Original research

Sex and race disparities in the association between work characteristics and vitamin D deficiency: findings from the National Health and Nutrition Examination Survey, 2005–2010

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ABSTRACT

Objectives Vitamin D deficiency is highly prevalent worldwide; however, few large population-based studies have examined occupational risk factors. We examined associations between shift work, work schedule, hours worked, outdoor work, occupation and serum 25-hydroxyvitamin D (25(OH)D) levels in the US working population.

Methods This cross-sectional study included 8601 workers from the 2005–2010 National Health and Nutrition Examination Survey (NHANES) cycles. NHANES occupational data were supplemented with measures of outdoor work from the Occupational Information Network. Serum 25(OH)D concentration in nanomoles per litre (nmol/L) was categorised as sufficient (≥75), insufficient (50–<75), moderately deficient (30–<50) and severely deficient (<30). Age-adjusted weighted multinomial and binary logistic regression were used to examine associations between work-related factors and vitamin D status with sex-race/ethnicity stratification.

Results Shift workers had higher odds of severe vitamin D deficiency compared with day workers (OR: 1.64, 95% CI 1.22 to 2.19). Compared with those in white-collar occupations, those in natural resources were less likely to be deficient (OR: 0.31, 95% CI 0.19 to 0.52), while those in production were more likely to be deficient (OR: 2.25, 95% CI 1.48 to 3.43). Women working ≥40 hours/week compared with <40 hours/week were more likely to be moderately deficient (OR: 1.30, 95% CI 1.06 to 1.59). Black women working in sales were more likely to be deficient than those in management (OR: 1.53, 95% CI 1.03 to 2.27). Mexican American men working nights had the highest odds of deficiency (OR: 2.64, 95% CI 1.38 to 5.06).

Conclusions Work-related factors were associated with vitamin D status and there were race/ethnicity and sex differences. Targeted vitamin D screening and supplementation interventions may reduce these disparities.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Vitamin D deficiency is associated with chronic health conditions, such as bone metabolic disorders and possibly cardiovascular disease. Shift workers and those working indoors appear to experience a higher prevalence of vitamin D deficiency, though studies are limited.

WHAT THIS STUDY ADDS

⇒ This study estimates that over three-quarters of US workers have at least some degree of vitamin D deficiency.
⇒ In this national sample of workers in the USA, shift work, long working hours and indoor work were associated with vitamin D deficiency. These associations were patterned by sex and race/ethnicity, which may be due in part to occupational and job task segregation.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Targeted vitamin D screening and supplementation for the most vulnerable workers may promote health equity around vitamin D deficiency and related health conditions.

INTRODUCTION

Vitamin D deficiency is an important public health problem in the USA. In the 2011–2012 National Health and Nutrition Examination Survey (NHANES) sample, 40% of participants were vitamin D deficient (<50 nmol/L).[1] Low vitamin D is associated with an increased risk of bone metabolic diseases, some cancers and cardiovascular disease.[2–4] Vitamin D deficiency is primarily attributed to inadequate sun exposure.[5] Ultraviolet B radiation from the sun initiates the endogenous synthesis of vitamin D in the skin that converts provitamin D to previtamin D to vitamin D.[6 7] Shift workers and indoor workers may be susceptible to vitamin D deficiency as they are less likely to be outside and exposed to the sun during the day.

A 2017 systematic review reported a high prevalence of vitamin D deficiency among shift (80%) and indoor workers (48%).[8] Shift workers also report a high prevalence of insomnia or excessive tiredness (32.1% in night workers and 26.1% in rotating workers), which is linked to vitamin D deficiency.[9 10] However, few studies have examined a more comprehensive range of occupational risk factors for vitamin D deficiency in large population-based samples. Even fewer have explored possible sex and race/ethnicity differences due to occupational segregation and differences in job tasks. A systematic review in 2018 highlighted the limitations of the literature on shift work and vitamin D deficiency[11]: out of nine published studies, only four included a sample of over 100 participants,[12–15] and only three studies examined sex differences.[12 13 15] To our knowledge, no studies to date have investigated these relationships by sex-race/ethnicity subgroups, factors which may contribute to social disparities in vitamin D deficiency.[1 16]

Our objectives were to examine the association between occupational risk factors and vitamin D status in a large representative US sample of 8601 NHANES participants. We hypothesised that shift work, long working hours and working indoors would be associated with vitamin D deficiency. We also examined how these relationships are patterned by sex and race/ethnicity-sex subgroups across occupational risk factors.

METHODS

Study population

The NHANES survey methodology for the 2005–2006, 2007–2008 and 2009–2010 cycles has been published previously.[17] Briefly, the NHANES is a US representative survey of resident non-institutionalised civilians that uses a complex, stratified, multistage probability sampling design. The 2005–2006 cycle oversampled for Mexican and black participants and participants of any race/ethnicity that were low-income (≤130% of federal poverty level), and ages 12–19 and 70+ years.[17] The 2007–2010 cycles oversampled for Hispanic and non-Hispanic black participants and participants of any race/ethnicity that were low-income or aged 80+ years.[17]

Study materials were available in English and Spanish. Participants completed interviews on nutrition, health status, lifestyle and other characteristics, and a standardised physical examination. Participants provided blood samples collected using standardised laboratory procedures. All participants provided written informed consent.

