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Vitamin D Status Predicts Physical Performance and Its Decline in Older Persons

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Context: Vitamin D deficiency is common among older people and can cause mineralization defects, bone loss, and muscle weakness.

Objective: The aim of this study was to investigate the association of serum 25-hydroxyvitamin D (25-OHD) concentration with current physical performance and its decline over 3 yr among elderly.

Design: The study consisted of a cross-sectional and longitudinal design (3-yr follow-up) within the Longitudinal Aging Study Amsterdam.

Setting: An age- and sex-stratified random sample of the Dutch older population was used.

Other Participants: Subjects included 1234 men and women (aged 65 yr and older) for cross-sectional analysis and 979 (79%) persons for longitudinal analysis.

Main Outcome Measure(s): Physical performance (sum score of the walking test, chair stands, and tandem stand) and decline in physical performance were measured.

Results: Serum 25-OHD was associated with physical performance after adjustment for age, gender, chronic diseases, degree of urbanization, body mass index, and alcohol consumption. Compared with individuals with serum 25-OHD levels above 30 ng/ml, physical performance was poorer in participants with serum 25-OHD less than 10 ng/ml [regression coefficient (B) = −1.69; 95% confidence interval (CI) = −2.28; −1.10], and with serum 25-OHD of 10–20 ng/ml (B = −0.46; 95% CI = −0.90; −0.03). After adjustment for confounding variables, participants with 25-OHD less than 10 ng/ml and 25-OHD between 10 and 20 ng/ml had significantly higher odds ratios (OR) for 3-yr decline in physical performance (OR = 2.21; 95% CI = 1.00–4.87; and OR = 2.01; 95% CI = 1.06–3.81), compared with participants with 25-OHD of at least 30 ng/ml. The results were consistent for each individual performance test.

Conclusions: Serum 25-OHD concentrations below 20 ng/ml are associated with poorer physical performance and a greater decline in physical performance in older men and women. Because almost 50% of the population had serum 25-OHD below 20 ng/ml, public health strategies should be aimed at this group. **(*J Clin Endocrinol Metab* 92: 2058–2065, 2007)**

VITAMIN D DEFICIENCY is common in the older population (1–3) and can result in secondary hyperparathyroidism, bone loss, and fractures (4–7). Osteomalacia, caused by severe vitamin D deficiency, is characterized by mineralization defects, bone and muscle pain, and weakness of the proximal muscles (8, 9). Older people are especially at risk of developing vitamin D deficiency due to low exposure to sunshine (10), decreased capacity of the older skin to synthesize vitamin D (11), and low dietary vitamin D intake (9).

Although the role of vitamin D in maintaining skeletal health is well known, knowledge about its role in relation to physical performance is still limited, and it is unknown whether vitamin D status can predict decline in physical performance. It was demonstrated in a randomized double-blind clinical trial that supplementation with vitamin D and calcium can prevent hip fractures and other nonvertebral fractures in nursing home residents (12). The effect of vitamin D supplementation on fractures may be due not only to a reduction in bone loss but also to a decrease in the number of falls. Population and case-control studies in older people have shown that low serum 25-hydroxyvitamin D (25-OHD) was related to a decrease in lower extremity muscle strength (13) or poorer physical performance (14–16). However, not all studies support these results (17, 18). The aims of the present study were 3-fold. The first aim was to determine the association between vitamin D status and physical performance in a large and representative sample of the Dutch older population. The second aim was to investigate whether lower vitamin D status increased the risk of a decline in physical performance over a 3-yr period. The final aim was to assess which of the physical performance tests in this study was most strongly related to vitamin D status.

Subjects and Methods

Study participants

Data for this study were collected within the framework of the Longitudinal Aging Study Amsterdam (LASA), an ongoing cohort study of predictors and consequences of changes in physical, cognitive, emotional, and social functioning in older people in The Netherlands (19). The sampling, data collection procedures, and nonresponse have been described elsewhere in detail (20). In summary, a random sample, strat-

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Abbreviations: B, Regression coefficient; BMI, body mass index; CI, confidence interval(s); EN Index, Edwards-Nunnally Index; 25-OHD, 25-hydroxyvitamin D; OR, odds ratio(s).

