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Is all physical activity equal? Investigating the total and domain-specific relationships between physical activity and cardiometabolic health in U.S. adults (NHANES 2013–2018)

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Abstract

Background Metabolic syndrome (MetS) increases the risk of cardiovascular disease morbidity and mortality. Physical activity (PA) reduces the likelihood of MetS, but it is a complex behavior and is accumulated in multiple domains.

Purpose To cross-sectionally investigate the total and domain-specific relationships between PA and MetS in U.S. adults.

Methods Data from 3,408 adults participating in the National Health and Nutrition Examination Survey (2013–2018) were analyzed. Blood pressure (BP), waist circumference (WC), fasting blood glucose (GLU), triglycerides (TRIG), and high-density lipoprotein (HDL) were measured. MetS and its risk factors were the primary and secondary outcomes, respectively. Weekly minutes of total PA and domain-specific PA (i.e., leisure-time (LTPA), transportation (TPA), occupational & household (OHPA)), were self-reported. For each exposure, participants were grouped into weekly PA: (1) 0 min, (2) 1–149 min, (3) 150–299 min, (4) 300–599 min, and (5) 600 + minutes. Logistic regression estimated the odds of having MetS, and its risk factors from PA.

Results Total PA was associated with lower odds of most MetS risk factors. Compared to no LTPA, and independent of TPA and OHPA, engaging in 150–299 and 300–599 min/week of LTPA was associated with 30% (OR = 0.70 [95%CI: 0.50, 0.98]) and 43% (OR = 0.57 [95%CI: 0.35, 0.92]) lower odds of MetS, respectively. LTPA was also associated with lower odds of having high WC, GLU, TRIG, and low HDL (ORs = 0.52–0.68). Compared to no TPA, and independent of LTPA and OHPA, engaging in 300–599 min/week of TPA was associated with 54% lower odds of MetS (OR = 0.46 [95%CI: 0.25, 0.84]) and 40% lower odds of having a high WC (OR = 0.40 [95%CI: 0.21, 0.76]). Engaging in OHPA was not associated with MetS but was associated with greater odds of having a high WC (OR = 1.44 [95%CI: 1.03, 2.01]), and GLU (ORs = 1.52–1.83), independent of LTPA and TPA.

Conclusion Total PA, seemingly driven by LTPA, was inversely associated with cardiometabolic health. TPA also showcases some protective associations, while OHPA appears to not confer cardiometabolic health benefits. Longitudinal data should confirm these associations using more robust PA measurement tools.

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Introduction

Cardiovascular disease (CVD) is the leading cause of death in the United States, and has been estimated to cost over $400 billion, annually [1]. The metabolic syndrome (MetS), a clustering of cardiometabolic risk factors, increases risk of CVD morbidity and mortality [2–5]. With over 1/3rd of the U.S. population living with MetS, and prevalence increasing over time [6], identifying strategies to reduce the risk of developing MetS is an important public health objective.

One behavioral strategy that reduces the risk of MetS, and improves cardiometabolic health, is engaging in physical activity (PA) [7–13]. Adults who do not meet PA recommendations are more than twice as likely to have MetS and its individual risk factors, compared to those meeting PA recommendations [8]. Furthermore, exercise training results in significant improvements in MetS and its individual risk factors [12]. Despite the wide-reaching, health-promoting benefits of PA, and a majority of U.S. adults believing that PA is important for overall health and well-being [14], most U.S. adults do not meet the current aerobic PA recommendations of engaging in at least 150 min of moderate-intensity PA, or at least 75 min of vigorous-intensity PA per week [15]. However, adherence to the PA recommendations depends largely on which domains of PA considered. Indeed, when considering only leisure-time PA (LTPA), only 38.6% of Americans meet recommended levels of PA [16]. Conversely, when combining PA from all domains (i.e., LTPA, transportational PA, and occupational/household PA), 63.7% of Americans meet recommendations [16]. Furthermore, nearly 50% of U.S. adults' moderate-vigorous PA (MVPA) is undertaken at work, while 28%, 15%, and 2% of MVPA is accumulated in the household, leisure, and transportation domains, respectively [17]. Taken together, these data suggest that the domain in which PA is undertaken is an important dimension to consider when examining PA's overall impact on health.

The positive health effects of LTPA are well documented. With respect to cardiometabolic health, specifically, LTPA reduces resting blood pressure [18], abdominal obesity [19], and elicits meaningful improvements in glycemic control [20, 21] and the blood lipid profile [13, 22]. These effects likely explain the reductions in all-cause, cancer, and CVD-related mortality that is consistently associated with adequate levels of PA [23–26]. Similarly, transportational physical activity (TPA) (e.g., active commuting) elicits similar changes in cardiometabolic health parameters [27–31], and confers long-term health-protective associations in some [32–34], but not all observational studies [35, 36]. Given the mixed findings related to long-term health outcomes, the relationship between TPA and cardiometabolic health is not completely understood and requires further investigation—particularly in the U.S. While occupational/household PA (OHPA) contributes to overall PA levels [37, 38], their independent relationships with cardiometabolic health outcomes are less clear. For example, some studies show health-protective associations [39–41], while others show mixed [36, 42, 43] or even adverse associations [26, 44–47]. The null or negative associations between occupational PA (OPA) and health has been termed, the "physical activity paradox", and may be due to OPA being undertaken at insufficient intensities to realize the health-promoting effects of PA. High OPA occupations are also often characterized by long working hours with few physical breaks, potentially elevating 24-hour heart rate, blood pressure, and chronic inflammation [48, 49], which might explain long-term maladaptive cardiac changes [50]. Moreover, having an occupation characterized by high levels of OPA is often associated with being male, having lower educational attainment, and higher rates of smoking [51], which are all independent risk factors of CVD. Therefore, whether poor health outcomes associated with high OPA can be attributed to PA, per se, remains to be elucidated.

