American Journal of
Preventive Medicine

RESEARCH ARTICLE

Association of Occupational and Leisure-Time Physical Activity With Allostatic Load

Tong Xia, MPH,[1] Jian Li, MD, PhD,[1,2,3] Liwei Chen, MD, PhD[1]

Introduction: Leisure-time physical activity decreases allostatic load, a measure of burden of chronic stress. However, the role of occupational physical activity is unknown. This study examined associations of occupational physical activity and leisure-time physical activity with allostatic load among workers in the U.S.

Methods: This cross-sectional study included 6,944 U.S. workers aged 20−64 years from the National Health and Nutrition Examination Survey (2007−2018). Physical activity was assessed using the Global Physical Activity Questionnaire. Allostatic load was calculated using biomarkers of cardiovascular, metabolic, and immune systems. Associations of occupational physical activity and leisure-time physical activity with allostatic load were examined using negative binomial regressions. Analyses were conducted between August 2022 and March 2023.

Results: Vigorous leisure-time physical activity inversely associated with allostatic load among all workers (count ratio=0.68, 95% CI=0.62, 0.76) and in each sex- and age-stratified group as well as in each race/ethnicity-stratified group. Vigorous occupational physical activity positively associated with allostatic load only among females aged 20−44 years (1.38, 95% CI=1.10, 1.73). Inverse associations of vigorous leisure-time physical activity with allostatic load were similar in young females with high or low vigorous occupational physical activity.

Conclusions: Increasing vigorous leisure-time physical activity associates with a lower allostatic load for all workers, whereas increasing vigorous occupational physical activity associates with a higher allostatic load only in young females. Promoting vigorous leisure-time physical activity reduces allostatic load among young females with either low or high vigorous occupational physical activity.
Am J Prev Med 2024;67(3):328−338.

INTRODUCTION

Allostatic load (AL) is a measure of the burden of stress.[1,2] Long-term exposure to stressors activates the hypothalamic−pituitary−adrenal axis and the sympathetic−adrenal−medullary system, resulting in dysregulation in metabolic, cardiovascular, and immune systems.[1,2] Evidence has shown that higher AL associates with unfavorable health outcomes, such as mental health problems,[3] higher cardiovascular disease (CVD) risk,[4] and even mortality.[4,5] These findings point to the importance of understanding modifiable determinants of AL.

It is well known that leisure-time physical activity (LTPA) is an important factor for lowering CVD risk.[6] However, the relationships between occupational physical activity (OPA) and CVD remain unclear. Whereas some studies reported OPA to be inversely associated with cardiometabolic risk factors (e.g., hypertension, high BMI, dyslipidemia)[7−9] and CVD[10,11] or to have no association with Type 2 diabetes,[12] more studies found that higher OPA was related to worse cardiovascular health (e.g., blood pressure [BP], C-reactive protein [CRP], CVD).[6,13−19] Thus, some researchers propose that OPA may have health effects opposite to those of

From the [1]Department of Epidemiology, Fielding School of Public Health, University of California, Los Angeles, Los Angeles, California; [2]Department of Environmental Health Sciences, Fielding School of Public Health, University of California, Los Angeles, Los Angeles, California; and [3]School of Nursing, University of California, Los Angeles, Los Angeles, California

Address correspondence to: Liwei Chen, MD, PhD, Department of Epidemiology, University of California, Los Angeles, 650 Charles E. Young Drive South, Los Angeles CA 90095. E-mail: cliwei86@ucla.edu.

0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2024.04.009

LTPA, that is, the physical activity (PA) paradox.[6,13] However, the debate is continuing regarding whether the inconsistent findings are due to different measurements of OPA or insufficient controlling for confounders (e.g., smoking and SES).[7−12,20]

Previous studies in the U.S. also suggested that total PA[21,22] and LTPA[23,24] were inversely associated with AL. Research found that undesired job characteristics, such as effort−reward imbalance and job strain, were associated with higher AL.[25,26] However, studies examining the associations between direct measures of OPA and AL are lacking. This study aimed to examine whether there was PA paradox on AL using time on OPA and LTPA, controlling for sufficient confounders among a nationally representative sample of U.S. workers. Interactive associations of OPA and LTPA with AL were also examined to implicate whether high LTPA should be recommended among workers with high OPA. Because both OPA and LTPA levels vary by age, sex, and race/ethnicity,[27−31] and stress response also differs across these demographic factors,[32−35] this study further examined the associations mentioned earlier stratified by sex, age, and race subgroups. This study aimed to identify which groups may experience more health benefits or be more vulnerable to adverse effects of PA to enhance effectiveness of public health initiatives.

METHODS

Study Population

Study participants were from a cross-sectional nationally representative survey: the National Health and Nutrition Examination Survey (NHANES) 2007−2018.[36] This study included participants who were employed (i.e., working at a job or business) and had fasting subsample data (n=9,040) because triglycerides (TGs) (a biomarker used to calculate AL) was only measured in the fasting subsample. The study excluded participants aged <20 or >64 years (n=1,187), those who were pregnant (n=91), those having missing data on OPA or LTPA (n=22), or those on biomarkers for AL (n=796). Finally, 6,944 participants were included in this analysis (Appendix Figure 1, available online). The National Center for Health Statistics Ethics Review Board approved the NHANES study protocol. All participants gave written informed consent.[37] This manuscript followed the STROBE guidelines.

Measures

Starting in 2007, PA was assessed through the Global Physical Activity Questionnaire (GPAQ).[38] Participants reported the frequency and duration of moderate and vigorous work activities (e.g., paid or unpaid work) and leisure-time activities (e.g., sports and recreational activities) in a week.

AL scores were calculated on the basis of 9 biomarkers of cardiovascular health (i.e., systolic BP and diastolic BP, total cholesterol, TG), metabolic function (i.e., HbA1c, albumin, creatinine, BMI), and immune response (i.e., white blood cell [WBC]).[39,40] WBC instead of CRP was used, a widely accepted approach in the field,[41,42] because CRP was only measured in NHANES 2007−2010, and high-sensitivity CRP was only measured in NHANES 2015−2018. However, this study assessed Spearman rank correlation between AL calculated by WBC and high-sensitivity CRP in a subsample (i.e., NHANES 2015−2018) and found that they had high correlation (r=0.99). Each biomarker was classified as high or low risk using clinical cut off points (Appendix Table 1, available online).[43,44] An individual received a score of 1 if biomarker levels were at the high-risk level and 0 otherwise. AL score was calculated by taking the sum of all 9 biomarker scores, ranging from 0 to 9 and higher score meaning higher AL.

The sociodemographic information (i.e., age, sex, race/ethnicity, education, marital status, annual household income, and citizenship), behaviors (i.e., cigarettes smoking, alcohol drinking, dietary energy intake, sleep, and transportation PA), and working hours were collected from interviews.[36] Pre-existing cardiometabolic disease (i.e., CVD, Type 2 diabetes, hypertension, dyslipidemia, and obesity) were collected from interviews, examinations, and laboratory data.

