier in the association between the total time spent on total PA and 25(OH)D in men ($P = 0.03$ of fourth quartile of total PA) but not in women. However, after adjustment for confounding, no significant positive regression coefficient was found (data not shown). With regard to gardening, BMI did not modify the association between time spent on gardening and 25(OH)D in both men and women.

DISCUSSION

Consistent with the previous results,[18;25–29] PA was positively associated with serum 25(OH)D. When taken into account the sum of PA, PA expressed in kcal/d was positively associated with 25(OH)D in women but not in men. After adjustment for confounding this was not the case when total PA was expressed in min/d. Outdoor PA was not stronger associated with 25(OH)D than indoor PA. Also, we did not find an association with outdoor walking, whereas cycling and gardening showed a strong association with 25(OH)D in both men and women. When looking at the individual types of outdoor PA, no consistent difference between units of PA, that is, min/d or kcal/d, was observed

Our results are in contrast to results of Scragg and Carmargo,[30] who stated that it is the location of PA (outdoor rather than indoor) and the frequency of activity rather than the intensity that are related to vitamin D status. They classified self-reported activities as indoor or outdoor based on their judgment of the likely location of the activity, leading to potential misclassification of activity location. We avoided misclassification bias by including types of PA in the sum of indoor/outdoor PA that can, for sure, be classified as indoor and outdoor activities. Although both classifications are not optimal, in our study no consistent associations were observed for the individual types of outdoor PA; confirming that the location of PA might not be the only factor related to vitamin D status.

A difference between outdoor walking, gardening or cycling is that the latter two activities might be more often performed during sunny days but are also activities with a higher intensity. In accordance to our results, Brock et al.[18] found a significant association for vigorous exercise (for example, sport or heavy housework or garden work) but not for non-vigorous exercise (for example, walking, swimming, light house work) in Australian elderly. An indoor muscle-building intervention for at least a year in men increased 25(OH)D significantly as compared with controls.[31] Furthermore, in individuals 25(OH)D concentrations were positively associated with serum creatinine concentrations, a marker of muscle mass,[32] and with higher baseline levels of muscle mass, strength and quality.[3] This may indicate that both muscle mass and PA itself may directly affect vitamin D status. Therefore, finding an association between cycling or gardening and 25(OH)D but not for walking may be due to differences in intensity of PA and differences in body exposure, but further investigation is required.

In our study, intensity of PA was also estimated by energy expenditure. The calculation of energy expenditure includes time spent on PA, MET scores of PA and body weight. No consistent difference between time spent or energy expenditure on individual types of PA were found in the association with 25(OH)D. With regard to the sum of PA, only energy expenditure was associated with 25(OH)D in women, while

Table 2. Relationship between duration or energy expenditure spent on total, indoor or outdoor PA and serum 25(OH)D concentration (nmol/l) for men and women separately [a]