FIG. 1. Study sample of the Longitudinal Aging Study Amsterdam (LASA) and reasons for attrition and exclusion.

ified according to age, gender, degree of urbanization, and expected 5-yr mortality, was drawn from the population registers of 11 municipalities in three geographical areas in The Netherlands (19).

A total of 3107 participants (1506 men and 1601 women) were enrolled for the baseline examination in 1992–1993. The second cycle of data collection took place in 1995–1996, and the third in 1998–1999. The medical interview took place 2–6 wk after the main interview (20). For the current study, data of the second and third cycles are used. The study was approved by the Medical Ethics Committee of the VU University Medical Center, and informed consent was obtained from all participants.

The study sample comprised 1509 persons, aged 65 yr or older as of January 1, 1996, who participated in both the main and medical interview. Over 99% of the participants were Caucasian. Participants who did not provide a blood sample (or whose sample was insufficient, n = 189), who did not complete the performance tests (n = 60), or who had missing values for the potential confounders (n = 26) were excluded. This resulted in the inclusion of data on 1234 participants in the statistical analysis. Three years later, in 1998–1999, 979 of these 1234 participants completed the physical performance tests. Figure 1 shows the recruitment and exclusion of the participants.

TABLE 1. Baseline characteristics of 1234 LASA participants, according to serum 25-OHD classification

	Serum 25-OHD concentration (ng/ml)					Overall *P*
	Total	<10	10–20	20–30	≥30	
n	1234 (100)	134 (10.9)	453 (36.7)	420 (34.0)	227 (18.4)	
Gender						<0.001
Men	600 (48.6)	49 (8.2)	181 (30.2)	225 (37.5)	145 (24.2)	
Women	634 (51.4)	85 (13.4)	272 (42.9)	195 (30.8)	82 (12.9)	
Age (yr)	75.3 ± 6.5	79.8 ± 5.9	76.9 ± 6.5	73.8 ± 5.9	72.1 ± 5.4	<0.001
BMI (kg/m^2)						<0.001
<20 (underweight)	46 (3.7)	11 (23.9)	18 (39.1)	11 (23.9)	6 (13.0)	
20–25 (healthy weight)	379 (30.7)	32 (8.4)	123 (32.5)	125 (33.0)	99 (26.1)	
≥25 (overweight)	809 (65.6)	91 (11.2)	312 (38.6)	284 (35.1)	122 (15.1)	
Smoker status						<0.001
Never	440 (35.7)	66 (15.0)	176 (40.0)	132 (30.0)	66 (15.0)	
Former	570 (46.2)	37 (6.5)	191 (33.5)	221 (38.8)	121 (21.2)	
Current	224 (13.2)	31 (13.8)	86 (38.4)	67 (29.9)	40 (17.9)	
Alcohol consumption						<0.001
Nondrinker	295 (23.9)	42 (14.2)	138 (46.8)	87 (29.5)	28 (9.5)	
Light drinker	622 (50.4)	71 (11.4)	222 (35.7)	212 (34.1)	117 (18.8)	
Moderate drinker	242 (19.6)	20 (8.3)	67 (27.7)	91 (37.6)	64 (26.4)	
(Very) excessive drinker	75 (6.1)	1 (1.3)	26 (34.7)	30 (40.0)	18 (24.0)	
Chronic diseases from 7 majors[a] (median [interquartile range])	1 [0–2]	1 [1–2]	1 [0–2]	1 [0–2]	1 [0–2]	<0.001
Physical activity (min/d)	148.8 ± 96.8	129.7 ± 95.5	142.8 ± 93.5	159.9 ± 101.8	151.5 ± 92.7	0.004
Degree of urbanization (no. of addresses/km^2)						<0.001
Rural (<500)	241 (19.5)	24 (10.0)	84 (34.9)	75 (31.1)	58 (24.1)	
Low (500–1000)	267 (21.6)	23 (8.6)	90 (33.7)	99 (37.1)	55 (20.6)	
Moderate (1000–1500)	203 (16.5)	16 (7.9)	72 (35.5)	72 (35.5)	43 (21.1)	
High (1500–2500)	220 (17.8)	17 (7.7)	87 (39.5)	74 (33.6)	42 (19.1)	
Very high (>2500)	303 (24.6)	54 (17.8)	120 (39.6)	100 (33.0)	29 (9.6)	
Level of education						0.197
Low (≤9 yr)	889 (72.0)	96 (10.8)	339 (38.1)	302 (34.0)	152 (17.1)	
High (>9 yr)	345 (28.0)	38 (11.0)	114 (33.0)	118 (34.2)	75 (21.7)	
Season of blood collection						<0.001
Winter	686 (55.6)	90 (13.1)	271 (39.5)	212 (30.9)	113 (16.5)	
Summer	548 (44.4)	44 (8.0)	182 (33.2)	208 (38.0)	114 (20.8)	
Creatinine (μmol/liter)	94.9 ± 33.5	91.9 ± 35.9	95.9 ± 45.5	93.7 ± 20.4	96.8 ± 20.7	<0.001
Physical performance (0–12)	7.4 ± 3.3	5.0 ± 3.1	6.9 ± 3.1	8.1 ± 2.8	8.7 ± 2.6	<0.001