Statistical Analysis

Sampling weights were applied on the basis of NHANES guides,[45] so results can be generalizable to U.S. workers. This study used SAS (Version 9.4) and R 4.2.1 and considered the statistically significant level as a 2-sided alpha level <0.05.

For the primary analysis, this study used duration of PA (minutes/week) and treated OPA and LTPA as binary variables, separating by moderate and vigorous levels (i.e., moderate-intensity PA: high [PA≥150 minutes/week] versus low [PA<150 minutes/week]; vigorous-intensity PA: high [PA≥75 minutes/week] versus low [PA<75 minutes/week]) on the basis of 2018 Physical Activity Guidelines.[31,46,47] Associations of OPA and LTPA with count of AL were examined using negative binomial regression models. Crude and adjusted associations controlling for age, sex, race/ethnicity, education, marital status, income, citizenship, working hours, cigarette smoking, alcohol use, energy intake, sleep, and transportation PA were estimated. In adjusted models, OPA and LTPA were mutually adjusted. The analyses described earlier were performed overall as well as by age and sex (females aged 20−44 years, females aged 45−64 years, males aged 20−44 years, and males aged 45

−64 years) and in racial/ethnic groups (Whites, Blacks, and Hispanics). The missing values of each covariate were <6.5%; thus, completed data analyses were applied.

In sensitivity analysis, this study first assessed OPA and LTPA as energy costs and treated those as binary variables (moderate-intensity PA: high [PA≥500 metabolic equivalent-minutes/week] versus low [PA<500 metabolic equivalent-minutes/week]; vigorous-intensity PA [PA≥500 metabolic equivalent-minutes/week] versus low [PA<500 metabolic equivalent-minutes/week]).[46] Second, this study calculated the count of AL from age- and sex-based distribution classified biomarkers (i.e., high-risk: either >75th percentile for all biomarkers except serum albumin or <25th percentile for serum albumin by age and sex) as the outcome.[48] Third, pre-existing cardiometabolic diseases were additionally controlled for. Fourth, missing values of covariates were treated as a separate category in adjusted models.

RESULTS

Among 6,944 workers, 37.2% had high levels of moderate-intensity OPA, 24.0% had high levels of vigorous-intensity OPA, 21.0% had high levels of moderate-intensity LTPA, and 27.0% had high levels of vigorous-intensity LTPA. Workers having high moderate OPA or high vigorous OPA were more likely to be younger (61.1% vs 55.4% for moderate OPA and 63.6% vs 55.6% for vigorous OPA) and Whites (68.1% vs 63.0% for moderate OPA and 67.5% vs 64.1% for vigorous OPA) but less likely to be females (36.0% vs 50.4% for moderate OPA and 25.1% vs 51.3% for vigorous OPA) than workers having counterpart low OPA. Workers having high moderate LTPA were more likely to work 1−34 hours per week (24.1% vs 20.9%) than workers having low moderate LTPA. Workers having high vigorous LTPA were more likely to be younger (69.0% vs 53.3%) and less likely to be females (38.0% vs 47.6%) and Hispanics (14.0% vs 16.6%) than workers having low vigorous LTPA (Table 1).

The AL count ranged from 0 to 7. Almost half of participants (43.3%) had an AL score of 0, followed by AL score of 1 (30.4%) and 2 (16.2%), and only 10.1% of workers had AL score ≥3 (Figure 1).

In unadjusted models, moderate LTPA was not associated with AL (Table 2). Vigorous LTPA inversely associated with AL in overall participants and stratified age and sex groups. After adjusting for confounders, moderate LTPA was not associated with AL. Vigorous LTPA still inversely associated with AL in overall participants (count ratio=0.68, 95% CI=0.62, 0.76) and each stratified age and sex group. In unadjusted models, moderate OPA was not associated with AL. Vigorous OPA positively associated with AL but only in females aged 20−44 years. After adjusting for confounders, moderate OPA was not associated with AL either. Vigorous OPA remained positively associated with AL in females aged 20−44 years (1.38, 95% CI=1.10, 1.73) (Table 2). In sensitivity analysis, results remained unchanged after using energy cost for LTPA and OPA (Appendix Table 2, available online), using AL calculated by age- and sex-based distribution classified biomarkers (Appendix Table 3, available online), further controlling for pre-existing cardiometabolic disease (Appendix Table 4, available online), or creating a category for missing covariates (Appendix Table 5, available online).

In overall participants stratified by race/ethnicity, moderate LTPA was not associated with AL. There were similar inverse associations of vigorous LTPA with AL in Whites, Blacks, and Hispanics. None of moderate or vigorous OPA was associated with AL. Results were unchanged when examining the associations stratified by race in age and sex subgroups (Appendix Table 6, available online).

Because OPA was only associated with AL among females aged 20−44 years, we assessed the interaction of OPA and LTPA on AL in this group. Having high vigorous LTPA was associated with lower AL in workers with either high (0.64, 95% CI=0.49, 0.84) or low (0.66, 95% CI=0.58, 0.75) vigorous OPA (Figure 2). The test for interaction using Wald chi-square test was not significant (p for interaction=0.29).

DISCUSSION

In the nationally representative sample of U.S. workers, vigorous LTPA instead of moderate LTPA was inversely associated with AL in all age and sex groups as well as in Whites, Blacks, and Hispanics. More importantly, this study is the first to find positive associations of vigorous OPA with AL in young females after controlling for major confounders. There was no significant association of moderate OPA with AL. These findings support the PA paradox and suggest that varying intensity of OPA and LTPA may have different relationships with AL. In addition, sex and age may play a role in associations of vigorous OPA with AL. To reduce AL, interventions are essential to encourage vigorous LTPA among all workers and reduce vigorous OPA, especially among young female workers. Furthermore, benefits of LTPA on AL were found in young females with either high or low vigorous OPA.

Results of this study for LTPA and AL were in line with those of 2 studies in the U.S.,[23,24] but this study added new evidence on the effect of LTPA intensity on