Despite the seemingly divergent responses to PA, depending on the domain in which its undertaken, the most recent PA Guidelines for Americans [52] do not delineate between the domains of PA as they relate to health. Therefore, using nationally representative data from the National Health and Nutrition Examination Survey (NHANES), the purpose of this study is to examine the total and domain-specific relationships between PA and cardiometabolic health. We hypothesize that the relationships between PA will differ, depending on the domain of PA. Specifically, we hypothesize that LTPA and TPA will be associated with lower odds of poor cardiometabolic health, while OHPA will display greater odds of poor cardiometabolic health. The results of this study may inform future public health recommendations and help better understand the domain-specific impacts of PA on health to inform future PA interventions.

Methods

Participants

Data analyzed in this study were from the 2013–2018 waves of NHANES, which is representative of non-institutionalized U.S. civilians. The data were downloaded directly from the Centers of Disease Control and Prevention's NHANES website (https://www.cdc.gov/nchs/nhanes/). Using the NHANES Tutorials, all data were imported into R for analysis. Participants were excluded from the current study if they were under the age of 20 or older than 79 years, were pregnant, or had any missing exposure, outcome, or covariate data. A flowchart of participant inclusion/exclusion is shown in Fig. 1.

Outcomes

The primary outcome of this study was MetS, defined by the revised version of the National Cholesterol Education Program Adult Treatment Panel III [53]. According to this definition, participants had MetS if they had three or more of the following risk factors: (1) blood pressure (BP) ≥ 130/85 mmHg, or taking hypertensive medication, (2) waist circumference (WC) > 102 cm and 88 cm for male and female participants, respectively, (3) fasting blood glucose (GLU) ≥ 100 mg/dL, or taking glucose-lowering medication or insulin, (4) triglycerides (TRIG) ≥ 150 mg/dL, or taking blood lipid-altering medication, and (5) high-density lipoprotein (HDL) < 40 and < 50 for male and female participants, respectively. The individual risk factors of MetS were treated as secondary outcomes.

Exposures

The primary exposures of this study were total and domain-specific PA, expressed as minutes of MVPA per week, and categorized according to current PA recommendations [52]. Participants self-reported their domain-specific PA using a modified version of the Global Physical Activity Questionnaire (GPAQ) [54]. The GPAQ is validated against device-based PA estimates, with relationships ranging from $r = 0.31–0.48$ [54–56]. While these relationships are considered weak-moderate in magnitude, the GPAQ's ability to assess domain-specific PA is unique, compared to other self-report PA tools. The GPAQ also demonstrates high long-term reliability across domains [55], making it useful to investigate domain-specific PA questions. Briefly, participants were asked to report

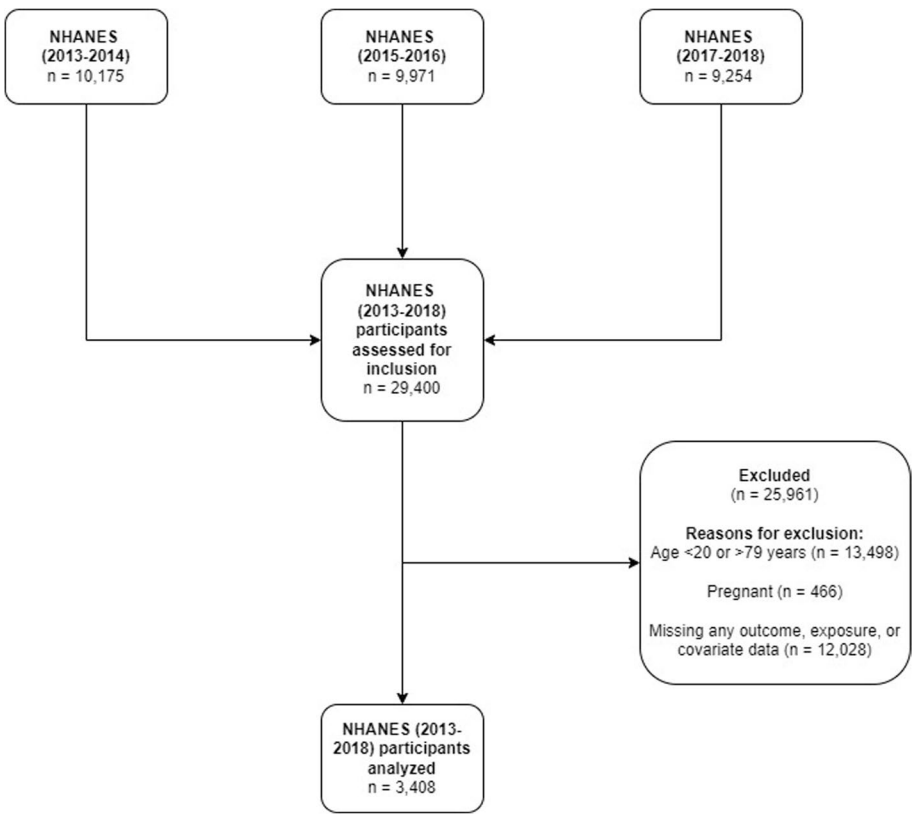

Fig. 1 Participant inclusion/exclusion flowchart

the average number of days and minutes per week they engaged in moderate- and vigorous-intensity LTPA, TPA, and OHPA. The GPAQ assumes that "moderate" and "vigorous"-intensity activities represent activities of 4 and 8 metabolic equivalents of tasks (METS), respectively. Furthermore, the GPAQ assumes that all TPA is undertaken at 4 METS. As light-intensity activities (i.e., activities < 3 METS) are not estimated in the questionnaire, the total number of minutes calculated from the GPAQ represents an estimate of weekly MVPA minutes within each domain, and the summation of MVPA in each domain represents the total weekly minutes of MVPA. In accordance with the current PA recommendations of engaging in at least 150–300 min of MVPA/week [52], five groups were constructed for both total and domain-specific PA: (1) 0 weekly minutes, (2) 1–149 weekly minutes, (3) 150–299 weekly minutes, (4) 300–599 weekly minutes, and (5) 600 + weekly minutes. Additional groups beyond the current PA guidelines were constructed to better illustrate the dose-response relationships between PA and cardiometabolic health, in addition to accommodate domains in which substantially higher volumes of PA are usually accumulated (e.g., OHPA).