Values are means ± SD or number (percentage), unless otherwise indicated. To convert to SI units, multiply by 2.496 for 25-OHD (nanomoles per liter).

[a] Seven chronic diseases: chronic obstructive pulmonary disease (asthma, chronic bronchitis, and pulmonary emphysema), cardiac disease, peripheral arterial disease, stroke, diabetes mellitus, rheumatoid arthritis/osteoarthritis, and cancer.

Physical performance

Physical performance was assessed by means of three performance tests, the scores for which were summed to obtain a total performance score (21). The tests included: the time taken to walk 3 m, turn 180° and walk back (walking test); time taken to rise five times from a kitchen chair with arms folded in front of the chest (chair stands); and the ability to stand with the heel of one foot directly in front of, and touching the toes of, the other foot for at least 10 sec (tandem stand). The walking test, chair stands test, and tandem stand, respectively, are indicators of coordination, proximal muscle strength, and balance; proximal muscle strength; and balance. The time required for the walking test and chair stand test was categorized according to quartiles (scored 1–4) of the time required by the LASA population. A score of 4 was assigned to the fastest quartile, and those who could not complete the test were assigned a score of 0. The tandem stand was categorized as follows: unable (score 0), able to hold position for 3–9 sec (score 2), and able to hold position for at least 10 sec (score 4). The individual test scores were summed to derive the total physical performance score, ranging from 0 to 12, with 12 points representing an excellent performance. The score on physical performance tests was well associated with falls (22) and fractures (22), cognitive function (23), visual impairment (24), and frailty (25) and has shown to be a reliable and valid measure of physical performance.

Decline in physical performance

To assess whether there was a decline in physical performance during the 3-yr follow-up, the Edwards-Nunnally Index (EN Index)[1] was used to determine clinically significant change (26). The index is adjusted for regression to the mean; thus, apart from the individual and mean raw scores, reliability parameters are part of the formula. The EN Index implies that whether or not the decline is significant depends on the individual's baseline score (27). Based on confidence intervals (CI), the EN Index classifies change as improved, stable, or declined. For the analyses, changes in physical performance scores were dichotomized into decline *vs.* no decline (stability or improvement), using a critical value of 1.96 ($P < 0.05$).