The population eligible for this analysis included 16 348 NHANES participants who had a measured serum 25-hydroxyvitamin D (25(OH)D) concentration and completed the occupation questionnaire. We excluded unemployed participants (N=7745) and those in the military reserves or National Guard (N=2). The final sample included 8601 workers. Eligible participants were more likely to be aged ≥40 years (55% vs 35%), non-Hispanic white (70% vs 64%) and male (53% vs 45%) compared with ineligible participants (data not shown in online supplemental tables).

Patient and public involvement

No patient involved.

NHANES occupation questionnaire

The NHANES occupational questionnaire was administered to participants aged ≥16 years and primarily collected data on the participants' current job. This survey collected information on employment status, work hours and schedule, and occupation. If a participant worked more than one job, they were asked to select one job to refer to during the interview.

During the 2005–2010 NHANES cycles, participants were asked which best described hours worked in their main job or business with the option to select a regular day-time shift, a regular evening shift, a regular night shift, a rotating shift or another schedule. A dichotomous shiftwork variable was defined as day-time schedule (no) versus evening, night, and rotating or another schedule (yes). Participants were asked how many hours they worked within the last week at all jobs, which was categorised as <40 and ≥40 hours.

Occupation data for participants' current jobs were coded using the 2000 (2005–2006 cycles) and 2002 (2007–2010 cycles) US Census Bureau's Occupation and Industry coding system and grouped into 23 categories. Due to sample size limitations, we condensed occupation into five standard categories ((1) management, business, science and arts, (2) service, (3) sales and office, (4) natural resources, construction and maintenance, (5) production, transportation and material moving). Effect estimates for each occupation group compared with all other groups combined, overall and by sex, are provided in online supplemental table 1.

Occupational Information Network

NHANES occupational data were supplemented with a measure of outdoor work obtained from the Occupational Information Network (O*NET), an online database of job characteristics for civilian occupations in the US labour market.[18] O*NET has been used as a job exposure matrix in prior epidemiological studies.[19] The O*NET outdoor work measure is a single survey item that asked job incumbents 'how often does your current job require you to work outdoors, exposed to all weather conditions?' and responses were registered on a 5-point Likert scale denoting frequency, ranging from never (1) to daily (5). O*NET measures are reported as means and SEs for each 2010 Standard Occupation Classification (SOC), or for each subgroup within an occupation. NHANES occupation was coded to US Census occupation code, so the imputation of O*NET scores for outdoor work required aggregating the data from O*NET SOC to Census, described previously by Fujishiro *et al*.[20] To account for varying scale sizes across Likert scale measures, the O*NET data were standardised onto the same scale with a range of 0–100. We categorised the O*NET outdoor work measure into tertiles (T) (T1: 0.00–<18.17, T2: 18.17–<32.12, T3: ≥32.12).

NHANES 25(OH)D concentration and NHANES dietary data

Serum 25(OH)D was measured using the Diasorin radioimmunoassay (RIA) method from 2005 to 2006 and ultra-high-performance liquid chromatography-tandem mass spectrometry (UHPLC-MS/MS) was used from 2007 to 2010. A subsample of data from NHANES participants in the 1988–1994 and 2001–2006 cycles were reanalysed using the LC-MS/MS method to produce predictive models to convert RIA measurements to equivalent LC-MS/MS measurements.[21] The standardisation of total serum 25(OH)D concentration allows for comparisons across the 2005–2010 NHANES cycles. Serum 25(OH)D measurements are provided in SI units of nanomoles per litre (nmol/L). In these analyses, total serum 25(OH)D concentration was calculated as the sum of 25(OH)D3 and 25(OH)D2. Based on recommendations from the Institutes of Medicine and Endocrine Society, we categorised serum 25(OH)D concentration as sufficient (≥75 nmol/L), insufficient (50–<75 nmol/L), moderately deficient (30–<50 nmol/L) and severely deficient (<30 nmol/L).[22 23]

Total vitamin D (µg) intake from all food and beverages consumed was estimated using data from the 2-day, 24-hour dietary recall component of the 2007–2010 NHANES cycles (n=5700). Dietary data was collected by interviewers using the USDA Automated Multiple Pass Method. The US Department of Agriculture's Food and Nutrient Database for Dietary Studies was used to estimate nutrient intakes for about 7000 foods and beverages and indicated which foods contained vitamin D.[24]

The first dietary recall interview was conducted in-person and 3–10 days later a second dietary recall phone interview was conducted. The dietary interviews were conducted in English and Spanish. Vitamin D supplement use was collected following the dietary recall component using a similar process. Further details on the NHANES dietary interview can be found elsewhere.[25]

Statistical analysis

We used the Rao Scott χ^2 test and the analysis of variance test to evaluate differences in sociodemographic, lifestyle and work history characteristics across categories of vitamin D status. Since the proportional odds assumption was not met, we used age-adjusted weighted multinomial logistic regression to estimate associations between work characteristics and vitamin D status, with 'sufficient (≥75 nmol/L)' modelled as the reference category. Binary logistic regression was used in race/ethnicity-sex stratified analyses where vitamin D status was modelled as a dichotomous variable (not deficient: ≥50 nmol/L compared with deficient: <50 nmol/L).