Covariates

Covariates were selected based on previous literature examining the associations between PA and health outcomes [23, 57, 58]. Age at the time of recruitment (continuous), sex (dichotomized as male/female), income-to-poverty ratio (continuous) [59], current smoking status (dichotomized as having smoked in the previous 5 days or not), average daily units of alcohol consumed (continuous) [60], marital status (categorized as divorced, living with partner, married, never married, separated, or widowed), highest educational completed (categorized as less than 9th grade, 9-11th grade with no high school diploma, high school graduate/GED or equivalent, some college or associate's degree, college graduate or above), race/ethnicity (categorized as Mexican American, non-Hispanic Asian, non-Hispanic black, non-Hispanic white, other Hispanic, and other race – including multi-racial), and self-reported dietary quality (categorized as excellent, very good, good, fair, and poor) were all used as covariates within the models examining the association between total PA and MetS, and its individual risk factors. For the models assessing the domain-specific relationships between PA and MetS, and individual risk factors, the other domains of PA were also added as covariates (categorized as 0, 1–149, 150–299, 300–599, and 600 + minutes/week of domain-specific PA).

Statistical analysis

To account for the multistage, probability sampling design of NHANES, the appropriate survey weights were calculated, using the NHANES survey methods and analytic guidelines. Using these guidelines, we pooled data across three NHANES waves (2013-14, 2015-16, and 2017-18), and calculated sample weights by multiplying the 2-year cycle weights by 1/3 (i.e., 1 over the number of combined cycles), and used the "svydesign" function in the *survey* R package to construct the weighted dataset. Participants with complete data with respect to our main exposures, outcomes, and covariates of interest were subsequently analyzed for this study. In total, 3,408 U.S. adults, representing 128.5 million U.S. adults, were included in this study.

Unweighted and weighted summary statistics were calculated and described using the constructed *survey* object and the "tbl_svysummary" function in the *gtsummary* R package. Using the "svyglm" function in the *survey* R package, weighted logistic regression analyses estimated the likelihood of having MetS and its individual risk factors from total and domain-specific PA, adjusted for relevant covariates. Three models were constructed for each main exposure and outcome. When examining the relationship between total PA and MetS, and its individual risk factors, the first model included total PA, with age and sex as covariates. Model 2 included the variables in model 1, plus income-to-poverty ratio, smoking status, weekly alcohol consumption, marital status, education, race/ethnicity, and self-reported dietary quality. When examining the domain-specific relationships between PA and MetS, and its individual risk factors, the first model included the domain-specific PA, with age and sex as covariates. Model 2 included the variables in model 1, plus income-to-poverty ratio, smoking status, weekly alcohol consumption, marital status, education, race/ethnicity, and self-reported dietary quality. Finally, model 3 included the variables in model 2, plus PA in the other domains. Odds ratios (ORs) and their 95% confidence intervals (95%CIs) are reported, using an alpha value of 0.05 as the threshold for statistical significance. All statistical analyses and visualizations were conducted in RStudio.

Results

Our sample comprised 3,408 participants, of whom 1,337 (39%) had MetS (Table 1 and Additional file 1). Participants with MetS tended to be older, more male, had lower educational attainment, and self-reported lower dietary quality, compared to those without MetS (Table 1 and Additional file 1). There were trends towards more beneficial cardiometabolic health outcomes with higher total and domain-specific PA, but with substantial heterogeneity depending on the domain (Table 2 and Additional file 2). In the fully

Table 1 Participant characteristics, stratified by MetS status

Characteristic	Overall, *n* = 3,408[1]	No MetS, *n* = 2,071[1]	MetS, *n* = 1,337[1]
Age, years	45 (16)	40 (15)	52 (14)
Sex, %			
Female	1,605 (48%)	999 (50%)	606 (46%)
Male	1,803 (52%)	1,072 (50%)	731 (54%)
Race/ethnicity, %			
Mexican American	468 (8.4%)	262 (8.1%)	206 (8.9%)
Non-Hispanic Asian	351 (3.9%)	260 (4.7%)	91 (2.6%)
Non-Hispanic Black	709 (10%)	444 (11%)	265 (9.2%)
Non-Hispanic White	1,390 (68%)	827 (67%)	563 (70%)
Other Hispanic	345 (5.5%)	193 (5.8%)	152 (5.0%)
Other Race - Including Multi-Racial	145 (4.0%)	85 (3.7%)	60 (4.5%)
Educational status, %			
Less than 9th grade	165 (2.6%)	77 (2.2%)	88 (3.3%)
9-11th grade, no diploma	372 (7.5%)	214 (7.1%)	158 (8.3%)
High school graduate/GED or equivalent	769 (22%)	443 (20%)	326 (26%)
Some college/AA degree	1,139 (33%)	682 (32%)	457 (34%)
College graduate or above	963 (35%)	655 (39%)	308 (28%)
Marital status, %			
Divorced	400 (11%)	196 (9.4%)	204 (14%)
Living with partner	325 (9.3%)	247 (11%)	78 (6.2%)
Married	1,762 (55%)	981 (51%)	781 (62%)
Never married	692 (19%)	532 (25%)	160 (10%)
Separated	105 (2.0%)	64 (1.9%)	41 (2.1%)
Widowed	124 (3.0%)	51 (1.2%)	73 (6.1%)
Income/Poverty Ratio, %			
<1	622 (12%)	392 (13%)	230 (11%)
1–1.99	834 (19%)	476 (18%)	358 (20%)
2–2.99	547 (16%)	324 (16%)	223 (17%)
3–3.99	405 (13%)	238 (12%)	167 (16%)
4–4.99	288 (11%)	186 (11%)	102 (9.7%)
≥5	712 (29%)	455 (31%)	257 (27%)
Currently smoking, %	947 (24%)	613 (26%)	334 (22%)
Exceeds daily recommended alcohol consumption[a], %	1,729 (51%)	1,095 (54%)	634 (46%)
Self-rated Diet Quality, %			
Excellent	231 (6.1%)	157 (7.5%)	74 (3.6%)
Very good	675 (21%)	442 (22%)	233 (19%)
Good	1,393 (43%)	827 (43%)	566 (44%)
Fair	873 (23%)	509 (21%)	364 (27%)
Poor	236 (6.5%)	136 (6.3%)	100 (6.8%)
Systolic blood pressure, mmHg	120 (15)	116 (13)	128 (16)
Diastolic blood pressure, mmHg	71 (10)	69 (9)	74 (12)
High blood pressure, %	1,385 (36%)	408 (15%)	977 (71%)
Waist circumference, cm	99 (17)	93 (14)	111 (15)
High waist circumference, %	1,838 (55%)	705 (36%)	1,133 (87%)
Fasting blood glucose, mg/dL	106 (29)	98 (17)	119 (38)
High fasting blood glucose, %	1,909 (54%)	717 (34%)	1,192 (88%)
Fasting triglycerides, mg/dL	108 (67)	85 (46)	149 (78)
High fasting blood triglycerides, %	1,110 (32%)	239 (12%)	871 (66%)
Fasting blood HDL, mg/dL	55 (17)	60 (17)	48 (17)
Low HDL, %	884 (25%)	230 (11%)	654 (50%)