Biochemistry

In 1995–1996, fasting blood samples were collected in the morning and were subsequently centrifuged. Serum samples were stored at −20 C, and serum 25-OHD was measured by a competitive protein-binding

[1] EN Index: $X_L >$ or $<$ ([alpha * X_P − M] + M [± 1.96; * SE]), where X_L = individual final physical performance score (in 1998–1999); X_P = individual previous physical performance score (in 1995–1996); M = mean score of the group in 1995–1996, SE = (SD * [1 − alpha]^2).

assay (Nichols Diagnostics, San Juan Capistrano, CA). The interassay coefficient of variation was 10%. The analyses were carried out in 1997–1998 at the Endocrine Laboratory in the VU University Medical Center. For the current analysis, traditional cutoff points were used: lower than 10 ng/ml, 10–20 ng/ml, 20–30 ng/ml, and 30 ng/ml[2] or more (4). Serum creatinine was analyzed according to routine laboratory methods.

Confounders

The following potential confounders, measured in 1995–1996, were included in the statistical analysis: gender, age, level of education, degree of urbanization, body mass index (BMI), alcohol consumption, smoking status, number of chronic diseases, physical activity, season of blood collection, and serum creatinine (as a marker of renal function). The participants were asked about highest level of education they had achieved, ranging from incomplete elementary school to university education. This was converted into years of education, ranging from 5 to 18 yr. The score was dichotomized into low level (≤9 yr) *vs.* high level (>9 yr) of education. 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 kilometer (28). The categories ranged from less than 500 addresses per square kilometer to 2500 or more addresses per square kilometer. BMI was calculated as weight (kilograms)/height (meters)^2. Body weight was measured without clothes and shoes, using a calibrated balance beam scale. Body height was measured with a stadiometer. BMI was categorized into three groups: underweight (BMI < 20 kg/m^2), normal weight (20 kg/m^2 $\leq$ BMI $<$ 25 kg/m^2), and overweight (BMI $\geq$ 25 kg/m^2). The alcohol consumption index was used to classify alcohol drinkers into four categories [nondrinker, light drinkers, moderate drinker and (very) excessive drinker] based on the number of days on which alcohol was consumed and the number of alcoholic drinks consumed each time (29). 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+ age group in The Netherlands (19). These were: chronic obstructive pulmonary disease (asthma, chronic bronchitis, and pulmonary emphysema), cardiac disease, peripheral arterial disease, stroke, diabetes mellitus, rheumatoid arthritis/osteoarthritis, and cancer. Information about the diseases was based on self-report (30). Physical activity (minutes per day) was assessed with the LASA Physical Activity Questionnaire (LAPAQ), a validated interviewer-administered questionnaire (31). The participants were asked about the duration and frequency of their involvement in the following activities during the previous 2 wk: walking outdoors, bicycling, light household activities, heavy household activities, and sports activities. Vitamin D synthesis depends on sun exposure and season, and in The Netherlands it is not synthesized between October and March (6, 9). The season for blood collection was dichotomized in winter (October–March) and summer (April–September).

Statistical analysis

The tests used to assess potential differences in gender, age, and serum 25-OHD between included and excluded participants were the Pearson χ^2 test (for gender) and independent *t* tests (for age and serum 25-OHD). Pearson χ^2 tests were also performed to assess differences in categorical variables in the separate vitamin D categories, *i.e.* less than 10, 10–20, 20–30 and at least 30 ng/ml. The Kruskall-Wallis H test was used to assess differences in means of skewed continuous variables among vitamin D categories. Multiple linear regression analysis was used to investigate the association between the vitamin D categories and physical performance. The vitamin D category of at least 30 ng/ml served as a reference group. First potential confounders, *i.e.* gender, age, level of education, degree of urbanization, BMI, alcohol consumption, smoking status, number of chronic diseases, season of blood collection, and serum creatinine were added one by one to the univariate model. Confounders that led to a change in the regression coefficient (B) of 10% or more were retained in the model. Secondly, physical activity was added separately to the multiple linear regression model to assess whether it acted as a mediator or a confounder. Logistic regression analysis was performed to determine whether vitamin D status was associated with change in physical performance. The calculation of change in physical performance was based on the EN Index (26, 27) (see *Decline in physical performance*). Finally, to investigate which aspect of physical performance (walking test, chair stands, tandem stand) was most strongly related to vitamin D, cumulative logistic ordinal regression, with the feature of proportional odds, was performed (32, 33). The confounders that were identified in the linear regression analyses were included in all other analyses.

