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Vitamin D, Cognitive Function, and Gait Speed in Older Adults: A NHANES Study

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Abstract

Background: Vitamin D deficiency has been linked to poor cognition and neuromuscular impairment. We evaluated the relationships of vitamin D levels with cognitive function and gait speed in older adults.

Methods: The study sample included 1,076 individuals (age => 60 years) from the 2001-2002 National Health Examination Survey (NHANES). The relationships between vitamin D and cognition and gait speed were studied. Cognitive function was measured as the number of questions correct on a digit-symbol test. Gait speed was measured as seconds to walk 20 feet. Serum 25(OH)D concentrations were measured via the DiaSorin radioimmunoassay.

Results: In our study, 32% were deficient in vitamin D (< 20 ng/ml) and 43% were insufficient in vitamin D (20-29 ng/ml). Only 25% had vitamin D values in the normal range (30-100 ng/ml). The mean vitamin D level, cognition score, and gait speed were found to be 24.71 ng/ml, 48.55 number correct, and 6.80 seconds, respectively. The relationship between vitamin D and cognitive function was an inverted U-shaped curve. Maximum cognition score was at a vitamin D value of 28.09 ng/ml. The relationship between vitamin D and gait speed was U-shaped. Minimum walking time was at a vitamin D level of 31.42 ng/ml.

Conclusion: Optimal vitamin D levels were similar for both cognition and gait speed. Vitamin D may have a role in supporting both cognition and gait. Given the high prevalence of vitamin D deficiency in the elderly, we recommend that older individuals are tested and treated to achieve 25(OH) D values at least between 28-30 ng/ml.

Introduction

By 2030, the U.S. elderly population in the United States will grow to 74 million or 20 percent of the overall population. The projected disease burden to be experienced by this group has been characterized as a silver tsunami.[1] Two of the top health risks for this population come from cognitive health and falling (CDC). The costs of health care for patients with dementia is expected to reach 1.1 trillion dollars in 2050.[2] Similarly, in 2012, the cost of falls for this population was $30.3 billion.[3] Vitamin D is thought to improve both health outcomes. Unfortunately, there is pandemic of vitamin D insufficiency (measured as 25(OH)D < 30 ng/ml). Over 50% of the U.S. population is deficient in vitamin D.[4]

While the existence of this pandemic is widely accepted, considerable controversy surrounds optimal vitamin D dosing.[5] The Institute of Medicine prefers lower replacement doses such as 600 to 800 iu, although it does agree that doses up to 4000 iu daily are safe.[6] The Endocrine Society is more inclined to use higher doses such as 2000 iu daily or higher.[7] The optimal dose of vitamin D may be, to some extent, disease dependent. For example, prevention of rickets only requires a very small dose of vitamin D, such as 200 iu, daily. For prevention of other diseases such as osteoporosis, the commonly used doses are around 800 iu daily. However, with this type of dosage, many patients remain vitamin D deficient. The issue is complicated by the fact that mega-doses of vitamin D given episodically and, therefore, non-physiologically, can induce adverse effects such as increased fractures and falls.[8,9] However, some studies that have used megadose Vitamin D have reported that the elderly experience a better quality of life with improved functional mobility.[10]

The existing academic research also is not definitive as to the effects of vitamin D dosage on cognitive function and gait. Although vitamin D has been shown to improve cognitive capability in some studies[11,12] and to reduce falls in others, these studies are based either on old data[11] or on small samples that are not nationally representative for example.[13] They also examine only one outcome at a time, although a different dosage of vitamin D might be optimal for cognitive function than for gait. In addition, the data on falls come from only relatively small clinical trials that have focused on falling events. Even for someone predisposed to falling, falling is a relatively rare event that may not be captured well in a small clinical trial. As such, our study focuses instead upon gait, which has been shown to be strongly predictive of falls and can be measured in small changes.[14,15] Speed of walking is a valid, reliable, and sensitive measure for assessing and monitoring functional status and overall health and longevity in the elderly. It has been designated the "6th vital sign". A low vitamin D value is associated with slow gait speed.[16] In elderly Chilean subjects, vitamin D supplementation was associated with improved gait speed and body sway.[17]

To more firmly establish what the recommended levels of vitamin D should be for older Americans, and to find the differential effects of vitamin D based on two essential health outcomes, it is necessary to have a data set that includes both outcome variables for the relevant population. . We obtained a large, nationally representative sample from the 2001-2002 National Health and Nutrition Examination Survey (NHANES) conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention (CDC). These data include information on vitamin D from blood work and cognitive function as well as walking speed from examinations. Control variables include demographic and economic characteristics. They also allowed us to control for the summer season, as vitamin D levels may be higher in the summer due to greater sunlight exposure.