Table 1. Characteristics of Participants by OPA and LTPA Groups

Characteristics	Moderate OPA			Vigorous OPA			Moderate LTPA			Vigorous LTPA		
	High (37.2%, *n*=2,475)	Low (62.8%, *n*=4,469)	*p*-values	High (24.0%, *n*=1,639)	Low (76.0%, *n*=5,305)	*p*-values	High (21.0%, *n*=1,360)	Low (79.0%, *n*=5,584)	*p*-values	High (27.0%, *n*=1,706)	Low (73.0%, *n*=5,238)	*p*-values
Age, % (*n*)			0.002			0.001			0.51			<0.001
20–44 years	61.1 (1,520)	55.4 (2,419)		63.6 (1,031)	55.6 (2,908)		58.5 (802)	57.3 (3,137)		69.0 (1,201)	53.3 (2,738)	
45–64 years	38.9 (955)	44.6 (2,050)		36.4 (608)	44.4 (2,397)		41.5 (558)	42.7 (2,447)		31.0 (505)	46.7 (2,500)	
Female, % (*n*)	36.0 (923)	50.4 (2,260)	<0.001	25.1 (424)	51.3 (2,759)	<0.001	44.3 (600)	45.2 (2,583)	0.64	38.0 (628)	47.6 (2,555)	<0.001
Race/ethnicity, % (*n*)			<0.001			<0.001			0.08			0.04
Non-Hispanic White	68.1 (1,077)	63.0 (1,525)		67.5 (711)	64.1 (1,891)		67.9 (560)	64.1 (2,042)		65.2 (652)	64.8 (1,950)	
Non-Hispanic Black	9.9 (468)	11.4 (924)		9.8 (305)	11.2 (1,087)		10.6 (275)	10.9 (1,117)		11.8 (371)	10.5 (1,021)	
Hispanic	16.6 (721)	15.5 (1,270)		18.8 (520)	15.0 (1,471)		13.5 (334)	16.5 (1,657)		14.0 (411)	16.6 (1,580)	
Other including multiracial	5.4 (209)	10.1 (750)		3.9 (103)	9.7 (856)		8.1 (191)	8.4 (768)		9.0 (272)	8.1 (687)	
Education, % (*n*)			<0.001			<0.001			<0.001			<0.001
High school or less	41.6 (1,164)	29.0 (1,640)		49.4 (881)	28.7 (1,923)		25.7 (425)	35.8 (2,379)		20.2 (448)	38.7 (2,356)	
Some college or associates degree	36.7 (871)	29.5 (1,287)		34.2 (540)	31.6 (1,618)		33.3 (455)	31.9 (1,703)		31.0 (560)	32.7 (1,598)	
College graduate or above	21.7 (439)	41.5 (1,540)		16.4 (217)	39.7 (1,762)		40.9 (480)	32.3 (1,499)		48.8 (697)	28.7 (1,282)	
Marital Status, % (*n*)			0.04			0.70			0.38			<0.001
Married/living with partner	63.3 (1,551)	67.1 (2,838)		64.9 (1,046)	65.9 (3,343)		64.6 (837)	66.0 (3,552)		62.7 (999)	66.8 (3,390)	
Widowed/divorced/separated	12.8 (342)	12.7 (666)		13.6 (235)	12.5 (773)		12.1 (175)	12.9 (833)		9.1 (185)	14.1 (823)	
Never married	23.9 (581)	20.2 (964)		21.6 (357)	21.6 (1,188)		23.4 (348)	21.1 (1,197)		28.2 (522)	19.1 (1,023)	
Annual household income, % (*n*)			<0.001			<0.001			<0.001			<0.001
<$20,000	10.1 (345)	8.2 (509)		12.3 (279)	7.8 (575)		8.6 (152)	9.0 (702)		6.4 (152)	9.8 (702)	
$20,000–$44,999	25.7 (734)	20.5 (1,083)		27.6 (503)	20.8 (1,314)		18.0 (289)	23.6 (1,528)		18.5 (364)	23.9 (1,453)	
$45,000–$74,999	26.2 (571)	21.3 (845)		27.7 (362)	21.7 (1,054)		21.1 (254)	23.6 (1,162)		19.8 (331)	24.3 (1,085)	
≥$75,000	37.9 (648)	50.1 (1,620)		32.5 (368)	49.7 (1,900)		52.3 (542)	43.8 (1,726)		55.2 (715)	42.0 (1,553)	
Citizen of U.S., % (*n*)	91.0 (2,079)	88.9 (3,631)	0.01	88.9 (1,335)	90.0 (4,375)	0.19	92.3 (1,185)	89.0 (4,525)	<0.001	90.8 (1,457)	89.3 (4,253)	0.14
Working hours, % (*n*)			0.01			<0.001			0.01			0.03
1–34 hours/week	22.0 (568)	21.3 (997)		18.7 (346)	22.4 (1,219)		24.1 (334)	20.9 (1,231)		20.2 (387)	22.0 (1,178)	
35–40 hours/week	35.8 (936)	38.8 (1,882)		35.1 (607)	38.5 (2,211)		37.9 (541)	37.6 (2,277)		35.8 (650)	38.4 (2,168)	
41–48 hours/week	13.6 (333)	15.2 (565)		15.3 (234)	14.4 (664)		11.0 (159)	15.6 (739)		16.8 (243)	13.8 (655)	
49–54 hours/week	11.3 (229)	11.5 (438)		11.4 (159)	11.4 (508)		11.4 (132)	11.4 (535)		13.3 (195)	10.7 (472)	
≥55 hours/week	17.4 (409)	13.2 (587)		19.6 (293)	13.3 (703)		15.6 (194)	14.6 (802)		14.0 (231)	15.1 (765)	
Smoking, % (*n*)			<0.001			<0.001			0.04			<0.001
Never	49.9 (1,269)	63.7 (2,847)		48.0 (781)	61.9 (3,335)		57.4 (810)	58.9 (3,306)		66.9 (1,137)	55.5 (2,979)	
Former	24.8 (544)	20.7 (838)		22.3 (341)	22.2 (1,041)		25.2 (288)	21.4 (1,094)		20.5 (320)	22.8 (1062)	
Current	25.3 (659)	15.6 (780)		29.7 (516)	15.9 (923)		17.3 (261)	19.7 (1,178)		12.6 (247)	21.6 (1,192)	

(*continued on next page*)

Table 1. Characteristics of Participants by OPA and LTPA Groups (*continued*)

Characteristics	Moderate OPA			Vigorous OPA			Moderate LTPA			Vigorous LTPA		
	High (37.2%, *n*=2,475)	Low (62.8%, *n*=4,469)	*p*-values	High (24.0%, *n*=1,639)	Low (76.0%, *n*=5,305)	*p*-values	High (21.0%, *n*=1,360)	Low (79.0%, *n*=5,584)	*p*-values	High (27.0%, *n*=1,706)	Low (73.0%, *n*=5,238)	*p*-values
Alcohol drinking, % (*n*)			0.001			0.15			0.03			<0.001
Never	6.4 (198)	9.2 (470)		7.0 (109)	8.6 (559)		7.2 (113)	8.4 (555)		6.4 (121)	8.8 (547)	
Former	12.1 (296)	9.7 (476)		12.1 (193)	10.1 (579)		8.2 (131)	11.2 (641)		7.1 (131)	11.9 (641)	
Current	81.5 (1,839)	81.1 (3,164)		80.9 (1,249)	81.4 (3,754)		84.5 (1,023)	80.4 (3,980)		86.5 (1,337)	79.3 (3,666)	
Energy intake, % (*n*)			<0.001			<0.001			0.47			0.12
Quartile 1	19.3 (494)	24.3 (1,163)		16.5 (272)	24.3 (1,385)		24.5 (337)	21.9 (1,320)		20.1 (357)	23.3 (1,300)	
Quartile 2	22.9 (561)	26.1 (1,095)		20.5 (348)	26.3 (1,308)		24.9 (318)	24.9 (1,338)		25.8 (426)	24.6 (1,230)	
Quartile 3	25.2 (590)	26.3 (1,068)		24.3 (376)	26.4 (1,282)		25.0 (316)	26.1 (1,342)		27.8 (426)	25.2 (1,232)	
Quartile 4	32.6 (740)	23.3 (917)		38.7 (590)	23.0 (1,067)		25.7 (323)	27.1 (1,334)		26.4 (426)	27.0 (1,231)	
Sleep, % (*n*)			<0.001			<0.001			0.29			<0.001
Short (<7 hours)	37.6 (1,009)	31.1 (1,592)		40.3 (691)	31.3 (1,910)		31.4 (479)	34.0 (2,122)		28.7 (578)	35.2 (2,023)	
Adequate (7–9 hours)	59.7 (1,401)	66.3 (2,751)		57.7 (909)	65.8 (3,243)		66.1 (847)	63.3 (3,305)		69.3 (1,090)	61.9 (3,062)	
Long (> 9 hours)	2.7 (59)	2.6 (123)		1.9 (34)	2.9 (148)		2.6 (33)	2.7 (149)		2.0 (37)	2.9 (145)	
High time on transportation PA, % (*n*)	15.1 (604)	11.9 (429)	0.005	16.1 (306)	12.1 (727)	0.01	14.8 (247)	12.6 (786)	0.03	15.7 (308)	12.1 (725)	0.001
With cardiometabolic diseases, % (*n*)	75.2 (1,888)	75.1 (3,442)	0.94	76.3 (1,263)	74.8 (4,067)	0.39	74.0 (1,019)	75.5 (4,311)	0.42	63.7 (1,126)	79.4 (4,204)	<0.001