[2] To convert to SI units, multiply by 2.496 for 25-OHD (nmol/liter).

Results

A total of 1234 participants (600 men, 634 women) were included in the analysis. Their mean (SD) age was 75.3 (6.5) yr, and their mean (SD) serum 25-OHD was 21.6 (9.7) ng/ml. Excluded participants with known serum 25-OHD (n = 86) were significantly older [78.7 (6.8) yr; $P < 0.001$] and had lower serum 25-OHD [18.2 (8.3) ng/ml; $P = 0.002$]. They were more often female, although this difference was not

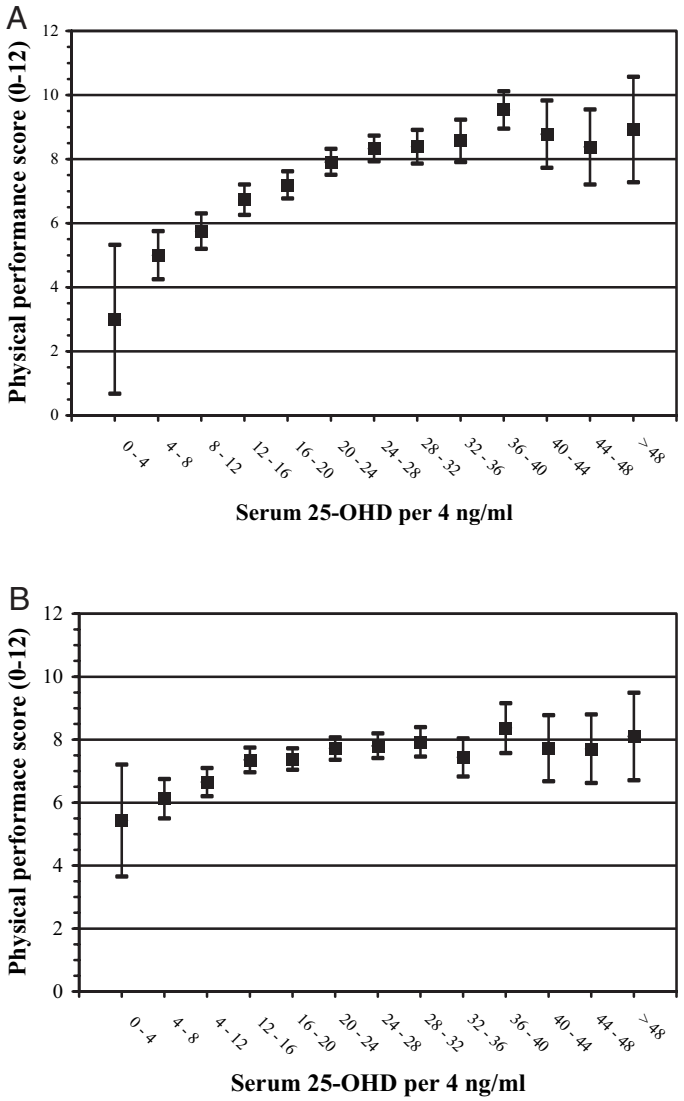

FIG. 2. Physical performance in 1234 older persons in relation to 25-OHD. Shown are CI for the mean. A, Unadjusted data. B, Adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, and alcohol consumption.

TABLE 2. Results of multiple regression analyses of serum 25-OHD as a predictor of physical performance score in 1234 older persons

25-OHD category	Difference in physical performance score of different vitamin D categories with respect to the reference group (0–12)#		
	Model 1[a]	Model 2[b]	Model 3[c]
<10 ng/ml (n = 134)	−1.96 [−2.56; −1.35]***	−1.69 [−2.28; −1.10]***	−1.65 [−2.24; −1.07]***
10–20 ng/ml (n = 453)	−0.69 [−1.14; −0.25]**	−0.46 [−0.90; −0.03]*	−0.45 [−0.88; −0.02]*
20–30 ng/ml (n = 420)	−0.12 [−0.56; 0.31]	−0.03 [−0.42; 0.41]	−0.04 [−0.45; 0.38]
≥30 ng/ml (n = 227)	0 (reference group)	0 (reference group)	0 (reference group)

Data are expressed as B [95% CI]. #, Physical performance score of 12 points represents an excellent performance. To convert to SI units, multiply by 2.496 for 25-OHD (nanomoles per liter).