Methods

The data for the current study come from the 2001-2002 National Health and Nutrition Examination Survey (NHANES). This is the most recent period for which all key variables for the study are available. Since 1959, the NHANES has been gathering annual data on the health and nutrition of persons in the United States for the National Center for Health Statistics. The survey's data-gathering procedures include interviews and laboratory and physical assessments of participants.

We examined a subsample of the data to focus on older Americans. In order to obtain data on both cognitive function and gait speed, we could not examine individuals under age 60. The total number of observations for the analysis, after cleaning the data to remove individuals with missing information from the sample, was 1,076 individuals aged 60 and older. Survey weights were used in both the descriptive and multivariate analyses to allow inferences to be made for the U.S. population of individuals aged 60 and older. STATA SE Version 14 software was used to perform all analyses.

Outcome Variables

Two health outcomes, cognitive functioning and gait speed, were examined in this study. Cognitive functioning was measured in NHANES as the score a participant received on a version of the WAIS III (Wechsler Adult Intelligence Scale, Third Edition) Digit Symbol exercise. Given a two-minute time frame, a person's score depended on the number of digit symbols coded correctly. The scores of the test range from zero to 133. Higher scores on the DSS test represented higher cognitive ability. Gait speed was measured in NHANES as the amount of time (measured in seconds) a person took to complete a 20-foot walk. More information on these measures is provided in the publicly available documentation for NHANES.

Key Explanatory Variable

The level of vitamin D served as the main explanatory variable. It was obtained from blood samples drawn during laboratory examinations and assessed through a 25-Hydroxyvitamin D test. In the NHANES data the variable was measured in nmol/L. Therefore, we converted the vitamin D measurement from nmol/L to ng/ml, which is used more commonly. We allowed this vitamin D measure to affect our outcome measures in a nonlinear fashion, including this continuous measure with its square in our regression equations.

Other Explanatory Variables

Our study controlled for economic, demographic, and other variables. Educational attainment dummy variables indicated whether a person's highest educational attainment was some high school, high school graduate, some college, or college graduate. The omitted or reference category was less than high school. For example, if a person's highest educational attainment was some college, that dummy variable took a value of 1 and all the other dummy variables took a value of 0. Age was included as a continuous variable in the analysis. However, because this variable was top coded in the NHANES at age 85, a dummy variable that indicated whether a value was top coded also was included. Hispanic, Black, and Other Race/Ethnicity dummy variables were included, with White as the omitted or reference category. Gender was measured as whether the person was a male or not. A dummy variable for whether a person was born in the United States or not was included in the model. There also was a dummy variable for whether a person was married or not. Household size was measured as the number of persons in the household and thus was a continuous variable in the analysis. However, because this variable was top coded at 7 persons, a dummy variable equal to 1 if the value was 7 and 0 otherwise was included also. A dummy variable for summer was included to capture the degree of sunlight exposure at the time of the test. The study also included dummy variables for a person's annual household income, representing the following categories: $10,000 to $19,999; $20,000 to $34,999, $35,000 to $54, 999; $55,000 to $74,999; and $75,000 and over, with $0 to $9,999 as the reference category.

Table 1 shows the descriptive statistics for the dependent and explanatory variables. The average score for the cognitive function test was 48.55 correct answers out of a possible 133, while the average gait speed was 6.80 seconds to walk 20 feet. The average vitamin D contained in the blood of individuals was 24.71 ng/ml, indicating that these individuals had insufficient vitamin D levels, on average, according to existing guidelines. Regarding the other explanatory variables, average age was 70, 91.80 percent were born in the United States, 68.38 percent were married, 24.44 percent were college graduates, 45.48 percent were males, the average household size was two, and 19.27 percent had household income levels of $75,000 and over. 63.70 percent of the individuals were examined during summer (May 1st to October 31st).