Note: Data are presented as weighted % (actual frequency, *n*) for categorical variables. According to PA guidelines, high moderate PA (moderate PA≥150 minutes/week) and low moderate PA (0≤moderate PA<150 minutes/week) and high vigorous PA (vigorous PA≥75 minutes/week) and low vigorous PA (0≤vigorous PA<75 minutes/week) were used. *P*-values were compared between groups using chi-square tests for categorical variables.

LTPA, leisure-time physical activity; OPA, occupational physical activity; PA, physical activity.

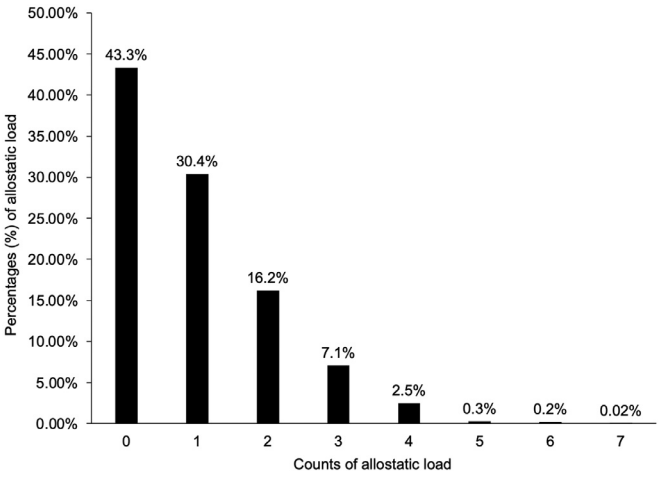

Figure 1. Percentages of allostatic load count.

Allostatic load was calculated from 9 biomarkers of immune response, metabolic function, and cardiovascular health. For each of the 9 biomarkers, an individual received a score of 1 if their biomarker level was more extreme than the high-risk clinical cut off and 0 otherwise. The allostatic load sum score was calculated by taking the sum of all 9 biomarker scores.

AL. One NHANES study found that participants who had no or insufficient vigorous LTPA had higher AL than those with sufficiently vigorous LTPA.[24] Although these studies did not examine separate moderate-intensity LTPA, it is well known that vigorous LTPA is more beneficial on health conditions (e.g., CVD) than moderate LTPA.[49−51] Some studies have actually suggested that moderate LTPA may not have effects on cardiovascular health.[50,51]

Up to now, no studies have examined associations of OPA with AL. One cross-sectional study reported that workers with lower occupational position had higher AL, but it was only found in females,[52] consistent with findings from this study. Although the study did not assess OPA, persons in low occupational positions (e.g., manual workers) may undertake higher intensity OPA than those in high occupational positions (e.g., professors).[52] In addition, evidence indicated that intensity of OPA positively associated with job stress,[53] and a cohort study found effects of job stress on coronary heart disease only among workers aged 35−40 years, not among workers aged 40−50 years.[54] A study among 11,126 participants found that positive associations between OPA type (i.e., blue collar versus white collar) and all-cause mortality were higher in Hispanics than in Whites and Blacks.[55] However, the OPA was classified using job classifications, which may be inaccurate. This study did not find significant associations between OPA and AL across racial/ethnic groups, which may be due to small effect size (e.g., 1.14, 95% CI=0.98, 1.33 comparing high with low vigorous OPA in Blacks) and limited sample sizes. More studies with larger sample sizes are needed.

Findings for the PA paradox on AL were consistent with those of previous PA paradox studies on CVD[6,13,56] and CVD biomarkers (e.g., BP).[16−18] However, some studies found that OPA associated with decreased cardiometabolic risk factors[7−9] and CVD risk.[10,11] Inconsistent findings may be due to different measurements of OPA or insufficient controlling for confounders (e.g., smoking or SES).[7−12,20]

This study implicated that increasing vigorous LTPA was beneficial for workers with either low or high vigorous OPA. Although interactions between OPA and LTPA on AL have not been examined, previous studies showed the beneficial effect of LTPA on cardiometabolic health regardless of OPA levels.[57−59] For example, a cohort study found inverse associations of LTPA with CVD existing in all of high, moderate, and low OPA groups.[57] Some studies showed that effectiveness of LTPA on cardiometabolic health depends on OPA.[12,13,60,61] The varying findings may be due to different measurements of OPA, insufficient controlling for confounders (e.g., SES), and different age groups.[12,13,60,61]

Potential explanations for inverse associations of LTPA with AL being observed only with vigorous LTPA rather than with moderate LTPA may be because vigorous exercise is more effective in improving cardiovascular fitness and reducing AL than moderate exercise.[62,63] This was confirmed in this study through physiological links identified between moderate and vigorous LTPA and biomarkers of AL (Appendix Table 7, available online). In overall participants, vigorous LTPA inversely associated with almost each biomarker of AL, except for creatinine, potentially owing to limited sample sizes of participants at high-risk creatinine and lack of robustness in the results.