We considered the following covariates as potential confounders using a 10% change-in-estimate approach based on the age-adjusted shift work models, though these covariates did not meet the criteria for inclusion in the final models: body mass index, season of survey completion, alcohol consumption, smoking status and sleep duration. Effect modification was evaluated by including a cross-product term in the model. Due to evidence of significant interaction (p≤0.10) by sex and race/ethnicity in the age-adjusted models (p-interactions in online supplemental table 3), results were stratified by sex and race/ethnicity-sex subgroups. Regression analyses for Hispanic participants were limited to Mexican Americans due to changes in oversampling methods that occurred between the 2005–2006 and 2007–2010 NHANES cycles that do not allow reliable effect estimates to be calculated for non-Mexican American Hispanics.[17] Due to small sample sizes, those with missing information on race or categorised as 'other race' were also excluded from analyses with race/ethnicity-sex subgroup stratification.

Sensitivity analyses were performed in the 2007–2010 NHANES survey subsample among sex and race/ethnicity-sex subgroups with additional adjustment for total vitamin D from dietary intake (µg) and total vitamin D from supplementation (µg) to estimate the influence of sunlight alone on vitamin D status (online supplemental tables 3 and 4). These analyses were conducted to account for dietary and supplemental vitamin D sources, which are important predictors of vitamin D status. Intake of dietary vitamin D and vitamin D supplement use may vary by race and sex.[26 27]

All statistical analyses were performed using SAS V.9.4 survey procedures (SAS Institute, Cary, NC) and a p value of 0.05 was considered statistically significant. To account for the complex survey design, NHANES-specific model weights, strata and primary sampling units were included in all analyses. To create a combined weight variable across the 2005–2010 data cycles, the 2-year weight was divided by two or three to account for the number of cycles used in the analysis, per NHANES guidelines.[28] An adjusted weight was applied to analyses using the dietary interview data, which accounts for participant non-response and the proportion of various weekend and weekday combinations of 2-day recalls.

ORs and their associated 95% CIs using complete cases were estimated using PROC SURVEYLOGISTIC. Effect estimates based on small sample sizes (<10) were suppressed, consistent with National Center for Health Statistics data presentation guidance.[29]

RESULTS

Among 8601 participants, 3976 (46%) were women (table 1). There were 3897 non-Hispanic white, 1667 non-Hispanic black, 1835 Mexican American and 1202 participants of other or unknown race.

The mean age of participants was 41 years (range: 16–85, SE: 0.21). About 74% of participants worked a day shift, 6% worked an evening shift, 4% worked a night shift and 8% worked a rotating shift. The majority (70%) of participants reported working ≥40 hours per week. The most common occupations held by participants were in management, business, science and arts (36%) and the least common were in natural resources, construction and maintenance (11%).

Overall, nearly three-quarters of US workers (70%) were estimated to have suboptimal levels of serum 25(OH)D. A higher proportion of women were severely vitamin D deficient compared with men (56% and 44%, respectively) (table 2). Severe vitamin D deficiency was also more prevalent among non-Hispanic black participants compared with non-Hispanic white participants (48% and 22%, respectively). Among shift workers, moderate and severe vitamin D deficiency was most common among those working rotating shifts (9% and 10%, respectively) (table 3). About 68% of those with severe vitamin D deficiency reported working at least 40 hours per week. Moderate and severe vitamin D deficiency was highest among those working in management, business, science and arts (32% and 27%, respectively) and lowest among those working in natural resources, construction and maintenance (9% and 3%, respectively).

ORs for examining the association between the work-related factors and vitamin D, overall and by sex, are shown in table 4 and online supplemental table 2 (for vitamin D insufficiency results). Those working night or rotating shifts were more likely to be *severely* vitamin D deficient compared with those working days (OR: 2.37, 95% CI 1.50 to 3.73 and OR: 1.65, 95% CI 1.15 to 2.36, respectively) . Those working ≥40 hours per week were more likely to be vitamin D *insufficient* compared with those working <40 hours per week (OR: 1.16, 95% CI 1.01 to 1.33). Compared with those working in management, those working in production were more likely (OR: 2.25, 95% CI 1.48 to 3.43) to be *severely* deficient, while those working in natural resources were less likely (OR: 0.31, 95% CI 0.19 to 0.52). Within the natural resources category, those in construction had the lowest odds of any vitamin D deficiency compared with all other occupation groups combined (online supplemental table 1). Those in occupations involving frequent outdoor exposure were less likely to be *severely* vitamin D deficient compared with those in occupations that rarely involve outdoor exposure (OR: 0.49, 95% CI 0.36 to 0.68).

In sex stratified analyses (table 4), women working nights were more likely to be *severely* vitamin D deficient compared with women working days (OR: 1.96, 95% CI 1.08 to 3.57). Women working ≥40 hours per week were more likely to be *moderately* vitamin D deficient compared with those working <40 hours per week (OR: 1.30, 95% CI 1.06 to 1.59). Women working in production also had the highest odds of *severe* vitamin D deficiency relative to those in management occupations (OR: 2.73, 95% CI 1.45 to 5.13). Among men, any shift work was associated with *severe* vitamin D deficiency (OR: 2.55, 95% CI 1.77 to 3.68), with the odds being highest for rotating shift workers (OR: 3.02, 95% CI 1.90 to 4.81). Men in sales

Table 1 Sociodemographic, lifestyle and work history characteristics, by race-sex subgroups, National Health and Nutrition Examination Survey (N=8601)*