Model

Two equations were estimated for the same individuals:

$$Y_{ij} = B_{0j} + B_{1j}\text{Vitamin D} + B_2X + E_{ij}$$

where Y_{ij} was outcome j for person i (j stands for either the cognitive measure or the walking measure), vitamin D was a matrix of explanatory variables for Vitamin D that allowed it to enter nonlinearly (vitamin D and vitamin D squared and), X was the matrix of variables representing demographic and economic factors, B_0 and B_1 were the coefficients to be estimated, and E_{ij} was the error term for the jth outcome for the ith person. Linear regression analysis that accounts for the weighting structure of the survey data was used to estimate these equations.

Results

Table 2 shows the results of the regression of cognitive score on vitamin D, vitamin D squared, and the other explanatory variables. The R^2 of this regression is 0.47, which means that 47% of the variation in cognitive score is explained by our included variables. A p-value of $\leq$ .05 was used to determine statistical significance. The estimated coefficients on the vitamin D variable and its square indicate that vitamin D increases cognitive score at a decreasing rate. Thus, the relationship between vitamin D and cognitive score is a nonlinear, inverted U-shaped relationship. Figure 1 shows how the predicted cognitive score changes as vitamin D level changes, holding all else constant. Cognitive score increases with vitamin D level until it reaches its maximum at a level of 28.09 ng/ml and then declines. The covariance of the two measures was -0.3598.

Other variables also are statistically significant predictors of a person's cognitive score, controlling for the other variables. Males have lower cognitive scores than females, all else equal. Older individuals have lower cognitive scores than younger individuals. Blacks have lower cognitive scores than non-Hispanic whites. Those born in the U.S. have higher cognitive scores than those who were not. Those with higher levels of education have higher cognitive scores than those with a less-than-high-school education. Those with higher levels of income have higher cognitive scores than those in the lowest income category. However, a greater number of people in the household reduces a person's cognitive score.

Table 3 shows the results of the regression of walking speed on vitamin D, vitamin D squared, and the other explanatory variables. The R^2 for this regression is 0.23, meaning that 23% of the variation in walking speed is explained by our included variables. The coefficients on the vitamin D variable and its square indicate that vitamin D decreases the number of seconds it takes to walk 20 feet at an increasing rate. Thus, the relationship between vitamin D and time to walk 20 feet is a nonlinear, U-shaped relationship. Figure 2 shows how the predicted gait speed changes as vitamin D level changes, holding all else constant. Time to walk 20 feet declines until it reaches its minimum at 31.42 ng/ml and then increases.

Fewer demographic variables were statistically significant in the walking speed regression than were in the cognitive function regression. However, all else equal, older individuals were found to take more time than younger individuals, those of other race were found to take more time than non-Hispanic whites, those with greater levels of education were found to take less time than those with less than a high school education, and those with income of at least $55,000 were found to take less time than those with the lowest level of income.

Conclusion

In our study, 32% of the elderly were deficient in vitamin D (< 20 ng/ml) and 43% were insufficient in vitamin D (20-29 ng/ml). Only 25% had vitamin D values in the normal range (30-100 ng/ml). The mean vitamin D level, cognition score, and gait speed were found to be 24.71 ng/ml, 48.55 number correct, and 6.80 seconds, respectively. The relationship between vitamin D and cognitive function was an inverted U-shaped curve. Maximum cognition score was at a vitamin D value of 28.09 ng/ml. The relationship between vitamin D and gait speed was U-shaped. Minimum walking time was at a vitamin D level of 31.42 ng/ml.

Both maximum cognitive score and minimum time to walk 20 feet are close to the lower end of the currently recommended level of 30-100 ng/ml. While these results suggest that vitamin D levels near the lower end of this range are optimal, they are based on a sample of people with low levels of vitamin D and focus only on two health outcomes, cognitive function and walking speed. Future research could examine samples with higher vitamin D levels and additional health outcomes if such data were made available.