Table 2. Independent Associations of LTPA and OPA With Allostatic Load

	Overall		Females aged 20–44 years		Females aged 45–64 years		Males aged 20–44 years		Males aged 45–64 years	
Models	**Count ratio (95% CI)**	***p*-value**	**Count ratio (95% CI)**	***p*-value**	**Count ratio (95% CI)**	***p*-value**	**Count ratio (95% CI)**	***p*-value**	**Count ratio (95% CI)**	***p*-value**
Moderate LTPA (high versus low)										
Unadjusted	0.95 (0.88, 1.04)	0.27	0.97 (0.81, 1.16)	0.72	0.91 (0.76, 1.10)	0.34	1.00 (0.86, 1.16)	0.96	0.92 (0.78, 1.08)	0.29
Adjusted	0.99 (0.90, 1.08)	0.80	0.98 (0.81, 1.19)	0.82	0.99 (0.81, 1.22)	0.94	1.05 (0.90, 1.22)	0.57	0.91 (0.76, 1.08)	0.27
Vigorous LTPA (high versus low)										
Unadjusted	**0.61 (0.55, 0.68)**	**<0.001**	**0.65 (0.54, 0.79)**	**<0.001**	**0.60 (0.46, 0.78)**	**<0.001**	**0.67 (0.59, 0.77)**	**<0.001**	**0.62 (0.52, 0.75)**	**<0.001**
Adjusted	**0.68 (0.62, 0.76)**	**<0.001**	**0.72 (0.58, 0.89)**	**0.003**	**0.72 (0.55, 0.95)**	**0.02**	**0.72 (0.62, 0.84)**	**<0.001**	**0.60 (0.49, 0.74)**	**<0.001**
Moderate OPA (high versus low)										
Unadjusted	1.06 (0.97, 1.16)	0.18	0.96 (0.80, 1.16)	0.68	1.08 (0.89, 1.31)	0.43	1.08 (0.93, 1.27)	0.30	1.11 (0.95, 1.30)	0.18
Adjusted	1.04 (0.94, 1.15)	0.42	0.94 (0.79, 1.12)	0.52	1.03 (0.84, 1.25)	0.81	1.09 (0.93, 1.28)	0.29	1.10 (0.93, 1.32)	0.27
Vigorous OPA (high versus low)										
Unadjusted	1.02 (0.92, 1.14)	0.64	**1.49 (1.22, 1.84)**	**<0.001**	0.94 (0.69, 1.29)	0.71	1.02 (0.88, 1.20)	0.76	0.88 (0.73, 1.06)	0.19
Adjusted	0.98 (0.88, 1.09)	0.71	**1.38 (1.10, 1.73)**	**0.01**	0.82 (0.63, 1.06)	0.12	0.97 (0.82, 1.16)	0.75	0.87 (0.73, 1.04)	0.14

Note: Boldface indicated statistical significance ($p<0.05$).

Negative binominal regression model was used. Count ratio, 95% CI, and *p*-value were reported. Sampling weights were applied. According to PA guidelines, high moderate PA (moderate PA≥150 minutes/week) and low moderate PA (0≤moderate PA<150 minutes/week) and high vigorous PA (vigorous PA≥75 minutes/week) and low vigorous PA (0≤vigorous PA<75 minutes/week) were used. Allostatic load was calculated from 9 biomarkers of immune response, metabolic function, and cardiovascular health. For each of the 9 biomarkers, an individual received a score of 1 if their biomarker level was more extreme than the high-risk clinical cut off and 0 otherwise. The allostatic load sum score was calculated by taking the sum of all 9 biomarker scores. Unadjusted model: crude model. Adjusted model: besides adjusting for age, sex, race/ethnicity, marital status, education, annual household income, citizenship, working hours, smoking, alcohol drinking, energy intake, sleep, and transportation PA, the fully adjusted model was also adjusted for vigorous LTPA, moderate OPA, and vigorous OPA for moderate LTPA; moderate LTPA, moderate OPA, and vigorous OPA for vigorous LTPA; vigorous OPA, moderate LTPA, and vigorous LTPA for moderate OPA; and moderate OPA, moderate LTPA, and vigorous LTPA for vigorous OPA. When stratified by age and sex, those variables were not controlled for.

LTPA, leisure-time physical activity; OPA, occupational physical activity; PA, physical activity.

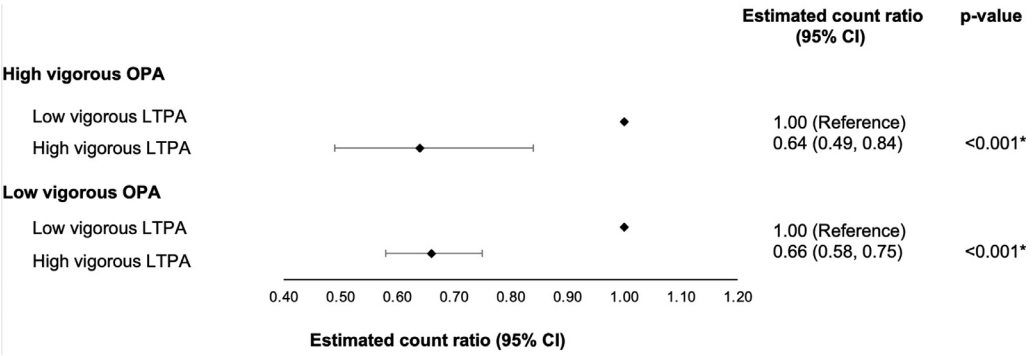

Figure 2. Associations of vigorous LTPA with allostatic load stratified by vigorous OPA among female workers aged 20–44 years in NHANES 2007–2018.

Multivariable negative binominal regression model was used. Count ratio, 95% CI, and *p*-values were reported. The asterisk (*) indicated statistical significance ($p<0.05$). Sampling weights were applied. According to PA guidelines, high moderate PA (moderate PA≥150 minutes/week) and low moderate PA (0≤moderate PA<150 minutes/week) and high vigorous PA (vigorous PA≥75 minutes/week) and low vigorous PA (0≤vigorous PA<75 minutes/week) were used. Allostatic load was calculated from 9 biomarkers of immune response, metabolic function, and cardiovascular health. For each of the 9 biomarkers, an individual received a score of 1 if their biomarker level was more extreme than the high-risk clinical cut off and 0 otherwise. The allostatic load sum score was calculated by taking the sum of all 9 biomarker scores. Analysis was adjusted for race/ethnicity, marital status, education, annual household income, citizenship, working hours, smoking, alcohol drinking, energy intake, sleep, transportation PA, moderate LTPA, and moderate OPA.

LTPA, leisure-time physical activity; NHANES, National Health and Nutrition Examination Survey; OPA, occupational physical activity; PA, physical activity.

In contrast, moderate LTPA displayed inverse relationships with only half of the biomarkers examined (Appendix Table 7, available online). OPA and LTPA may have opposite effects on AL because OPA may be of longer duration or require heavy lifting without sufficient recovery periods, causing higher stress hormones secretion, increased heart rate, and increased heart BP.[6,56] In addition, OPA was associated with impaired neural baroreflex sensitivity, which increased BP.[64]

The reasons why positive associations of OPA with AL only existed for vigorous OPA instead of moderate OPA could be that workers with vigorous OPA had heavier uncomfortable postures than those with moderate OPA, related with higher increased BP and inflammation, resulting in elevated AL.[6,56] Why positive associations of vigorous OPA with AL only existed in young females could be attributable to several factors. First, vigorous OPA such as heavy lifting requires muscle engagement without oxygen consumption.[65] During these activities, heart rate increases to deliver more blood and nutrients to active muscles.[66] Females, who generally have less muscle mass than males,[67] may experience a higher heart rate and BP, leading to higher AL. Second, research has shown that females[32,33] and younger persons[34] may secrete more cortisol in response to stress than males, potentially increasing AL. Third, young females had the highest percentage of income <$20,000 (Appendix Table 8, available online), and workers with low income may have more harmful working environments and fewer resources to cope with stressful work,[68–71] resulting in higher AL. These explanations are supported by physiologic evidence linking vigorous OPA with AL biomarkers (Appendix Table 7, available online). This study found that the point estimates between vigorous OPA and most biomarkers (e.g., WBC, HbA1c, TG, BMI, and diastolic BP) were relatively stronger in young females than in other groups (Appendix Table 7, available online). The study also found higher level of WBC in young females (Appendix Table 1, available online). These findings supported the earlier-mentioned 3 potential mechanisms physiologically that characteristics of OPA and young females as well as young females' more pronounced responses to stress lead to higher AL through dysregulation in immune, metabolic, and cardiovascular systems.