[a] Adjusted for age and gender.

[b] Adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, and alcohol consumption.

[c] Adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, alcohol consumption, and physical activity.

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ *vs.* reference group.

statistically significant ($P = 0.06$). Excluded participants with unknown serum 25-OHD (n = 32) were similar in age to the included participants [76.2 (6.9) yr].

The baseline characteristics of the 1234 participants classified according to serum 25-OHD level are shown in Table 1. Serum 25-OHD below 10 ng/ml was observed in 10.9% of the study sample, and serum 25-OHD of 10–20 ng/ml was observed in 36.7%. Participants in the lower vitamin D categories had lower performance scores. Participants with serum 25-OHD below 20 ng/ml were more often women, were older, had a higher BMI, were less physically active, and were more often living in cities; their blood samples were more often collected during the winter, and their serum creatinine was higher, compared with participants with serum 25-OHD of at least 20 ng/ml. The categories also differed from each other with regard to smoking status, alcohol consumption, and number of chronic diseases. Figure 2A shows the unadjusted mean scores for physical performance in steps of 4 ng/ml serum 25-OHD, and Fig. 2B shows mean scores adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, and alcohol consumption. After adjustments, an increase in physical performance was seen up to 16–20 ng/ml, above which the strength of the association leveled off.

The findings from the linear regression model are shown in Table 2. In the first model, adjustments were made for gender and age. Participants with serum 25-OHD categories below 20 ng/ml had a significantly lower score for physical performance, compared with the reference category (25-OHD ≥ 30 ng/ml). Participants with serum 25-OHD below 10 ng/ml had a 1.96 lower score on the 12-point scale, compared with those who had serum 25-OHD levels of at least 30 ng/ml. The second model was adjusted for the following confounders (in order of influence on the association): age, gender, number of chronic diseases, grade of urbanization, BMI, and alcohol consumption. Because no change in B was observed when level of education, smoking status, season of blood collection, or serum creatinine was added to the model, these variables were omitted from the model. After adjustment for the confounding variables, participants in the serum 25-OHD categories up to 20 ng/ml had a significantly lower physical performance than the reference group. Physical activity, added in the third model, did not change the B. Thus, physical activity is neither a confounder nor a mediator.

The physical performance of 979 participants was measured again in 1998–1999. The physical performance of 160 participants declined, there was no significant change in the physical performance of 805 participants, and only 14 participants showed improvement in their performance. The results of the logistic regression analysis of decline *vs.* no decline, after adjustment for confounding variables, are shown in Table 3. In comparison with the reference group, participants with serum 25-OHD below 10 ng/ml had the highest risk of decline during the follow-up period [odds ratio (OR) = 2.21; 95% CI = 1.00–4.87], and participants with serum 10–20 ng/ml had an OR of 2.01 (95% CI = 1.06–3.81).

Cumulative logistic ordinal regression analysis was performed to investigate the relationship between serum 25-OHD and the three separate physical performance tests. Table 4 shows the cumulative OR, after adjustment for confounding. Participants with serum 25-OHD less than 10 ng/ml scored lower on all tests, compared with the reference group. The cumulative OR were 2.54, 2.23, and 2.17 for the walking test, chair stands, and tandem stand, respectively. This implies that the participants with serum 25-OHD below 10 ng/ml were 2.54 times more likely to score one point lower on the walking test, compared with the reference group. On the walking test, participants with serum 25-OHD of 10–20 ng/ml also scored significantly lower than the reference group (cumulative OR = 1.37; 95% CI = 1.01–1.89).