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Table 1: Descriptive Statistics for Analysis Sample (N=1,076)		
	Mean	**Standard Error**
Dependent Variables		
Cognitive test score (number correct)	48.5467	1.0523
Time to walk 20 feet (seconds)	6.7964	0.0830
Explanatory Variables		
Vitamin D level (ng/ml)	24.7125	0.5160
Summer (=1 if yes, =0 if no)	0.6370	0.0751
Male (=1 if yes, =0 if no)	0.4548	0.0150
Age	70.4652	0.3912
Age topcoded (=1 if yes, =0 if no)	0.0514	0.0081
Race/Ethnicity (white, non-Hispanic is the reference category)		
Hispanic (=1 if yes, =0 if no)	0.0506	0.0208
Black	0.0638	0.0125
Other	0.0280	0.0123
Born in the U.S. (=1 if yes, =0 if no)	0.9180	0.0155
Highest education level (less than high school is the reference category)		
Some high school (=1 if yes, =0 if no)	0.1458	0.0138
High school graduate (=1 if yes, =0 if no)	0.2848	0.0164
Some college (=1 if yes, =0 if no)	0.2161	0.0138
College graduate (=1 if yes, =0 if no)	0.2444	0.0210
Married (=1 if yes, =0 if no)	0.6538	0.0158
Number of persons in the household	2.1210	0.0623
Number of persons in the household top coded (=1 if yes, =0 if no)	0.0174	0.0055
Income ($0-$9,999 is the reference category)		
$10,000-$19,999	0.1697	0.0171
$20,000-$34,999	0.2534	0.0213
$35,000-$54,999	0.1933	0.0139
$55,000-$74,999	0.1193	0.0126
$75,000 and up	0.1927	0.0314
Survey weights were used.		

Table 2: Linear Regression of Cognitive Score on Vitamin D and Other Explanatory Variables (N=1,076)			
Explanatory Variable	**Coefficient**	**Standard Error**	
Vitamin D level (ng/ml)	0.5906	0.2059	*
Vitamin D level squared	-0.0105	0.0037	*
Summer (=1 if yes, =0 if no)	2.8060	1.3273	
Male (=1 if yes, =0 if no)	-5.6904	1.1082	*
Age	-0.7336	0.0648	*
Age top coded (=1 if yes, =0 if no)	-5.7562	1.2557	*
Race/Ethnicity (white, non-Hispanic is the reference category)			
Hispanic (=1 if yes, =0 if no)	-2.7178	1.5241	
Black	-9.1342	1.6370	*
Other	2.8707	3.9393	
Born in the U.S. (=1 if yes, =0 if no)	8.5504	2.3407	*
Highest education level (less than high school is the reference category)			
Some high school (=1 if yes, =0 if no)	7.8887	2.5437	*
High school graduate (=1 if yes, =0 if no)	12.8184	2.7532	*
Some college (=1 if yes, =0 if no)	15.4712	2.7722	*
College graduate (=1 if yes, =0 if no)	18.5039	2.3914	*
Married (=1 if yes, =0 if no)	3.0551	1.0004	*
Number of persons in the household	-1.7473	0.8140	*
Number of persons in the household top coded (=1 if yes, =0 if no)	10.5835	5.9330	
Income ($0-$9,999 is the reference category)			
$10,000-$19,999	4.9460	1.6364	*
$20,000-$34,999	7.0067	1.2448	*
$35,000-$54,999	9.3921	2.2747	*
$55,000-$74,999	12.5887	1.7584	*
$75,000 and up	13.0934	2.6085	*
intercept	67.0207	6.7072	*
R squared	0.4741		
Survey weights were used.			
* significance at p<=0.05			