This study had several strengths. It is the first study examining independent and interactive associations of OPA and LTPA with AL in the U.S. using a nationally representative sample. In addition, multiple sensitivity analyses were conducted, showing that results were robust. Furthermore, the study collected potential confounders and controlled for sociodemographic factors, health status, and behaviors. Importantly, OPA and LTPA were mutually adjusted.

Limitations

First, OPA and LTPA were self-reported through the GPAQ in NHANES. However, objective measures of PA

using accelerometer are costly and hard to evaluate domain-specific PA; thus, GPAQs are the most common and valid method to assess PA in large epidemiologic studies.[72–74] In addition, OPA assessed in NHANES included household chores and yard work; however, this study only included employed participants who may focus on actual work activities. Furthermore, in both nonworker and worker females, the percentage of high vigorous OPA was similar across age groups (Appendix Table 9, available online). Thus, positive associations of vigorous OPA and AL in young females may not be attributed to household PA. Second, types of occupation were not included in this study because these were not available in NHANES since 2015. Third, this study was cross-sectional, so the temporality and the causation cannot be established. Fourth, because this study is observational, residual confounding may still exist.

CONCLUSIONS

In a nationally representative sample of U.S. workers, moderate LTPA and OPA were not associated with AL. Vigorous LTPA inversely associated with AL in both males and females aged 20–64 years and in Whites, Blacks, and Hispanics, whereas vigorous OPA was positively associated with AL only in young females. Young females with high vigorous LTPA had lower AL than those with low vigorous LTPA among both high and low vigorous OPA groups. Interventions on promoting high vigorous LTPA among all workers and low vigorous OPA particularly among young female workers are needed to reduce AL.

ACKNOWLEDGMENTS

Authors would like to acknowledge and thank the participants in the National Health and Nutrition Examination Survey. Ethical review and approval were waived for this study because the National Health and Nutrition Examination Survey is a publicly available deidentified data set. Informed consent was obtained from all subjects involved in the study. Publicly available data sets were analyzed in this study. These data can be found at https://www.cdc.gov/nchs/nhanes/index.htm.

The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official view of Centers for Disease Control and Prevention. The funding organizations had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

This publication was supported by the Pilot Project Research Training Program of the Southern California NIOSH Education and Research Center, Grant Agreement Number T42 OH008412 from the Centers for Disease Control and Prevention.

No financial disclosures were reported by the authors of this paper.

CREDIT AUTHOR STATEMENT

Tong Xia: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing — original draft, Writing — review & editing, Visualization, Project administration, Funding acquisition. Jian Li: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing — original draft, Writing — review & editing, Visualization, Project administration, Funding acquisition. Liwei Chen: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing — original draft, Writing — review & editing, Visualization, Supervision, Project administration, Funding acquisition.

SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2024.04.009.

REFERENCES

1. McEwen BS, Seeman T. Protective and damaging effects of mediators of stress. Elaborating and testing the concepts of allostasis and allostatic load. *Ann N Y Acad Sci.* 1999;896(1):30–47. https://doi.org/10.1111/j.1749-6632.1999.tb08103.x.
2. Guidi J, Lucente M, Sonino N, Fava GA. Allostatic load and its impact on health: a systematic review. *Psychother Psychosom.* 2021;90(1):11–27. https://doi.org/10.1159/000510696.
3. McEwen BS. Mood disorders and allostatic load. *Biol Psychiatry.* 2003;54(3):200–207. https://doi.org/10.1016/S0006-3223(03)00177-X.
4. Seeman TE, Singer BH, Rowe JW, Horwitz RI, McEwen BS. Price of adaptation—allostatic load and its health consequences. MacArthur studies of successful aging. *Arch Intern Med.* 1997;157(19):2259–2268. https://doi.org/10.1001/archinte.157.19.2259.
5. Borrell LN, Dallo FJ, Nguyen NN. Racial/ethnic disparities in all-cause mortality in U.S. adults: the effect of allostatic load. *Public Health Rep.* 2010;125(6):810–816. https://doi.org/10.1177/003335491012500608.
6. Li J, Loerbroks A, Angerer P. Physical activity and risk of cardiovascular disease: what does the new epidemiological evidence show? *Curr Opin Cardiol.* 2013;28(5):575–583. https://doi.org/10.1097/HCO.0b013e328364289c.
7. Chu AHY, Moy FM. Associations of occupational, transportation, household and leisure-time physical activity patterns with metabolic risk factors among middle-aged adults in a middle-income country. *Prev Med.* 2013;57(suppl):S14–S17. https://doi.org/10.1016/j.ypmed.2012.12.011.
8. Gómez-Recasens M, Alfaro-Barrio S, Tarro L, Llauradó E, Solà R. Occupational physical activity and cardiometabolic risk factors: a cross-sectional study. *Nutrients.* 2023;15(6):1421. https://doi.org/10.3390/nu15061421.
9. Gupta N, Korshøj M, Dumuid D, Coenen P, Allesøe K, Holtermann A. Daily domain-specific time-use composition of physical behaviors and blood pressure. *Int J Behav Nutr Phys Act.* 2019;16(1):4. https://doi.org/10.1186/s12966-018-0766-1.
10. Morris JN, Heady JA, Raffle PAB, Roberts CG, Parks JW. Coronary heart-disease and physical activity of work. *Lancet.* 1953;262(6795):1053–1057. https://doi.org/10.1016/s0140-6736(53)90665-5.