		Duration (min/d)						*Energy expenditure (kcal/d)*					
		Men			*Women*			*Men*			*Women*		
		b[b]	*s.e.*	*P*[*]	*b*	*s.e*	P	*b*	*s.e.*	*P*	*b*	*s.e.*	P
Total physical activity													
Model 1[c]	Q1[d,e]	0			0			0			0		
	Q2	− 0.32	2.37	0.891	4.50	2.73	0.100	1.77	2.52	0.483	5.44	2.53	**0.032**
	Q3	4.83	2.62	0.065	5.43	2.69	**0.044**	1.80	2.63	0.494	6.61	2.52	**0.009**
	Q4	1.02	2.76	0.713	6.77	2.65	**0.011**	4.18	2.62	0.112	6.96	2.61	**0.008**
Model 2[f]	Q1[e]	0			0			0			0		
	Q2	− 1.77	2.33	0.449	2.74	2.63	0.298	− 0.21	2.49	0.932	4.83	2.41	**0.046**
	Q3	3.43	2.57	0.183	3.76	2.59	0.148	0.50	2.61	0.848	5.65	2.43	**0.021**
	Q4	− 0.53	2.72	0.846	4.30	2.56	0.094	2.65	2.62	0.312	6.39	2.58	**0.013**
Total indoor physical activity													
Model 1	Q1[e]	0			0			0			0		
	Q2	− 1.28	2.20	0.561	5.30	3.32	0.111	− 2.85	2.32	0.220	3.20	3.09	0.302
	Q3	− 3.09	2.67	0.248	7.29	3.20	**0.023**	− 2.60	2.59	0.316	4.14	3.00	0.168
	Q4	− 4.96	3.27	0.130	5.17	3.17	0.104	− 2.11	2.89	0.465	5.86	3.00	0.051
Model 2	Q1[e]	0			0			0			0		
	Q2	− 1.59	2.15	0.459	4.55	3.22	0.158	− 2.65	2.29	0.247	2.82	2.98	0.344
	Q3	− 4.58	2.61	0.080	5.51	3.10	0.076	− 3.85	2.55	0.131	4.06	2.87	0.158
	Q4	− 5.19	3.21	0.106	4.01	3.07	0.192	− 2.28	2.86	0.426	5.88	2.90	**0.043**
Total outdoor physical activity													
Model 1	Q1[e]	0			0			0			0		
	Q2	2.14	2.87	0.455	2.92	2.24	0.192	2.07	2.90	0.476	4.41	2.19	**0.044**
	Q3	1.45	2.78	0.602	4.97	2.32	**0.033**	0.82	2.82	0.770	5.24	2.31	**0.023**
	Q4	5.96	2.70	**0.028**	4.34	2.54	0.088	6.27	2.71	**0.021**	7.10	2.61	**0.007**
Model 2	Q1[e]	0			0			0			0		
	Q2	0.49	2.87	0.863	1.12	2.18	0.607	0.65	2.89	0.823	3.02	2.12	0.155
	Q3	− 0.74	2.79	0.790	2.60	2.28	0.254	− 1.38	2.86	0.629	2.61	2.27	0.251
	Q4	3.87	2.72	0.156	1.40	2.49	0.574	4.42	2.74	0.107	5.41	2.56	**0.035**

Abbreviations: PA, physical activity; 25(OH)D, 25-hydroxyvitamin D. **P* = *P*-value (in bold, $P < 0.05$). [a]*n* = 610 men and 645 women. [b]b = regression coefficient. [c]Model 1 = adjusted for age. [d]Q = quartiles for total PA (duration Q1 ⩽78.29; Q2 78.30–135.00; Q3 135.01–204.14; Q4 ⩾204.15min/d, energy expenditure Q1 ⩽292.13; Q2 292.14–509.54; Q3 509.55–763.39; Q4 ⩾763.40 kcal/d), total indoor PA (duration Q1 ⩽41.43; Q2 41.44–90.00; Q3 90.01–150.00; Q4 ⩾150.01 min/d, energy expenditure Q1 ⩽139.23; Q2 139.24–293.72; Q3 293.73–498.86; Q4 ⩾498.87 kcal/d), total outdoor PA (duration Q1 ⩽9.64; Q2 9.65–27.14; Q3 27.15–55.71; Q4 ⩾55.72 min/d, and energy expenditure Q1⩽41.13; Q2 41.14–118.53; Q3 118.54–258.56; Q4 ⩾258.57 kcal/d). [e]Reference quartile; [f]Model 2 = adjusted for age, BMI, number of chronic disease (0–5), use of calcium tablets, smoking, alcohol use, season of vitamin D assessment and consumption of milk products.

duration was not. Others classified PA based on MET or by own judgement[18,30] without taken into account body weight. As body weight indices such as body fat[29] and BMI[25] are important determinants of vitamin D status, energy expenditure might be a better unit to use when studying the association between total PA and 25(OH)D.

In women, after adjustment for confounding, including BMI and season of vitamin D assessment, the highest tertile of gardening (>8.6 min/d) was associated with a 5.8 nmol/l higher serum 25(OH)D concentration. This was in accordance with results of Kluczynski *et al.*[27] who found an increase in 25(OH)D between 0.26 or 0.61 nmol/l for each min/week of gardening in women with a small waist circumference or who did gardening during summer/fall, respectively. A much stronger positive association between gardening and serum 25(OH)D was found in men. The stronger association for men than women might be due to unmeasured behavior. Women may have worn more clothing when they participated in gardening, subsequently lowering dermal vitamin D production.[27] Alternatively, the weaker association with gardening in women may be explained by a narrow distribution of time spent on gardening among women compared with men (median (interquartile range): 0 (0–6.4) versus 4.3 (0–30.0) min/d).