[1] Mean (SD); n (weighted %), *MetS* Metabolic syndrome, *mmHg* millimeters of mercury, *cm* centimeters, *mg/dL* milligrams per deciliter, *HDL* High-density lipoprotein

[a] Recommended alcohol consumption was defined as ≤2 and ≤1 drink for males and females, respectively, based on American Heart Association guidelines

Table 2 Cardiometabolic risk factors and metabolic syndrome, by total and domain-specific PA

Characteristic	Total PA (minutes/week)[a]					OHPA (minutes/week)[a]					TPA (minutes/week)[a]					LTPA (minutes/week)[a]				
	0 *n*=695	1-149 *n*=506	150-299 *n*=429	300-599 *n*=550	600+*n*=1,228	0 *n*=1,781	1-149 *n*=301	150-299 *n*=194	300-599 *n*=240	600+ *n*=892	0 *n*=2,591	1-149 *n*=373	150-299 *n*=188	300-599 *n*=141	600+ *n*=115	0 *n*=1,569	1-149 *n*=671	150-299 *n*=504	300-599 *n*=419	600+*n*=245
Systolic blood pressure, mmHg	122 (17)	121 (15)	118 (15)	120 (14)	121 (15)	120 (16)	121 (15)	118 (13)	121 (14)	121 (15)	121 (15)	120 (14)	119 (15)	119 (14)	124 (16)	122 (16)	120 (14)	118 (14)	118 (14)	119 (15)
Diastolic blood pressure, mmHg	71 (11)	71 (11)	70 (10)	71 (10)	70 (11)	70 (10)	71 (12)	69 (10)	71 (10)	71 (11)	70 (10)	71 (11)	71 (11)	68 (11)	71 (11)	71 (11)	71 (10)	70 (10)	68 (10)	69 (11)
High blood pressure, %	334 (43%)	234 (39%)	164 (30%)	211 (34%)	442 (33%)	730 (35%)	147 (43%)	77 (36%)	93 (38%)	338 (34%)	1,068 (37%)	143 (31%)	71 (27%)	51 (28%)	52 (46%)	727 (41%)	271 (33%)	185 (32%)	130 (27%)	72 (31%)
Waist circumference, cm	102 (17)	101 (17)	98 (17)	97 (16)	99 (17)	98 (17)	101 (18)	102 (17)	102 (16)	100 (17)	100 (17)	96 (16)	95 (17)	95 (17)	97 (17)	103 (17)	99 (17)	97 (16)	94 (17)	95 (14)
High waist circumference, %	450 (65%)	280 (58%)	230 (57%)	267 (49%)	611 (50%)	956 (54%)	159 (57%)	113 (59%)	134 (61%)	476 (53%)	1,493 (58%)	169 (42%)	74 (44%)	47 (31%)	55 (44%)	970 (64%)	353 (53%)	258 (52%)	167 (38%)	90 (41%)
Fasting blood glucose, mg/dL	113 (39)	105 (26)	105 (26)	102 (21)	105 (27)	107 (32)	103 (14)	110 (30)	105 (24)	106 (28)	106 (28)	104 (26)	103 (27)	103 (23)	115 (54)	109 (33)	105 (29)	105 (25)	100 (17)	104 (23)
High fasting blood glucose, %	438 (62%)	284 (53%)	234 (50%)	286 (48%)	667 (55%)	977 (50%)	180 (56%)	116 (64%)	127 (57%)	509 (58%)	1,497 (56%)	194 (51%)	89 (43%)	67 (45%)	62 (52%)	971 (61%)	365 (53%)	255 (47%)	199 (44%)	119 (51%)
Fasting triglycerides, mg/dL	122 (70)	115 (68)	99 (63)	103 (65)	105 (67)	108 (67)	107 (67)	111 (63)	119 (71)	106 (68)	110 (68)	109 (71)	97 (51)	97 (59)	107 (54)	119 (71)	112 (69)	96 (58)	94 (60)	93 (57)
High fasting triglycerides, %	291 (41%)	173 (36%)	134 (26%)	167 (29%)	345 (28%)	605 (32%)	112 (34%)	62 (34%)	79 (37%)	252 (28%)	886 (33%)	108 (26%)	47 (23%)	36 (27%)	33 (27%)	584 (38%)	227 (35%)	139 (24%)	106 (22%)	54 (21%)
Fasting HDL, mg/dL	53 (19)	55 (15)	59 (18)	58 (18)	54 (17)	56 (18)	58 (19)	55 (17)	53 (15)	53 (16)	55 (17)	58 (20)	55 (14)	54 (15)	52 (17)	52 (17)	55 (16)	59 (17)	59 (20)	59 (20)
Low HDL, %	237 (34%)	120 (22%)	103 (22%)	111 (19%)	313 (26%)	472 (25%)	66 (19%)	51 (29%)	51 (22%)	244 (28%)	701 (26%)	77 (21%)	37 (20%)	30 (21%)	39 (37%)	489 (32%)	148 (22%)	104 (18%)	92 (20%)	51 (19%)
Total MetS risk factors, %																				
0	58 (8.2%)	70 (16%)	86 (23%)	106 (22%)	222 (18%)	292 (20%)	49 (18%)	24 (9.9%)	40 (14%)	137 (15%)	372 (15%)	69 (22%)	51 (31%)	30 (22%)	20 (23%)	152 (10%)	114 (17%)	109 (22%)	104 (29%)	63 (28%)
1	127 (20%)	107 (22%)	94 (24%)	133 (27%)	298 (26%)	399 (24%)	52 (18%)	45 (26%)	54 (24%)	209 (27%)	548 (23%)	106 (32%)	44 (22%)	43 (35%)	18 (12%)	299 (20%)	152 (26%)	127 (28%)	118 (29%)	63 (23%)
2	167 (26%)	116 (22%)	79 (19%)	124 (19%)	284 (22%)	390 (21%)	61 (20%)	44 (24%)	60 (23%)	215 (22%)	599 (22%)	70 (17%)	35 (21%)	33 (24%)	33 (28%)	384 (24%)	151 (21%)	94 (19%)	80 (20%)	61 (22%)
3	143 (19%)	122 (24%)	95 (19%)	109 (18%)	231 (18%)	340 (17%)	85 (28%)	50 (22%)	43 (19%)	182 (20%)	540 (20%)	78 (16%)	35 (13%)	24 (13%)	23 (16%)	369 (23%)	135 (17%)	94 (18%)	66 (13%)	36 (16%)
4	140 (19%)	69 (13%)	47 (10%)	56 (9.9%)	146 (11%)	259 (13%)	35 (11%)	19 (11%)	34 (17%)	111 (11%)	381 (13%)	39 (9.2%)	16 (9.4%)	5 (3.3%)	17 (20%)	258 (15%)	90 (15%)	56 (8.9%)	37 (7.0%)	17 (7.1%)
5	60 (8.4%)	22 (4.3%)	28 (5.3%)	22 (4.2%)	47 (4.7%)	101 (5.4%)	19 (5.2%)	12 (7.9%)	9 (4.3%)	38 (5.0%)	151 (5.8%)	11 (4.0%)	7 (3.1%)	6 (3.5%)	4 (1.9%)	107 (7.5%)	29 (3.7%)	24 (3.9%)	14 (3.6%)	5 (3.8%)
MetS, %	343 (46%)	213 (41%)	170 (34%)	187 (32%)	424 (34%)	700 (35%)	139 (44%)	81 (41%)	86 (40%)	331 (36%)	1,072 (39%)	128 (29%)	58 (25%)	35 (20%)	44 (38%)	734 (46%)	254 (36%)	174 (31%)	117 (23%)	58 (27%)