11. Morris JN, Kagan A, Pattison DC, Gardner MJ. Incidence and prediction of ischæmic heart-disease in London busmen. *Lancet.* 1966;2 (7463):553–559. https://doi.org/10.1016/s0140-6736(66)93034-0.
12. Biswas A, Gilbert-Ouimet M, Mustard CA, Glazier RH, Smith PM. Combined associations of work and leisure time physical activity on incident diabetes risk. *Am J Prev Med.* 2021;60(3):e149–e158. https://doi.org/10.1016/j.amepre.2020.09.017.
13. Ferrario MM, Roncaioli M, Veronesi G, et al. Differing associations for sport versus occupational physical activity and cardiovascular risk. *Heart.* 2018;104(14):1165–1172. https://doi.org/10.1136/heartjnl-2017-312594.
14. Hu GC, Chien KL, Hsieh SF, Chen CY, Tsai WH, Su TC. Occupational versus leisure-time physical activity in reducing cardiovascular risks and mortality among ethnic Chinese adults in Taiwan. *Asia Pac J Public Health.* 2014;26(6):604–613. https://doi.org/10.1177/1010539512471966.
15. Holtermann A, Marott JL, Gyntelberg F, et al. Occupational and leisure time physical activity: risk of all-cause mortality and myocardial infarction in the Copenhagen City Heart Study. A prospective cohort study. *BMJ Open.* 2012;2(1):e000556. https://doi.org/10.1136/bmjopen-2011-000556.
16. Kitano N, Kai Y, Jindo T, Fujii Y, Tsunoda K, Arao T. Association of domain-specific physical activity and sedentary behavior with cardiometabolic health among office workers. *Scand J Med Sci Sports.* 2022;32(8):1224–1235. https://doi.org/10.1111/sms.14165.
17. Lee J, Kim HR, Jang TW, Lee DW, Lee YM, Kang MY. Occupational physical activity, not leisure-time physical activity, is associated with increased high-sensitivity C reactive protein levels. *Occup Environ Med.* 2021;78(2):86–91. https://doi.org/10.1136/oemed-2020-106753.
18. Quinn TD, Kline CE, Nagle E, Radonovich LJ, Alansare A, Barone Gibbs B. Cardiovascular responses to physical activity during work and leisure. *Occup Environ Med.* 2022;79(2):94–101. https://doi.org/10.1136/oemed-2021-107551.
19. Harari G, Green MS, Zelber-Sagi S. Combined association of occupational and leisure-time physical activity with all-cause and coronary heart disease mortality among a cohort of men followed-up for 22 years. *Occup Environ Med.* 2015;72(9):617–624. https://doi.org/10.1136/oemed-2014-102613.
20. Shephard RJ. Is there a 'recent occupational paradox' where highly active physically active workers die early? Or are there failures in some study methods? *Br J Sports Med.* 2019;53(24):1557–1559. https://doi.org/10.1136/bjsports-2018-100344.
21. Bu S, Li Y. Physical activity is associated with allostatic load: evidence from the National Health and Nutrition Examination Survey. *Psychoneuroendocrinology.* 2023;154:106294. https://doi.org/10.1016/j.psyneuen.2023.106294.
22. Gay JL, Salinas JJ, Buchner DM, et al. Meeting physical activity Guidelines is associated with lower allostatic load and inflammation in Mexican Americans. *J Immigr Minor Health.* 2015;17(2):574–581. https://doi.org/10.1007/s10903-013-9950-1.
23. Upchurch DM, Rainisch BW, Chyu L. Greater leisure time physical activity is associated with lower allostatic load in white, Black, and Mexican American Midlife Women: findings from the National Health and Nutrition Examination Survey, 1999 through 2004. *Womens Health Issues.* 2015;25(6):680–687. https://doi.org/10.1016/j.whi.2015.07.002.
24. Memiah P, Biadgilign S, Kuhlman J, et al. Allostatic load, single, and dual chronic conditions: evidence from the National health and nutrition examination survey. *Metab Syndr Relat Disord.* 2022;20(2):104–113. https://doi.org/10.1089/met.2021.0008.
25. Mauss D, Li J, Schmidt B, Angerer P, Jarczok MN. Work-related stress and the Allostatic Load Index - a systematic review. *Gesundheitswesen.* 2017;79(12):e134–e144. https://doi.org/10.1055/s-0035-1555951.
26. Schnorpfeil P, Noll A, Schulze R, Ehlert U, Frey K, Fischer JE. Allostatic load and work conditions. *Soc Sci Med.* 2003;57(4):647–656. https://doi.org/10.1016/S0277-9536(02)00407-0.
27. Prevalence of leisure-time and occupational physical activity among employed adults — United States. *Centers for Disease Control and Prevention.* 1990 https://www.cdc.gov/mmwr/preview/mmwrhtml/mm4919a3.htm.
28. Men spent 5.5 hours per day in leisure activities, women 4.9 hours, in 2019. U.S. Bureau of Labor Statistics. https://www.bls.gov/opub/ted/2020/men-spent-5-point-5-hours-per-day-in-leisure-activities-women-4-point-9-hours-in-2019.htm. Accessed January 25, 2024.
29. Martínez-González MA, Varo JJ, Santos JL, et al. Prevalence of physical activity during leisure time in the European Union. *Med Sci Sports Exerc.* 2001;33(7):1142–1146. https://doi.org/10.1097/00005768-200107000-00011.
30. He XZ, Baker DW. Differences in leisure-time, household, and work-related physical activity by race, ethnicity, and education. *J Gen Intern Med.* 2005;20(3):259–266. https://doi.org/10.1111/j.1525-1497.2005.40198.x.
31. Coenen P, Huysmans MA, Holtermann A, et al. Towards a better understanding of the 'physical activity paradox': the need for a research agenda. *Br J Sports Med.* 2020;54(17):1055–1057. https://doi.org/10.1136/bjsports-2019-101343.
32. Murphy MO, Loria AS. Sex-specific effects of stress on metabolic and cardiovascular disease: are women at higher risk? *Am J Physiol Regul Integr Comp Physiol.* 2017;313(1):R1–R9. https://doi.org/10.1152/ajpregu.00185.2016.
33. Chopra KK, Ravindran A, Kennedy SH, et al. Sex differences in hormonal responses to a social stressor in chronic major depression. *Psychoneuroendocrinology.* 2009;34(8):1235–1241. https://doi.org/10.1016/j.psyneuen.2009.03.014.
34. Mikneviciute G, Pulopulos MM, Allaert J, et al. Adult age differences in the psychophysiological response to acute stress. *Psychoneuroendocrinology.* 2023;153:106111. https://doi.org/10.1016/j.psyneuen.2023.106111.
35. Springfield S, Qin F, Hedlin H, et al. Modifiable resources and resilience in racially and ethnically diverse older women: implications for health outcomes and interventions. *Int J Environ Res Public Health.* 2022;19(12):7089. https://doi.org/10.3390/ijerph19127089.
36. Nhanes. About the National Health and Nutrition Examination Survey. Centers for Disease Control and Prevention; 2022. https://www.cdc.gov/nchs/nhanes/about_nhanes.htm.
37. Nhanes. NCHS Research Ethics Review Board approval. Centers for Disease Control and Prevention; 2022. https://www.cdc.gov/nchs/nhanes/irba98.htm.
38. GPAQ analysis guide - World Health Organization. https://cdn.who.int/media/docs/default-source/ncds/ncd-surveillance/gpaq-analysis-guide.pdf?sfvrsn=1e83d571_2. Accessed July 18, 2023.
39. Moore JX, Bevel MS, Aslibekyan S, Akinyemiju T. Temporal changes in allostatic load patterns by age, race/ethnicity, and gender among the US adult population; 1988-2018. *Prev Med.* 2021;147:106483. https://doi.org/10.1016/j.ypmed.2021.106483.
40. Kobrosly RW, Seplaki CL, Jones CM, Van Wijngaarden E. Physiologic dysfunction scores and cognitive function test performance in U.S. adults. *Psychosom Med.* 2012;74(1):81–88. https://doi.org/10.1097/PSY.0b013e3182385b1e.
41. Wahrendorf M, Chandola T, Goldberg M, Zins M, Hoven H, Siegrist J. Adverse employment histories and allostatic load: associations over the working life. *J Epidemiol Community Health.* 2022;76(4):374–381. https://doi.org/10.1136/jech-2021-217607.
42. Langellier BA, Fleming PJ, Kemmick Pintor JB, Stimpson JP. Allostatic load among U.S.- and foreign-born Whites, Blacks, and latinx. *Am J Prev Med.* 2021;60(2):159–168. https://doi.org/10.1016/j.amepre.2020.08.022.
43. Frei R, Haile SR, Mutsch M, Rohrmann S. Relationship of serum vitamin D concentrations and allostatic load as a measure of cumulative biological risk among the US population: a cross-sectional study. *PLoS One.* 2015;10(10):e0139217. https://doi.org/10.1371/journal.pone.0139217.