	White		Black		Mexican American		Another racial/ethnic group or unknown	
	Women	Men	Women	Men	Women	Men	Women	Men
N (weighted %)								
Total	1818 (33)	2079 (38)	811 (5)	856 (5)	772 (3)	1063 (6)	575 (5)	627 (6)
Age (years)								
<30	488 (22)	445 (21)	235 (25)	243 (27)	270 (31)	383 (35)	169 (27)	156 (23)
30–<40	372 (20)	438 (19)	168 (24)	161 (22)	153 (26)	214 (29)	138 (28)	148 (29)
40–<50	379 (24)	450 (25)	179 (25)	173 (25)	159 (24)	208 (21)	123 (22)	135 (24)
≥50	579 (34)	746 (34)	229 (25)	279 (27)	190 (18)	258 (15)	145 (22)	188 (24)
Body mass index (kg/m^2)								
<18.5	54 (3)	28 (1)	12 (1)	11 (1)	13 (1)	7 (<1)	16 (4)	10 (2)
18.5–<25	704 (39)	560 (25)	177 (20)	253 (28)	200 (27)	272 (24)	218 (47)	185 (31)
25–<30	499 (27)	816 (41)	211 (26)	285 (34)	254 (32)	478 (46)	177 (27)	243 (38)
≥30	553 (31)	661 (32)	409 (52)	305 (37)	301 (40)	301 (30)	161 (22)	187 (29)
Unknown	8 (<1)	14 (<1)	2 (<1)	2 (<1)	4 (<1)	5 (<1)	3 (<1)	2 (<1)
Smoking status								
Never	913 (54)	894 (46)	519 (70)	424 (55)	506 (71)	478 (51)	378 (71)	322 (56)
Former	384 (22)	533 (26)	85 (10)	127 (14)	101 (13)	224 (19)	59 (8)	128 (19)
Current	393 (19)	522 (25)	122 (16)	214 (27)	66 (9)	221 (24)	87 (16)	129 (21)
Unknown	128 (5)	130 (4)	85 (4)	91 (5)	99 (6)	140 (6)	51 (6)	48 (4)
12+ alcohol drinks/year								
No	347 (19)	221 (10)	327 (42)	161 (19)	239 (31)	99 (10)	188 (36)	114 (19)
Yes	1232 (70)	1621 (81)	330 (44)	540 (68)	373 (53)	764 (78)	281 (49)	405 (66)
Unknown	239 (11)	237 (9)	154 (14)	155 (13)	160 (15)	200 (12)	106 (16)	108 (15)
Usual work schedule								
Day	1310 (75)	1514 (74)	552 (71)	537 (63)	560 (75)	796 (77)	422 (74)	445 (73)
Evening	117 (6)	116 (5)	75 (8)	70 (8)	57 (6)	64 (5)	41 (7)	51 (7)
Night	61 (3)	76 (4)	40 (5)	59 (7)	42 (5)	53 (5)	35 (6)	35 (5)
Rotating	169 (8)	135 (6)	95 (10)	106 (12)	70 (9)	96 (9)	49 (7)	57 (8)
Unknown	161 (8)	238 (11)	49 (6)	84 (9)	43 (5)	54 (4)	28 (6)	39 (8)
Work hours (per week)								
<40	788 (40)	553 (21)	338 (37)	273 (28)	321 (38)	288 (24)	251 (41)	165 (23)
≥40	1030 (60)	1524 (79)	472 (62)	583 (72)	447 (61)	774 (76)	323 (59)	462 (77)
Unknown	0 (0)	2 (<1)	1 (<1)	0 (0)	4 (<1)	1 (<1)	1 (<1)	0 (0)
Current occupation								
Management, business, science and arts	721 (43)	728 (38)	212 (29)	164 (19)	127 (19)	106 (11)	166 (36)	146 (31)
Service	414 (19)	267 (11)	252 (30)	204 (23)	282 (35)	260 (23)	185 (25)	137 (17)
Sales and office	573 (32)	312 (15)	279 (33)	153 (17)	239 (30)	104 (9)	159 (28)	100 (17)
Natural resources, construction, maintenance	20 (1)	416 (20)	1 (<1)	102 (12)	15 (2)	303 (30)	2 (<1)	115 (18)
Production, transportation, material moving	90 (5)	355 (16)	66 (8)	231 (29)	108 (14)	285 (26)	60 (10)	129 (17)
Other or unknown	0 (0)	1 (<1)	1 (<1)	2 (<1)	1 (<1)	5 (<1)	3 (<1)	0 (0)
Work outdoors, exposed to all weather conditions†								
Never or rarely (T_1)	867 (51)	348 (18)	402 (52)	167 (19)	268 (38)	94 (10)	218 (44)	107 (22)
Occasionally (T_2)	645 (32)	574 (27)	285 (32)	268 (31)	330 (40)	324 (28)	230 (39)	204 (31)
Frequently (T_3)	306 (17)	1156 (56)	123 (16)	419 (50)	173 (22)	640 (61)	124 (16)	316 (47)
Unknown	0	1 (<1)	1 (<1)	2 (<1)	1 (<1)	5 (<1)	3 (<1)	0 (0)

*Values shown are unweighted sample size and weighted proportions.
†Occupation-level variable derived from the Occupational Information Network (O*NET). T signifies tertiles.

(OR: 2.08, 95% CI 1.24 to 3.48) and production (OR: 2.09, 95% CI 1.30 to 3.36) occupations were similarly more likely to have *severe* vitamin D deficiency compared with men in management. Within the production category, vitamin D deficiency was most pronounced among men in transportation and material moving compared with all other groups combined (online supplemental table 1).