[a] Mean (SD); Unweighted n (Survey-weighted population prevalence %), *PA* Physical activity, *OHPA* Occupational/household PA, *TPA* Transportational PA, *LTPA* Leisure-time PA, *mmHg* millimeters of mercury, *cm* centimeters, *mg/dL* milligrams per deciliter, *HDL* High-density lipoprotein, *MetS* Metabolic syndrome

adjusted models, neither total PA nor OHPA were significantly associated with MetS at any level (Table 3). Conversely, compared to not engaging in any TPA, engaging in 300–599 min/week of TPA was associated with 54% lower odds of MetS (OR = 0.46 [95%CI: 0.25, 0.84]). Similarly, compared to not engaging in any LTPA, engaging in 150–299 and 300–599 min/week of LTPA was associated with 30% (OR = 0.70 [95%CI: 0.50, 0.98]) and 43% (OR = 0.57 [95%CI: 0.35, 0.93] lower odds of having MetS, respectively.

In general, the reported relationships between total and domain-specific PA and MetS extended to the individual risk factors of MetS (Fig. 2 and Additional files 3–7). Specifically, in the fully adjusted models, neither total nor domain-specific PA were associated, in either direction, with likelihood of having high BP. Engaging in 300–599 min/week of total PA (OR = 0.70 [95%CI: 0.49, 0.98]), TPA (OR = 0.40 [95%CI: 0.21, 0.76]), and LTPA (OR = 0.52 [95%CI: 0.38, 0.72]) were associated with significantly lower likelihood of having a high WC, while engaging in 300–599 min/week of OHPA was associated with 44% higher odds of having a high WC (OR = 1.44 [95%CI: 1.03, 2.01]). Engaging in 1–149 and 300–599 min/week of total PA was associated with 37% (OR = 0.63 [95%CI: 0.45, 0.88]) and 35% (OR = 0.65 [95%CI: 0.46, 0.92]) lower odds of having high GLU. Accumulating 150–299 and 300–599 min/week of LTPA was associated with 33% (OR = 0.67 [95%CI: 0.49, 0.91]) and 32% (OR = 0.68 [95%CI: 0.47, 0.99]) lower odds of having high GLU levels, respectively. Conversely, 150–299 and 600 + minutes/week of OHPA was associated with 83% (OR = 1.83 [95%CI: 1.13, 2.98]) and 52% (OR = 1.52 [95%CI: 1.11, 2.08]) higher odds of high GLU, respectively, while TPA was not significantly related with GLU. With respect to blood lipids, 150–299 and 600 + minutes/week of total PA was associated with 42% (OR = 0.58 [95%CI: 0.38, 0.88]) and 38% (OR = 0.62 [95%CI: 0.44, 0.87]) lower odds of having high TRIG, respectively, while 149–299 min/week of LTPA was associated with 35% (OR = 0.65 [95%CI: 0.45, 0.96]) lower odds of high TRIG. OHPA and TPA were not significantly associated with TRIG levels. Finally,

Table 3 Associations between total and domain-specific physical activity and metabolic syndrome