This study has a few limitations. Its cross-sectional design precludes determinations of cause and effect. Moreover, we cannot exclude the possibility of confounding by imperfectly measured or unmeasured factors. No quantitative measurements of PA were available; however the LAPAQ by which PA was assessed appeared to be a valid and reliable instrument for classifying PA in older people.[13] In addition, the individual level of sunlight exposure during PA was not available. The location of sporting PA was not assessed, and therefore not all sport activities were included in indoor or outdoor activities. The strength of this study was that PA in men and women was based on both frequency and duration of participation in a certain type of PA, while other studies included only frequency[30] or only women.[27] Intensity was included by estimating energy expenditure using MET scores.

In conclusion, kcal/d rather than min/d might be a better unit of PA when studying the association between sum of PA and 25(OH)D but not necessarily when looking at individual types of PA. Outdoor PA was not strongly associated with 25(OH)D than indoor PA. Individual types of outdoor PA with a high intensity such as cycling and gardening were associated with 25(OH)D in both men and women. Determination of cause and effect needs further study.

Table 3. Relationship between duration or energy expenditure spent on walking, cycling or gardening and serum 25(OH)D concentration (nmol/l) for men and women separately

		Duration (min/d)						Energy expenditure (kcal/d)					
		Men			*Women*			*Men*			*Women*		
		b[a]	*s.e.*	P*	*b*	*s.e.*	P	*b*	*s.e.*	P	*b*	*s.e.*	P
Walking[b]													
Model 1[c]	T1[d,e]	0			0			0			0		
	T2	−0.60	2.26	0.790	0.92	1.89	0.625	−1.17	2.40	0.626	2.00	1.96	0.306
	T3	−0.11	2.46	0.965	1.68	2.25	0.455	0.32	2.31	0.888	1.91	2.10	0.363
Model 2[f]	T1[e]	0			0			0			0		
	T2	−1.12	2.22	0.613	−0.46	1.84	0.801	−1.76	2.37	0.457	0.90	1.91	0.636
	T3	−0.97	2.44	0.691	−0.27	2.20	0.901	−0.35	2.29	0.880	−0.09	2.06	0.967
Cycling[b]													
Model 1	T1[e]	0			0			0			0		
	T2	4.58	2.82	0.104	8.65	2.50	**0.001**	2.99	3.00	0.319	8.25	2.53	**0.001**
	T3	7.57	2.05	**0.000**	6.23	2.05	**0.002**	7.90	2.02	**0.000**	6.48	2.04	**0.002**
Model 2	T1[e]	0			0			0			0		
	T2	3.00	2.80	0.285	8.68	2.40	**0.000**	1.17	2.97	0.694	7.90	2.44	**0.001**
	T3	6.30	2.05	**0.002**	5.60	1.98	**0.005**	6.66	2.01	**0.001**	6.07	1.97	**0.002**
Gardening[g]													
Model 1	T1[e]	0			0			0			0		
	T2	8.11	3.99	**0.043**	0.21	3.26	0.949	11.17	2.91	**0.000**	3.67	2.72	0.178
	T3	15.02	2.29	**0.000**	7.27	2.63	**0.006**	15.56	2.50	**0.000**	6.12	3.11	0.050
Model 2	T1[e]	0			0			0			0		
	T2	6.85	3.91	**0.081**	−0.21	3.26	0.950	9.07	2.89	**0.002**	2.34	2.73	0.392
	T3	14.24	2.28	**0.000**	5.79	2.65	**0.029**	15.40	2.47	**0.000**	5.42	3.12	0.083

Abbreviation: 25(OH)D, 25-hydroxyvitamin D. **P* = *P*-value (in bold, $P<0.05$). [a]b = regression coefficient. [b]$n=610$ men and 645 women. [c]Model 1 = adjusted for age. [d]T = tertiles for walking (duration T1 ⩽7.14; T2 7.15–30.00; T3 ⩾30.01 min/d, energy expenditure T1 ⩽28.79; T2 28.80–116.38; T3 ⩾116.39 kcal/d), cycling (duration T1 ⩽0; T2.01–6.43; T3 ⩾6.44 min/d, energy expenditure T1 ⩽0; T2.01–34.71; T3 ⩾34.72 kcal/d), gardening (duration T1 ⩽0; T2.01–8.57; T3 ⩾8.58 min/d, energy expenditure T1 ⩽0; T2.01–87.59; T3 ⩾87.60 kcal/d). [e]Reference tertile. [f]Model 2 = adjusted for age, BMI, number of chronic disease (0–5), use of calcium tablets, smoking, alcohol use, season of vitamin D assessment and consumption of milk products. [g]$n=431$ men and 374 women.

CONFLICT OF INTEREST

PL served as a consultant for Merck. The remaining authors declare no conflict of interest.

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