Results from binary logistic regression comparing odds of vitamin D deficiency across categories of the work-related factors, overall and stratified by race/ethnicity-sex subgroups, is shown in table 5. Mexican American women who worked the evening shift were less likely to be vitamin D deficient compared with those working days (OR: 0.30, 95% CI 0.16 to 0.57). Black women working in sales and Mexican American women

Table 2 Sociodemographic and lifestyle characteristics, by vitamin D status, National Health and Nutrition Examination Survey (NHANES) (N=8601)*

	Vitamin D status, N (weighted %)				
	Sufficient (≥75 nmol/L)	Insufficient (50–<75 nmol/L)	Moderately deficient (30–<50 nmol/L)	Severely deficient (<30 nmol/L)	P value†
N (weighted %)	2024 (31)	3351 (42)	2439 (22)	787 (6)	
Total vitamin D from dietary intake (µg), 2 days 24 hours recall, mean (SE)‡	10.64 (0.33)	10.04 (0.30)	7.87 (0.25)	5.69 (0.28)	<0.0001
Total vitamin D from supplementation (µg), 2 days 24 hours recall, mean (SE)‡	21.25 (3.10)	6.96 (0.48)	3.20 (0.43)	1.63 (0.39)	<0.0001
N (weighted %)					
Age (years)					0.004
<30	530 (24)	889 (23)	706 (23)	264 (28)	
30–<40	410 (20)	703 (22)	514 (23)	165 (24)	
40–<50	389 (23)	753 (26)	506 (24)	158 (24)	
≥50	695 (34)	1006 (30)	713 (30)	200 (24)	
Sex					<0.0001
Women	1019 (51)	1355 (40)	1154 (47)	448 (56)	
Men	1005 (49)	1996 (60)	1285 (53)	339 (44)	
Race/Ethnicity					<0.0001
Non-Hispanic white	1547 (90)	1717 (75)	558 (46)	75 (22)	
Non-Hispanic black	89 (2)	350 (5)	774 (21)	454 (48)	
Mexican American	202 (3)	758 (9)	711 (16)	164 (14)	
Another racial/ethnic group or unknown	186 (5)	526 (11)	396 (17)	94 (16)	
Body mass index (kg/m^2)					<0.0001
<18.5	53 (3)	46 (1)	31 (1)	21 (3)	
18.5–<25	797 (41)	1000 (29)	597 (24)	175 (22)	
25–<30	745 (37)	1209 (36)	798 (30)	211 (26)	
≥30	420 (20)	1075 (34)	1005 (44)	378 (48)	
Unknown	9 (<1)	21 (1)	8 (<1)	2 (<1)	
Smoking status					<0.0001
Never	958 (49)	1714 (53)	1324 (57)	438 (59)	
Former	475 (23)	694 (22)	379 (17)	93 (13)	
Current	434 (22)	665 (20)	488 (23)	167 (24)	
Unknown	157 (5)	278 (4)	248 (4)	89 (4)	
12+ alcohol drinks/1 year					<0.0001
No	273 (12)	608 (17)	595 (24)	220 (28)	
Yes	1466 (77)	2246 (72)	1424 (65)	410 (58)	
Unknown	285 (12)	497 (11)	420 (10)	157 (15)	
Sleep duration					<0.0001
<6 hours	214 (10)	415 (11)	416 (17)	187 (21)	
≥6 hours	1810 (90)	2935 (89)	2023 (83)	600 (79)	
Unknown	(0)	1 (<1)	(0)	(0)	
Season of survey completion					<0.0001
November–April	584 (26)	1416 (38)	1382 (53)	546 (69)	
May–October	1440 (74)	1935 (62)	1057 (47)	241 (31)	

*Values shown are weighted mean and SD for continuous variables and unweighted sample size and weighted proportions for categorical variables.
†P value for analysis of variance (continuous) or the Rao-Scott χ^2 test (categorical).
‡Excludes participants from the 2005–2006 NHANES cycles where variable was not reported.

working in production were more likely to be vitamin D deficient compared with those in management positions (OR: 1.53, 95% CI 1.03 to 2.27 and OR: 1.54, 95% CI 1.01 to 2.36, respectively). Any vitamin D deficiency was more likely among White men working rotating shifts (OR: 1.98, 95% CI 1.19 to 3.29) and Mexican American men working evening or night shifts (OR: 1.85, 95% CI 1.05 to 3.27 and OR: 2.64, 95% CI 1.38 to 5.06, respectively) compared with those working days. Mexican American men in occupations involving frequent outdoor exposure had the lowest odds of vitamin D deficiency (OR: 0.41, 95% CI 0.22 to 0.78). Sample sizes by sex and race/ethnicity for each work characteristic category are included in online supplemental tables 2 and 3. In sensitivity analyses adjusting for vitamin D dietary intake and supplementation (NHANES cycles 2007–2010), effect estimates for the sex (N=5700) and race/ethnicity-sex (N=4729) stratified models did not meaningfully differ (online supplemental tables 4 and 5).