	Model 1		Model 2		Model 3	
Characteristic	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Total PA[a]						
0 min/week	REF	REF	REF	REF	REF	REF
1–149 min/week	0.74	0.52, 1.06	0.79	0.53, 1.18	-	-
150–299 min/week	0.69	0.47, 1.02	0.87	0.59, 1.28	-	-
300–599 min/week	**0.58**	**0.41**, **0.83**	0.73	0.51, 1.05	-	-
600+mins/week	0.77	0.58, 1.02	0.81	0.60, 1.10	-	-
OHPA[b]						
0 min/week	REF	REF	REF	REF	REF	REF
1–149 min/week	**1.43**	**1.03**, **1.99**	1.40	0.96, 2.04	1.39	0.92, 2.11
150–299 min/week	1.24	0.73, 2.11	1.23	0.75, 2.01	1.27	0.75, 2.14
300–599 min/week	1.39	0.91, 2.12	1.22	0.78, 1.92	1.30	0.82, 2.05
600+mins/week	**1.36**	**1.04**,**1.78**	1.10	0.80, 1.52	1.14	0.80, 1.63
TPA[b]						
0 min/week	REF	REF	REF	REF	REF	REF
1–149 min/week	0.73	0.52, 1.02	0.82	0.58, 1.17	0.88	0.61, 1.26
150–299 min/week	**0.61**	**0.40**, **0.95**	0.69	0.44, 1.10	0.75	0.45, 1.25
300–599 min/week	**0.39**	**0.23**, **0.67**	**0.42**	**0.24**, **0.74**	**0.46**	**0.25**, **0.84**
600+mins/week	1.12	0.60, 2.10	1.08	0.54, 2.16	1.16	0.54, 2.49
LTPA[b]						
0 min/week	REF	REF	REF	REF	REF	REF
1–149 min/week	**0.65**	**0.45**, **0.93**	0.74	0.50, 1.08	0.75	0.50, 1.12
150–299 min/week	**0.53**	**0.40**, **0.71**	**0.69**	**0.50**, **0.94**	**0.70**	**0.50**, **0.98**
300–599 min/week	**0.40**	**0.26**, **0.62**	**0.56**	**0.35**, **0.90**	**0.57**	**0.35**, **0.93**
600+mins/week	**0.48**	**0.30**,**0.78**	0.62	0.37, 1.02	0.62	0.35, 1.10

Transportational PA, *LTPA* Leisure-time PA, *REF* Reference groupBolded ORs and 95% CIs are statistically significant at an alpha level = 0.05*OR* Odds ratio, *CI* Confidence interval, *PA P*hysical activity, *OHPA* Occupational/household PA, *TPA* [a]Model 1 is controlled for age and sex. Model 2 is controlled for variables in Model 1 + income-to-poverty ratio, smoking status, daily alcohol consumption, marital status, education, race/ethnicity, and self-reported dietary quality.[b]Model 1 is controlled for age and sex. Model 2 is controlled for variables in Model 1 + income-to-poverty ratio, smoking status, weekly alcohol consumption, marital status, education, race/ethnicity, and self-reported dietary quality. Model 3 is controlled for variables in Model 2 + the other domains of PA

engaging in 1–149, 150–299, and 300–599 min/week of total PA was associated with 38% (OR = 0.62 [95%CI: 0.39, 0.98]), 38% (OR = 0.62 [95%CI: 0.43, 0.90]), and 42% (OR = 0.58 [95%CI: 0.39, 0.88]) lower odds of having low HDL levels, while 150–299 min/week of LTPA was associated with 38% (OR = 0.62 [95%CI: 0.41, 0.93]) lower odds of low HDL. TPA and OHPA were not associated with HDL levels.

Discussion

The purpose of this study was to investigate the associations between total and domain-specific PA and cardiometabolic health, in a representative sample of U.S. adults. We report that total PA was not associated with MetS, per se, but it was associated with nearly all cardiometabolic risk factors. These protective associations were seemingly driven by LTPA, which showed consistent and robust relationships with cardiometabolic health. Regarding the other domains of PA, TPA was associated with lower likelihood of having MetS and a high WC, while OHPA did not show protective associations with cardiometabolic health.

It is largely established that meeting recommended levels of PA reduces the risk of numerous chronic health conditions, including poor cardiometabolic health and CVD [52], which our findings largely corroborate. In this study, total PA was associated with a lower likelihood of having a high WC, high blood glucose and triglycerides, and having low HDL levels. Abdominal obesity, poor glycemic control/insulin sensitivity, and dyslipidemia are all independent risk factors of CVD [5]. Therefore, increasing the proportion of adults meeting the PA guidelines should be an important public health priority.

Furthermore, we report that LTPA was associated with both MetS and nearly all its risk factors. Given the less robust relationships between TPA and OHPA, and cardiometabolic health, we conclude that the protective associations of total PA on cardiometabolic health are driven primarily by LTPA. Importantly, these protective relationships were realized at LTPA levels that are consistent with current PA guidelines, supporting their recommendations in a representative sample of U.S. adults. Interestingly, we found that LTPA was not protective of cardiometabolic health at levels that substantially exceed current PA guidelines (i.e., 600 + minutes/week), suggesting there could be an upper threshold of cardiometabolic benefit at this level of LTPA. However, caution should be taken when interpreting our effect estimates at this level of PA, as a low proportion of participants (~7%) were engaging in LTPA to this extent, reducing confidence in our estimates. Moreover, when pooling multiple, large prospective cohort studies, there are seemingly no deleterious associations at the highest levels of LTPA, with respect to all-cause and CVD-related mortality [23, 61]. Maximal aerobic capacity, which is closely linked with LTPA, has seemingly no upper threshold of cardiometabolic benefit [62]. Finally, the relationships between LTPA and cardiometabolic health were robust, even after adjusting for OHPA, which is consistently associated with poorer cardiometabolic health [42]. Nonetheless, recent research suggests that high levels of LTPA may not be protective of CVD in the presence of high OPA [26, 63]. To extend the current findings, future research in U.S. adults should examine the joint associations between LTPA and OPA on long-term cardiometabolic health endpoints, using more robust PA measurement tools.