Discussion

This study clearly shows that physical performance is not only associated with vitamin D status cross-sectionally, but that vitamin D status is also associated with decline over time in physical performance. Compared with the reference group (25-OHD ≥ 30 ng/ml), participants with levels up to 20

TABLE 3. Results of logistic regression analyses: OR for decline in physical performance after 3 yr according to baseline categories of baseline serum 25-OHD (n = 979)

25-OHD category	Decline in physical performance
<10 ng/ml (n = 89)	2.21 [1.00–4.87][a]
10–20 ng/ml (n = 347)	2.01 [1.06–3.81][a]
20–30 ng/ml (n = 348)	1.56 [0.82–2.97]
≥30 ng/ml (n = 195)	1.0 (reference group)

Data represent OR [95% CI]. To convert to SI units, multiply by 2.496 for 25-OHD (nanomoles per liter). Adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, and alcohol consumption.

[a] $P < 0.05$ *vs.* reference group.

TABLE 4. Adjusted cumulative OR for different physical performance tests according to categories of serum 25-OHD (n = 1234)

25-OHD category	Physical performance test		
	Walking test (0–4)	Chair stands (0–4)	Tandem stand (0, 2, 4)
<10 ng/ml (n = 134)	2.54 [1.63–3.97][c]	2.23 [1.45–3.41][c]	2.17 [1.31–3.59][b]
10–20 ng/ml (n = 453)	1.37 [1.01–1.89][a]	1.18 [0.87–1.62]	1.27 [0.86–1.89]
20–30 ng/ml (n = 420)	1.10 [0.81–1.51]	0.94 [0.70–1.26]	0.93 [0.63–1.38]
≥30 ng/ml (n = 227)	1.0 (reference group)	1.0 (reference group)	1.0 (reference group)

Data represent cumulative OR [95% CI]. To convert to SI units, multiply by 2.496 for 25-OHD (nanomoles per liter). Adjusted for age, gender, number of chronic diseases, degree of urbanization, BMI, and alcohol consumption.

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$ *vs.* reference group.

ng/ml had significantly lower scores for physical performance and had higher odds for decline in physical performance. This was significant after adjustment for age, gender, number of chronic diseases, degree of urbanization, BMI, alcohol consumption, and physical activity. In Fig. 2, it can also be observed in the curve describing physical performance in relation to 25-OHD, which levels off above 20 ng/ml. The chair stands and tandem stand were significantly related to serum 25-OHD, up to 10 ng/ml; the walking test was significantly related to serum 25-OHD up to 20 ng/ml. It has been well documented that vitamin D deficiency causes mineralization defects in bone (4–7). Because poor physical performance is a predictor for recurrent falls (34–36), it implies that people with vitamin D deficiency, who already have weaker bones, are at increased risk for both recurrent falls and fractures. Recently, it was shown by Snijder *et al.* (37) that vitamin D deficiency is independently associated with an increased risk of falling in the elderly.

Some investigators have found a relationship between vitamin D status and physical performance. Zamboni *et al.* (13) found, in a relatively small study population, that serum 25-OHD (cutoff point, 15 ng/ml) was related to arm and leg strength in women (n = 75), but not in men (n = 94). In the Osteoporosis Prospective Risk Assessment study (OPRA, n = 986) of elderly ambulatory women in Sweden, inferior gait speed and balance were related to 25-OHD below 30 ng/ml. However, the mean serum 25-OHD in this study was high (38 ng/ml), and only 4.4% of the women had a serum 25-OHD less than 20 ng/ml (16). The results of our study are in agreement with the data from the population-based National Health and Nutrition Examination Survey NHANES III (38) study, with regard to the walking test and chair stands. In our study we added the tandem stand, which also appears to be associated with vitamin D status.