DISCUSSION

This study represents one of the first large investigations of race/ethnicity and sex disparities in the association of work-related

Table 3 Work history characteristics, by vitamin D status, National Health and Nutrition Examination Survey (N=8601)*

	Vitamin D status, N (weighted %)				
	Sufficient (≥75 nmol/L)	Insufficient (50–<75 nmol/L)	Moderately deficient (30–<50 nmol/L)	Severely deficient (<30 nmol/L)	P value†
N, weighted %					
Total	2024 (31)	3351 (42)	2439 (22)	787 (6)	
Any shiftwork					<0.0001
No	1527 (77)	2402 (74)	1685 (72)	522 (71)	
Yes	316 (14)	680 (18)	554 (20)	219 (23)	
Unknown	181 (9)	269 (9)	200 (9)	46 (6)	
Usual work schedule					0.003
Day	1527 (77)	2402 (74)	1685 (72)	522 (71)	
Evening	118 (5)	234 (6)	176 (6)	63 (7)	
Night	63 (3)	142 (4)	140 (5)	56 (7)	
Rotating	135 (6)	304 (8)	238 (9)	100 (10)	
Unknown	181 (9)	269 (9)	200 (9)	46 (6)	
Work hours (per week)					0.17
<40	723 (32)	1132 (29)	840 (29)	282 (32)	
≥40	1301 (68)	2216 (71)	1593 (70)	505 (68)	
Unknown	0 (0)	3 (<1)	6 (<1)	0 (0)	
Current occupation					<0.0001
Management, business, science and arts	662 (37)	982 (38)	557 (32)	169 (27)	
Service	412 (16)	780 (17)	605 (19)	204 (22)	
Sales and office	441 (23)	630 (19)	594 (25)	254 (31)	
Natural resources, construction, maintenance	283 (14)	440 (12)	221 (9)	30 (3)	
Production, transportation, material moving	224 (10)	513 (13)	458 (16)	129 (16)	
Other or unknown	2 (<1)	6 (<1)	4 (<1)	1 (<1)	
Work outdoors, exposed to all weather conditions‡					<0.0001
Never or rarely (T_1)	614 (33)	894 (31)	674 (31)	289 (39)	
Occasionally (T_2)	607 (28)	1035 (29)	909 (35)	309 (38)	
Frequently (T_3)	801 (39)	1416 (40)	852 (34)	188 (23)	
Unknown	2 (<1)	6 (<1)	4 (<1)	1 (<1)	

*Values shown are unweighted sample size and weighted proportions.
†P value for the Rao-Scott χ^2 test (categorical)
‡Occupation-level variable derived from the Occupational Information Network (O*NET). T signifies tertiles.

factors to vitamin D deficiency among US workers. The findings showed that the prevalence of vitamin D insufficiency or deficiency (<75 nmol/L) in the US labour force was 76.5%. We found that severe vitamin D deficiency (<30 nmol/L) was significantly associated with shift work, occupation and indoor work, suggesting that some work characteristics may be important risk factors for developing vitamin D deficiency. Additionally, the results were patterned by race-sex subgroups. These findings were relatively consistent across the clinical cut-points used for serum 25(OH)D.

The results of the current study support previous findings. In an analysis of 186 workers in Denmark, Daugaard *et al* found that serum 25(OH)D concentrations increased on average by 5.2% (95% CI 1.1% to 9.5%) per hour spent working outdoors during the summer months.[30] Divakar *et al* reported a higher risk of D deficiency (<50 nmol/L) among office workers compared with control room workers (prevalence ratio (PR): 2.16, 95% CI 1.12 to 4.16) and for those working nights (PR for night shift per month: 1.31, 95% CI 1.03 to 1.67) in a cohort of 213 individuals in Singapore.[31] Using 2005–2006 NHANES data, Yang and colleagues reported lower average vitamin D levels with any form of shift work compared with day work among women and Mexican Americans.[32] In the 2010–2014 Korea NHANES, Park *et al* observed a statistically significant association between shift work and vitamin D deficiency (<50 nmol/L) compared with non-shift workers, which varied by sex (OR: 1.03, 95% CI 0.83 to 1.28 for women and OR: 1.45, 95% CI 1.20 to 1.75 for men).[33] Further, compared with agricultural workers whose occupations may involve greater outdoor exposure, those working in management, sales and assembly had significantly higher odds of vitamin D deficiency.[33] In the longitudinal Murakami Cohort Study, men in farming and fishing occupations, compared with other occupations, experienced a lower decline in vitamin D over 5 years of follow-up.[34] We also observed a significantly lower odds of vitamin D deficiency in those working in construction, which similarly involves a substantial amount of work outdoors.

In our study we report novel associations between work-related factors and vitamin D deficiency by race/ethnicity and sex. We found that Mexican American men working evening and night shifts were more likely to be vitamin D deficient compared with white men working the same shifts. Black women working ≥40 hours per week were also more likely to be vitamin D deficient compared with black women working <40 hours per week. We also observed higher odds of vitamin D deficiency, though not statistically significant, among black men working night shifts compared with those working days. The observed race/ethnicity and sex disparities are likely due to occupational segregation, with some groups experiencing higher or lower exposure to the sun during work hours. Notably, Mexican Americans represent 61% of Hispanics in the US labour force and account for 17% of

Table 4 Age-adjusted weighted ORs and 95% CIs for the association between occupation-related factors and moderate or severe vitamin D deficiency compared with sufficiency, overall and by sex, National Health and Nutrition Examination Survey (N=8601)*