Table 3: Linear Regression of Time to Walk 20 Feet on Vitamin D and Other Explanatory Variables (N=1,076)			
Explanatory Variable	**Coefficient**	**Standard Error**	
Vitamin D level (ng/ml)	-0.1081	0.0473	*
Vitamin D level squared	0.0017	0.0009	
Summer (=1 if yes, =0 if no)	0.2413	0.1670	
Male (=1 if yes, =0 if no)	-0.2240	0.2266	
Age	0.0806	0.0139	*
Age top coded (=1 if yes, =0 if no)	1.6913	0.8533	
Race/Ethnicity (white, non-Hispanic is the reference category)			
Hispanic (=1 if yes, =0 if no)	0.1774	0.4797	
Black	0.4456	0.2801	
Other	1.0316	0.3861	*
Born in the U.S. (=1 if yes, =0 if no)	0.3772	0.2882	
Highest education level (less than high school is the reference category)			
Some high school (=1 if yes, =0 if no)	-0.3956	0.4658	
High school graduate (=1 if yes, =0 if no)	-0.9752	0.3232	*
Some college (=1 if yes, =0 if no)	-0.9953	0.3690	*
College graduate (=1 if yes, =0 if no)	-1.1387	0.3227	*
Married (=1 if yes, =0 if no)	-0.2185	0.2193	
Number of persons in the household	0.1800	0.0921	
Number of persons in the household top coded (=1 if yes, =0 if no)	-0.9838	0.8995	
Income ($0-$9,999 is the reference category)			
$10,000-$19,999	-0.8086	0.6569	
$20,000-$34,999	-1.2796	0.7111	
$35,000-$54,999	-1.3112	0.6497	
$55,000-$74,999	-1.6839	0.6650	*
$75,000 and up	-1.7880	0.7594	*
intercept	3.9459	1.4044	*
R squared	0.2269		
Survey weights were used.			
* significance at p<=0.05			