While the relationships between LTPA and cardiometabolic health in this study were consistent and robust to confounding, the relationships between TPA and cardiometabolic health were comparably more variable. Specifically, we found that TPA was independently associated with MetS and a lower likelihood of having a high WC in U.S. adults. However, we did not find significant associations with other individual markers of cardiometabolic health. Given that both MetS and high WC are independently associated with greater risk of CVD morbidity and mortality [2, 3, 64], these findings may still have important public health implications. For instance, increasing population levels of TPA in the U.S. through changes in the built environment and transportation policy could be a strategy to reduce the risk of developing cardiometabolic and other chronic diseases. Indeed, walking behavior partially mediates the relationship between walkability and BMI in U.S. adults [65], and cycling commuting results in similar improvements to insulin sensitivity, cardiorespiratory fitness, and visceral adipose tissue as structured exercise [28], suggesting that increasing population levels

(See figure on next page.)

Fig. 2 Associations between total and domain-specific physical activity and individual cardiometabolic risk factors. Odds ratios (ORs) and 95% confidence intervals (CIs) represent the likelihood of having an individual cardiometabolic risk factor, by total and domain-specific physical activity (PA), using 0 minutes/week as the reference group (REF). Bolded ORs and 95% CIs are statistically significant at an alpha level = 0.05. For assessing the relationship between total PA and cardiometabolic risk factors, models are adjusted for age, sex, income-to-poverty ratio, smoking status, weekly alcohol consumption, marital status, education, race/ethnicity, and self-reported dietary quality. For assessing the domain-specific relationships between PA and cardiometabolic risk factors, models are additionally adjusted for the other domains of PA. OHPA = occupational/household PA, TPA = transportational PA, LTPA = leisure-time PA, HDL = high-density lipoprotein

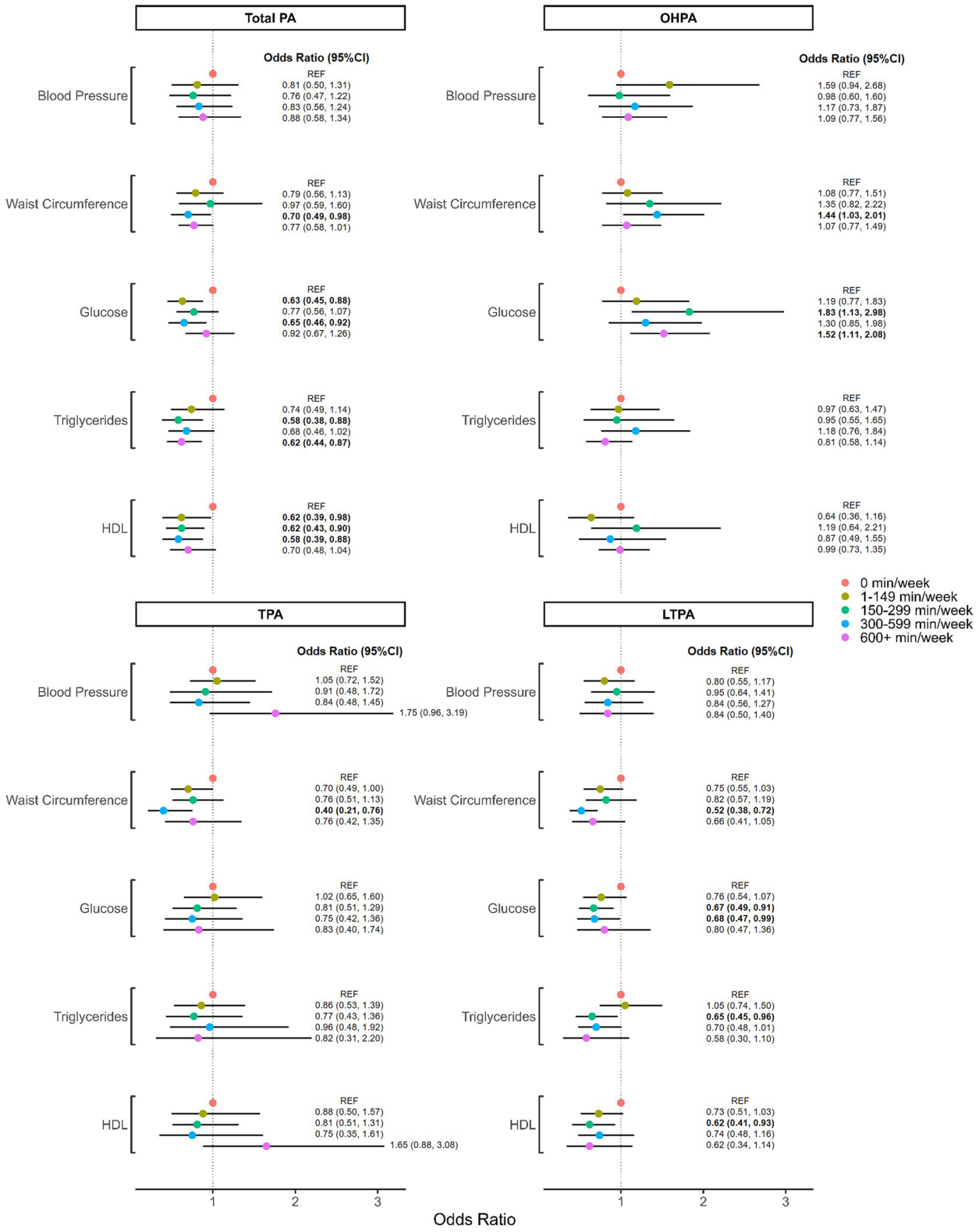

Fig. 2 (See legend on previous page.)

of TPA could be a viable chronic disease prevention strategy. While TPA was protective of cardiometabolic health in this study, the relationships were somewhat inconsistent, as protective associations were only seen at relatively high levels of TPA (i.e., 300–599 min/week). One possible explanation for this could be due to the relatively low intensities at which TPA is typically undertaken at in the U.S. Given that self-selected walking and cycling intensities occur at ~50% and 65% of maximal aerobic capacity, respectively [66], these different TPA modalities may result in differential cardiometabolic adaptations and health outcomes over time [30, 67]. Unfortunately, due to the limitations of the GPAQ, we were unable to assess differences in TPA modalities, and how they relate to cardiometabolic health in this study. Nonetheless, we confirm previous findings reporting that TPA is independently associated with markers of cardiometabolic health in U.S. adults [68]. Future studies should measure modality-specific TPA exposures, to better assess the associations between TPA and chronic disease, and to help inform the design of effective policies and interventions aimed at increasing population levels of TPA.