	Overall		Women		Men	
	Moderately deficient	Severely deficient	Moderately deficient	Severely deficient	Moderately deficient	Severely deficient
Any shift work						
No	1.00	1.00	1.00	1.00	1.00	1.00
Yes	**1.45 (1.15 to 1.83)**	**1.64 (1.22 to 2.19)**	0.97 (0.71 to 1.33)	1.10 (0.73 to 1.65)	**2.16 (1.62 to 2.88)**	**2.55 (1.77 to 3.68)**
Usual work schedule						
Day	1.00	1.00	1.00	1.00	1.00	1.00
Evening	1.13 (0.77 to 1.64)	1.22 (0.77 to 1.91)	0.80 (0.51 to 1.24)	0.76 (0.40 to 1.44)	1.54 (0.86 to 2.75)	**1.97 (1.07 to 3.62)**
Night	**1.90 (1.34 to 2.71)**	**2.37 (1.50 to 3.73)**	1.25 (0.71 to 2.20)	**1.96 (1.08 to 3.57)**	**2.72 (1.83 to 4.05)**	**2.90 (1.57 to 5.33)**
Rotating	**1.54 (1.14 to 2.06)**	**1.65 (1.15 to 2.36)**	1.00 (0.71 to 1.41)	1.02 (0.59 to 1.79)	**2.56 (1.68 to 3.90)**	**3.02 (1.90 to 4.81)**
Hours worked per week						
<40	1.00	1.00	1.00	1.00	1.00	1.00
≥40	1.14 (0.97 to 1.34)	1.06 (0.81 to 1.38)	**1.30 (1.06 to 1.59)**	1.33 (0.98 to 1.81)	0.89 (0.70 to 1.13)	0.81 (0.55 to 1.20)
Current occupation						
Management	1.00	1.00	1.00	1.00	1.00	1.00
Service	**1.33 (1.06 to 1.65)**	**1.71 (1.24 to 2.36)**	**1.40 (1.04 to 1.89)**	**1.62 (1.20 to 2.18)**	1.26 (0.93 to 1.69)	**1.88 (1.03 to 3.42)**
Sales and office	1.28 (0.99 to 1.65)	**1.79 (1.33 to 2.41)**	1.24 (0.96 to 1.61)	**1.67 (1.26 to 2.21)**	1.45 (0.95 to 2.19)	**2.08 (1.24 to 3.48)**
Natural resources	0.75 (0.56 to 1.00)	**0.31 (0.19 to 0.52)**	0.80 (0.33 to 1.90)	†	**0.66 (0.45 to 0.96)**	**0.33 (0.19 to 0.57)**
Production	**1.87 (1.35 to 2.59)**	**2.25 (1.48 to 3.43)**	1.77 (0.97 to 3.24)	**2.73 (1.45 to 5.13)**	**1.75 (1.22 to 2.52)**	**2.09 (1.30 to 3.36)**
Work outdoors, exposed to all weather conditions‡						
Never or rarely (T_1)	1.00	1.00	1.00	1.00	1.00	1.00
Occasionally (T_2)	**1.30 (1.05 to 1.63)**	1.10 (0.84 to 1.44)	1.23 (0.96 to 1.56)	1.13 (0.89 to 1.45)	1.24 (0.86 to 1.81)	0.96 (0.61 to 1.52)
Frequently (T_3)	0.92 (0.77 to 1.11)	**0.49 (0.36 to 0.68)**	0.94 (0.68 to 1.29)	**0.59 (0.36 to 0.94)**	0.76 (0.54 to 1.08)	**0.40 (0.24 to 0.65)**

Statistically significant associations are presented in bold.
*Vitamin D status was defined as follows: sufficient: ≥75 nmol/L; insufficient: 50–<75 nmol/L; moderately deficient: 30–<50 nmol/L; severely deficient: <30 nmol.
†Effect estimate suppressed due to small sample size (<10).
‡Occupation-level variable derived from the Occupational Information Network (O*NET). T signifies tertiles.

Table 5 Age-adjusted weighted ORs and 95% CIs for the association between occupation-related factors and any vitamin D deficiency compared with no deficiency, overall and by race/ethnicity-sex subgroups, National Health and Nutrition Examination Survey (N=7399)*