Nearly 50% of our study population had low serum 25-OHD levels: 10.9% of the participants had vitamin D deficiency (25-OHD < 10 ng/ml) (4) and 36.7% had vitamin D insufficiency (serum 25-OHD, 10–20 ng/ml) (4). Women were more likely than men to have serum 25-OHD less than 20 ng/ml (56.3 *vs.* 38.3%). This study confirms the high prevalence of low 25-OHD concentrations in older people in the general population (1–4). The definition of vitamin D deficiency will affect estimates of prevalence, but there is no generally accepted criterion for vitamin D deficiency. Our conservative categorization of vitamin D deficiency and insufficiency is based on the proposed classification for bone health (4). Recently, a group of investigators concluded that estimates of the serum 25-OHD concentration that is optimal for bone health ranged from 20–32 ng/ml (39). Proposals for adequate vitamin D status have frequently been made, but are based on levels of PTH, and not on physical performance or muscle strength. One study based on NHANES III concluded that for optimal lower extremity function it was desirable to reach 25-OHD concentrations of at least 16 ng/ml, whereas concentrations as high as 36–40 ng/ml appeared to be advantageous (38). Our study confirms that for physical performance, serum 25-OHD should be at least 20 ng/ml.

Adjustment of our model for physical activity was questionable because it can be hypothesized that less active people may already be weaker and, consequently, less often go outside into the sunlight, which results in lower values of vitamin D (13). However, physical activity and physical performance were only weakly positively correlated (Spearman's rho = 0.149; $P < 0.001$). Furthermore, additional adjustment for physical activity did not change the results. The degree of urbanization was related to differences in vitamin D status. In our study, serum 25-OHD below 20 ng/ml was more common in participants living in a highly urbanized environment (≥2500 addresses per square kilometer) than in those living in less urbanized environments. It could be speculated that this may be due to more shadow, more air pollution, less time spent outdoors, and a lower consumption of food containing vitamin D and calcium, but information about such factors was not available.

The main strengths of this study are its prospective and population-based design and the large sample size (n = 1234), with an equal number of men and women. The study sample is representative of the older population in The Netherlands. Another strength of this study is the number of potential confounders that were investigated. We also took into account the fact that regression to the mean could occur, and therefore any change in physical performance, according to the objective test scores, was based on the EN Index, and not on mean raw scores.

However, this study also has some limitations. Most importantly, underestimation of the relationship might have occurred for two reasons. First, the excluded participants were older, had lower serum 25-OHD, and were more often women, all of which are factors related to decreased physical performance. Secondly, because the frailest people were not able to visit the hospital or the health care center for blood collection, the LASA sample, on which this study was based, was relatively healthy. This could explain why only a few participants (n = 19; 1.5%) had serum 25-OHD levels of less than 5 ng/ml.

The strong association between vitamin D status and physical performance can be generalized to older Caucasians in The Netherlands, but this might also be the case for younger individuals. It can be hypothesized that younger people, in contrast to older people, have more skills to compensate for a decline in physical performance due to low serum 25-OHD.

Both sunlight and food are providers of vitamin D. However, although sunlight is a natural and inexpensive provider, frail elderly people may not be able to synthesize sufficient vitamin D in the skin (11). The ability of their skin to synthesize vitamin D depends on latitude and season (40) and decreases with age (11). During the summer, older persons should be encouraged to spend more time outdoors. Furthermore, they should include sufficient vitamin D and calcium in their diet because a low dietary intake of both calcium and vitamin D is very common among older people (9). In Europe, with the exception of several Scandinavian countries, food is not usually fortified with vitamin D, except for margarine (41). The efficacy of food fortification should therefore be evaluated, especially with regard to vitamin D status in the elderly. Because of the high prevalence of suboptimal levels of serum 25-OHD and the low risk of intoxication, routine supplementation during winter should be recommended to all elderly people who are at risk, especially those with restricted mobility. Physicians and the general public should be made more aware of the high prevalence of vitamin D deficiency and insufficiency, and more effort should be concentrated on the early detection and treatment of people with suboptimal levels of vitamin D.

In conclusion, the results of this population-based study show that lower serum 25-OHD is associated with a decline in physical performance in older men and women in The Netherlands.

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