In contrast to the relationships between LTPA and TPA with cardiometabolic health, we report that OHPA is not significantly associated with favorable cardiometabolic health in U.S. adults. Specifically, while not associated with greater likelihood of MetS, per se, OHPA was independently associated with greater likelihood of having a high WC and fasting blood glucose levels. One posited explanation for why OPA, in particular, does not confer cardiometabolic health benefits is that OPA is often done at insufficient intensities and for long periods of time without sufficient rest [48]. Studies have shown that workers in high OPA jobs overestimate their OPA intensity by ~50% [69], but also experience higher cardiovascular strain on workdays, compared to non-workdays [49], which may predispose them to deleterious cardiac re-modeling over time [50]. To date, however, large cohort studies have not been well-equipped to investigate the dose-response relationship between OPA and negative health outcomes [70], which is an important step to establishing the causality of OPA, per se, on health. This current study is unique in that we categorized participants based on their volume of PA, instead of job classifications or more descriptive OPA exposures (e.g., heavy lifting at work), which have frequently been used to examine the OPA-health relationship. Interestingly, across all outcomes, we detected no clear pattern between the volume of OHPA and cardiometabolic health outcomes. In addition, individuals working jobs characterized by high levels of OPA may also be exposed to non-activity related hazards (e.g., poor air quality) that could alternatively explain the harmful associations seen with high OPA. While our data demonstrates deleterious, cross-sectional associations between OPA and some cardiometabolic health outcomes, there is a need to more accurately and precisely estimate OPA exposures, and link them to health and disease outcomes, to establish the causality of these observed relationships.

Some key strengths of this study are: (1) its use of a large, nationally representative data set, which can be generalized to the larger U.S. adult population, (2) the quantification of PA in accordance with current PA guidelines, and (3) the use of objective cardiometabolic health markers as outcomes. Key limitations of this study include: (1) its use of a self-report PA questionnaire, (2) its cross-sectional design, and (3) its limited sample size for some specific exposures. While the use of a self-report PA questionnaire allowed for the assessment of domain-specific PA, its validity in assessing domain-specific PA is largely unknown. For example, while our estimates of weekly OHPA are nearly identical to previous population-based self-reported estimates [51], these estimates vary considerably, compared to device-based estimates of OHPA [37, 71]. While there are known discrepancies between self-reported and device-based estimates of PA [72], the ability to accurately recall PA is also not consistent across PA domains [73]. Therefore, caution should be used when interpreting the PA estimates from this study. Additionally, with respect to our findings and interpretations related to OPA, it should be noted that this exposure included household PA (HPA), which may differentially affect health [41, 43]. There is, however, compelling evidence to suggest that the direction of the relationships between OPA and HPA are similar, such that the protective associations seen with total PA are only realized after excluding HPA [43], and that HPA is independently associated with higher adiposity [74]. We therefore think that the inclusion of HPA in our OPA exposure does not pose a large threat to internal validity. Nonetheless, the independent relationships with health between OPA and HPA, in isolation, should be investigated further. Moreover, while we were able to statistically adjust for confounders that could alternatively explain our findings, it is unlikely that we were able to negate confounding completely. For example, regarding our exposures, it is well known that engagement in LTPA in the U.S. is positively associated with higher education, income, and socioeconomic status broadly [75], while TPA and OPA are generally negatively associated with these same factors [68, 76]. Future longitudinal and experimental studies are required to establish causality between domain-specific PA exposures and health. Finally, as aerobic PA is only one component of the current PA Guidelines for Americans [52],

future iterations of NHANES should include assessing muscle-strengthening, bone-strengthening, and balance activity exposures, to more comprehensively investigate the associations between PA behaviors and health outcomes.

Conclusion

In this study, the relationships between PA and cardiometabolic health appeared to be domain specific. Specifically, LTPA, and to a lesser extent TPA, were consistently protective of cardiometabolic health in U.S. adults. OHPA, on the other hand, was seemingly unrelated or deleterious to cardiometabolic health. More accurate and precise PA measurement tools should be used in both longitudinal observational and experimental studies, to determine the causality in these reported associations. If the effects of PA are modified by domain, national and international PA guidelines should be updated accordingly.

Abbreviations

MetS	Metabolic syndrome
CVD	Cardiovascular disease
PA	Physical activity
NHANES	National Health and Nutrition Examination Survey
BP	Blood pressure
WC	Waist circumference
GLU	Fasting blood glucose
TRIG	Fasting blood triglycerides
HDL	Fasting high-density lipoprotein
LTPA	Leisure-time physical activity
TPA	Transportational physical activity
OHPA	Occupational/household physical activity
OPA	Occupational physical activity
HPA	Household physical activity
OR	Odds Ratio
95%CI	95% confidence interval
GPAQ	Global Physical Activity Questionnaire
METS	Metabolic equivalents of tasks
MVPA	Moderate-vigorous physical activity

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Supplementary Material 5.

Supplementary Material 6.

Supplementary Material 7.

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Authors' contributions

GMS: Conceptualization, Methodology, Formal analysis, Interpretation of data, Writing – Original Draft, Visualization; JM: Conceptualization, Interpretation of data, Writing – Review & Editing, Visualization; AMS: Conceptualization, Interpretation of data, Resources, Writing – Review & Editing; CCC: Conceptualization, Formal analysis, Interpretation of data, Writing – Review & Editing; SJS: Conceptualization, Interpretation of data, Resources, Writing – Reviewing & Editing, Supervision.

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Data availability

The data used and analyzed are available through the National Center for Health Statistics (https://wwwn.cdc.gov/nchs/nhanes/Default.aspx), and the cleaned dataset is available from the corresponding authors upon reasonable request.

Declarations

Ethics approval and consent to participate

NHANES 2013-2018 received NCHS Ethics Review Board approval under"Protocol #2011-17". All participants provided their informed consent to participate in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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