	Overall†		White		Black		Mexican American	
	Women	Men	Women	Men	Women	Men	Women	Men
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Any shift work								
No	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yes	0.93 (0.70 to 1.23)	**1.79 (1.41 to 2.28)**	0.83 (0.48 to 1.44)	**1.77 (1.14 to 2.74)**	0.77 (0.50 to 1.19)	1.09 (0.71 to 1.67)	0.77 (0.52 to 1.13)	**1.68 (1.13 to 2.48)**
Usual work schedule								
Day	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Evening	0.77 (0.52 to 1.13)	1.43 (0.95 to 2.15)	0.65 (0.33 to 1.27)	1.54 (0.73 to 3.27)	0.81 (0.45 to 1.43)	0.66 (0.36 to 1.23)	**0.30 (0.16 to 0.57)**	**1.85 (1.05 to 3.27)**
Night	1.37 (0.84 to 2.22)	**2.09 (1.40 to 3.12)**	1.24 (0.52 to 3.00)	1.75 (0.82 to 3.74)	1.06 (0.44 to 2.55)	2.10 (0.81 to 5.47)	1.11 (0.57 to 2.16)	**2.64 (1.38 to 5.06)**
Rotating	0.90 (0.67 to 1.21)	**1.92 (1.44 to 2.57)**	0.83 (0.45 to 1.51)	**1.98 (1.19 to 3.29)**	0.64 (0.34 to 1.21)	1.15 (0.72 to 1.83)	1.14 (0.63 to 2.06)	1.26 (0.75 to 2.12)
Hours worked per week								
<40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
≥40	**1.26 (1.03 to 1.53)**	0.86 (0.73 to 1.02)	1.34 (0.96 to 1.87)	0.97 (0.73 to 1.30)	1.20 (0.88 to 1.62)	0.81 (0.59 to 1.11)	1.20 (0.86 to 1.68)	1.24 (0.83 to 1.87)
Current occupation								
Management	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Service	**1.46 (1.16 to 1.84)**	**1.47 (1.11 to 1.94)**	0.90 (0.59 to 1.39)	0.83 (0.50 to 1.39)	1.46 (0.95 to 2.25)	0.77 (0.48 to 1.22)	1.02 (0.70 to 1.48)	0.71 (0.44 to 1.16)
Sales and office	**1.37 (1.11 to 1.69)**	**1.70 (1.15 to 2.53)**	1.05 (0.76 to 1.45)	1.53 (0.88 to 2.63)	**1.53 (1.03 to 2.27)**	1.09 (0.66 to 1.80)	1.23 (0.85 to 1.76)	1.16 (0.70 to 1.92)
Natural resources	0.84 (0.35 to 2.00)	0.77 (0.56 to 1.07)	0.57 (0.15 to 2.21)	0.61 (0.35 to 1.04)	‡	0.62 (0.36 to 1.09)	1.23 (0.50 to 3.06)	**0.48 (0.29 to 0.79)**
Production	**2.23 (1.49 to 3.33)**	**1.75 (1.32 to 2.32)**	1.25 (0.64 to 2.43)	1.10 (0.73 to 1.64)	2.01 (0.94 to 4.28)	0.98 (0.52 to 1.84)	**1.54 (1.01 to 2.36)**	1.14 (0.68 to 1.93)
Work outdoors, exposed to all weather conditions§								
Never or rarely (T_1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Occasionally (T_2)	1.20 (0.99 to 1.46)	1.22 (0.91 to 1.64)	1.19 (0.89 to 1.60)	1.32 (0.82 to 2.12)	1.34 (0.94 to 1.91)	0.79 (0.50 to 1.25)	1.09 (0.70 to 1.70)	0.99 (0.51 to 1.91)
Frequently (T_3)	0.98 (0.73 to 1.30)	0.75 (0.57 to 1.00)	0.92 (0.62 to 1.35)	0.78 (0.49 to 1.23)	1.14 (0.75 to 1.74)	0.71 (0.46 to 1.10)	0.99 (0.59 to 1.66)	**0.41 (0.22 to 0.78)**

Statistically significant associations are presented in bold.
*Vitamin D status was defined as follows: not deficient: ≥50 nmol/L; deficient: <50 nmol/L .
†Excludes non-Mexican American Hispanics, races not specified and missing information on race, which are not included in the race-specific analyses (N=1202) .
‡Effect estimate suppressed due to small sample size (<10).
§Occupation-level variable derived from the Occupational Information Network (O*NET). T signifies tertiles.

total employment in natural resources, construction and maintenance, which can involve frequent sun exposure (compared with 10% among white Americans and 6% among black Americans).[35] Black and Hispanic individuals are also more likely to work a non-daytime schedule compared with non-Hispanic whites, thus putting them at increased risk for deficiency than non-Hispanic whites.[36] Workers may benefit from tailored guidance on vitamin D supplementation based on their specific job demands. For example, a randomised control crossover trial of 112 UK construction workers found that a season-specific Short Message Services-focused intervention with vitamin D supplementation increased 25(OH)D concentrations compared with controls.[37]

This study has numerous strengths. First, this study included a large, diverse sample of over 8000 workers in the USA across several years with both measured serum 25(OH)D and self-reported occupational data. The NHANES data is collected from a nationally representative sample, making the study findings generalisable to adult US workers. Additionally, information for other sources of vitamin D intake was available for 66% of the sample. Through O*NET data linkage we were able to impute exposure to outdoor work to further examine the role of work and inadequate sun exposure, improving the informativeness of our findings.

This study also has several limitations. Since this is a cross-sectional analysis, it does not provide direct evidence of a causal relationship between work-related factors and vitamin D deficiency. Further, due to changes in oversampling methods that occurred during the 2005–2010 data periods we could not calculate effect estimates for non-Mexican American Hispanic persons as a separate subgroup.[38] The magnitude of some of the observed associations may be due in part to residual confounding by uncontrolled factors, such as preexisting chronic diseases, medication use that can cause lower vitamin D levels, or environmental factors, like residential latitude. Analyses involving race/ethnicity-sex differences may be underpowered to detect some associations. Notably, we observed higher odds of vitamin D deficiency with some work-related factors among black participants, though findings did not reach statistical significance. Finally, data relevant to the analyses were only available for the 2005–2010 NHANES cycles, which may underestimate the current prevalence of vitamin D deficiency among US workers. Changes in work conditions resulting from the COVID-19 pandemic may shift recent trends in vitamin D deficiency, including work from home arrangements, gig work, and increased job demands in healthcare, warehousing and transportation, and service.[39]

Overall, we found that occupation, shiftwork and work hours were associated with vitamin D deficiency. These relationships varied by sex and race/ethnicity, possibly due to segregation of job tasks and employment opportunities within and across occupations. If validated in longitudinal studies, targeted vitamin D testing in clinical settings and inclusion of vitamin D education in occupation health promotion programmes may improve health equity around vitamin D deficiency and related illnesses.

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Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study involves human participants and the NHANES protocol was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board (protocol #2005-06). Participants gave informed consent to participate in the study before taking part.

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Data availability statement Data are available in a public, open access repository. This study uses data publicly accessible data from the National Health and Nutrition Examination Survey (NHANES) and can be downloaded from https://www.cdc.gov/nchs/nhanes/index.htm.

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