Figure 1

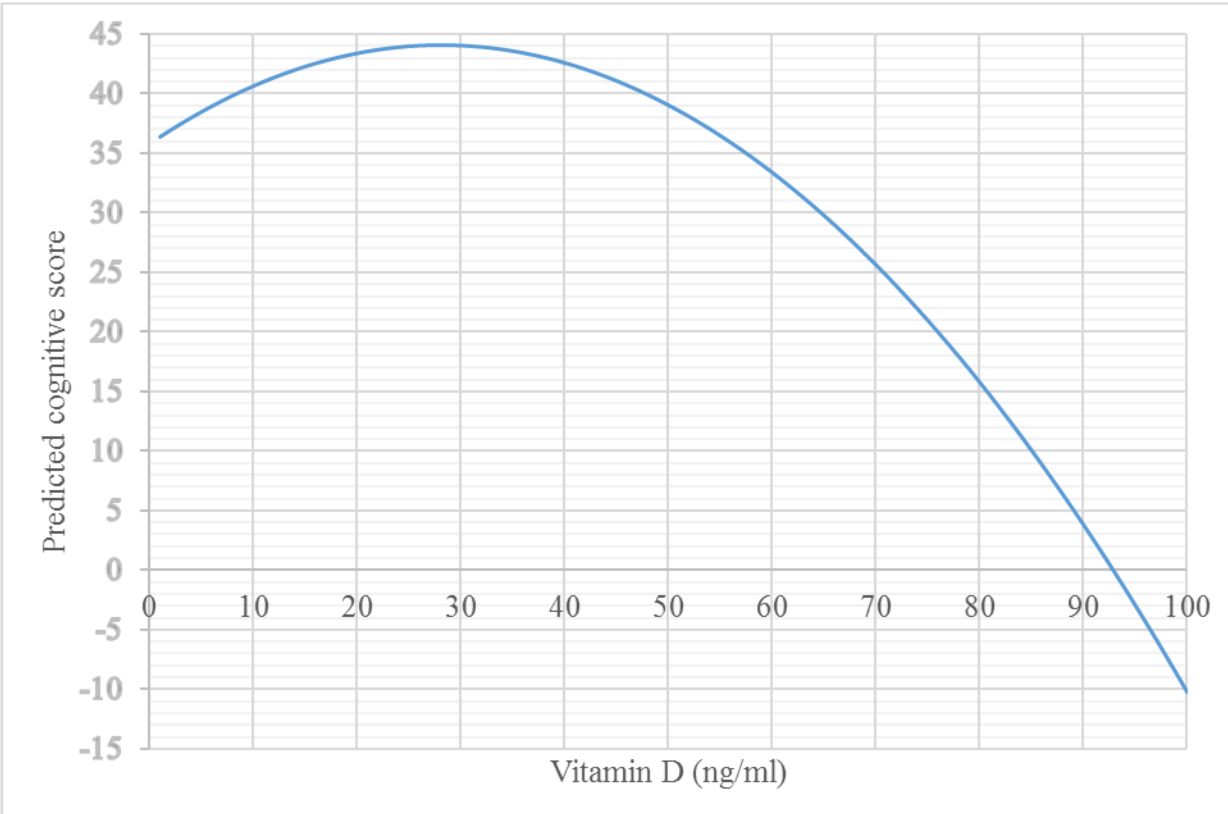
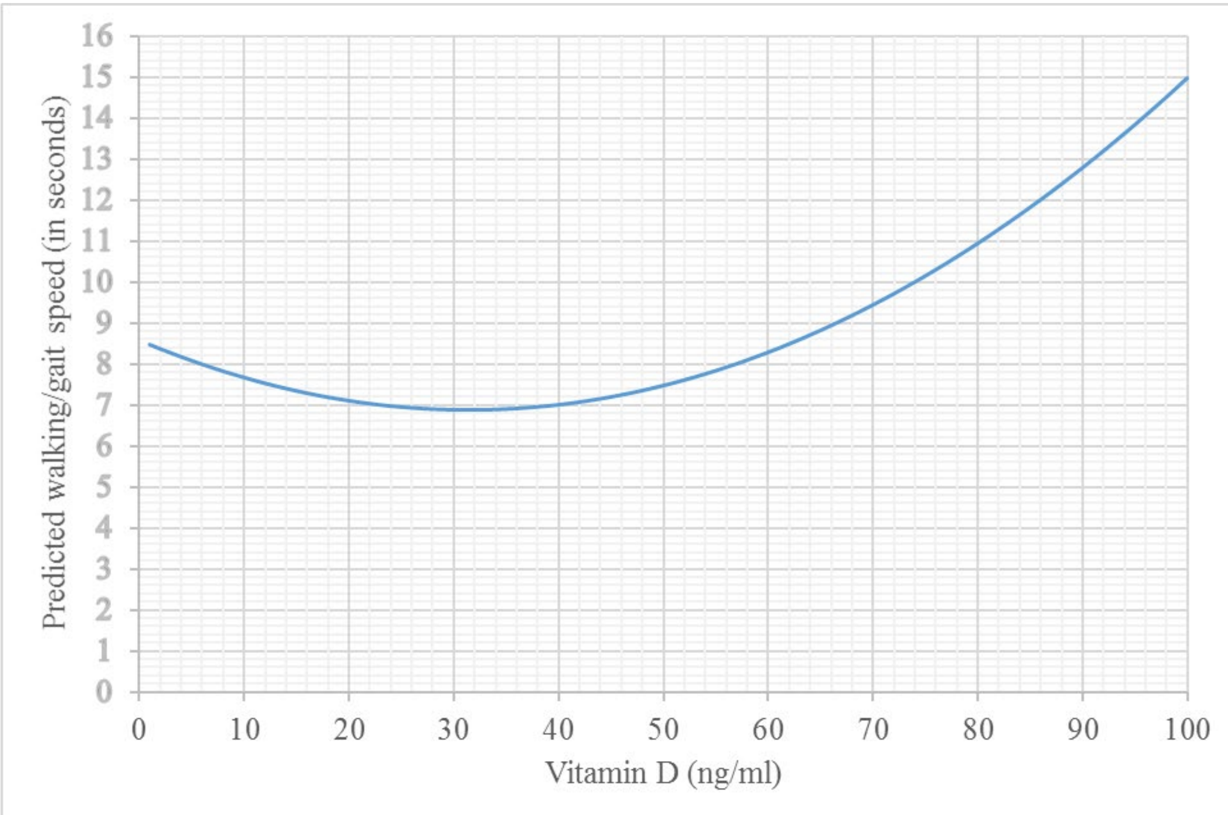

Predicted cognitive score
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0 10 20 30 40 50 60 70 80 90 100
Vitamin D (ng/ml)

Figure 2


16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Predicted walking/gait speed (in seconds)
0
10
20
30
40
50
60
70
80
90
100
Vitamin D (ng/ml)