44. Duong MT, Bingham BA, Aldana PC, Chung ST, Sumner AE. Variation in the calculation of allostatic load score: 21 examples from Nhanes. *J Racial Ethn Health Disparities.* 2017;4(3):455–461. https://doi.org/10.1007/s40615-016-0246-8.
45. Nhanes tutorials - weighting module. Centers for Disease Control and Prevention. https://wwwn.cdc.gov/nchs/nhanes/tutorials/weighting.asp. Accessed June 12, 2023.
46. US Department of Health and Human Services. Physical Activity Guidelines for Americans. 2nd ed. US Department of Health and Human Services. https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf. Accessed November 10, 2023.
47. Zhang Y, Yang J, Hou W, Arcan C. Obesity trends and associations with types of physical activity and sedentary behavior in US adults: National health and nutrition examination survey, 2007-2016. *Obesity (Silver Spring).* 2021;29(1):240–250. https://doi.org/10.1002/oby.23043.
48. Ribeiro AI, Fraga S, Kelly-Irving M, et al. Neighbourhood socioeconomic deprivation and allostatic load: a multi-cohort study. *Sci Rep.* 2019;9(1):8790. https://doi.org/10.1038/s41598-019-45432-4.
49. Lee IM, Hsieh CC, Paffenbarger RS. Exercise intensity and longevity in men. The Harvard alumni health study. *JAMA.* 1995;273(15):1179–1184. https://doi.org/10.1001/jama.1995.03520390039030.
50. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol.* 2006;97(1):141–147. https://doi.org/10.1016/j.amjcard.2005.07.130.
51. Sesso HD, Paffenbarger RS, Lee IM. Physical activity and coronary heart disease in men: the Harvard alumni health study. *Circulation.* 2000;102(9):975–980. https://DOI.ORG/10.1161/01.CIR.102.9.975.
52. Petrovic D, Pivin E, Ponte B, et al. Sociodemographic, behavioral and genetic determinants of allostatic load in a Swiss population-based study. *Psychoneuroendocrinology.* 2016;67:76–85. https://doi.org/10.1016/j.psyneuen.2016.02.003.
53. Wolff MB, O'Connor PJ, Wilson MG, Gay JL. Associations between occupational and leisure-time physical activity with employee stress, burnout and well-being among healthcare industry workers. *Am J Health Promot.* 2021;35(7):957–965. https://doi.org/10.1177/08901171211011372.
54. Kuper H, Marmot M. Job strain, job demands, decision latitude, and risk of coronary heart disease within the Whitehall II study. *J Epidemiol Community Health.* 2003;57(2):147–153. https://doi.org/10.1136/jech.57.2.147.
55. Richard A, Martin B, Wanner M, Eichholzer M, Rohrmann S. Effects of leisure-time and occupational physical activity on total mortality risk in Nhanes III according to sex, ethnicity, central obesity, and age. *J Phys Act Health.* 2015;12(2):184–192. https://doi.org/10.1123/jpah.2013-0198.
56. Holtermann A, Krause N, van der Beek AJ, Straker L. The physical activity paradox: six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does. *Br J Sports Med.* 2018;52(3):149–150. https://doi.org/10.1136/bjsports-2017-097965.
57. Holtermann A, Marott JL, Gyntelberg F, et al. Does the benefit on survival from leisure time physical activity depend on physical activity at work? A prospective cohort study. *PLoS One.* 2013;8(1):e54548. https://doi.org/10.1371/journal.pone.0054548.
58. Holtermann A, Mortensen OS, Burr H, Søgaard K, Gyntelberg F, Suadicani P. The interplay between physical activity at work and during leisure time - risk of ischemic heart disease and all-cause mortality in middle-aged Caucasian men. *Scand J Work Environ Health.* 2009;35(6):466–474. https://doi.org/10.5271/sjweh.1357.
59. Kuwahara K, Honda T, Nakagawa T, et al. Leisure-time exercise, physical activity during work and commuting, and risk of metabolic syndrome. *Endocrine.* 2016;53(3):710–721. https://doi.org/10.1007/s12020-016-0911-z.
60. Clays E, De Bacquer D, Janssens H, et al. The association between leisure time physical activity and coronary heart disease among men with different physical work demands: a prospective cohort study. *Eur J Epidemiol.* 2013;28(3):241–247. https://doi.org/10.1007/s10654-013-9764-4.
61. Hallman DM, Birk Jørgensen M, Holtermann A. On the health paradox of occupational and leisure-time physical activity using objective measurements: effects on autonomic imbalance. *PLoS One.* 2017;12(5):e0177042. https://doi.org/10.1371/journal.pone.0177042.
62. Swain DP. Moderate or vigorous intensity exercise: which is better for improving aerobic fitness? *Prev Cardiol.* 2005;8(1):55–58. https://doi.org/10.1111/j.1520-037X.2005.02791.x.
63. Swain DP, Franklin BA. VO(2) reserve and the minimal intensity for improving cardiorespiratory fitness. *Med Sci Sports Exerc.* 2002;34(1):152–157. https://doi.org/10.1097/00005768-200201000-00023.
64. Climie RE, Boutouyrie P, Perier MC, et al. Association between occupational, sport, and leisure related physical activity and baroreflex sensitivity: the Paris prospective Study III. *Hypertension.* 2019;74(6):1476–1483. https://DOI.ORG/10.1161/HYPERTENSIONAHA.119.13461.
65. Hargreaves M, Spriet LL. Skeletal muscle energy metabolism during exercise. *Nat Metab.* 2020;2(9):817–828. https://doi.org/10.1038/s42255-020-0251-4.
66. Hellsten Y, Nyberg M. Cardiovascular adaptations to exercise training. *Compr Physiol.* 2015;6(1):1–32. https://doi.org/10.1002/cphy.c140080.
67. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol (1985).* 2000;89(1):81–88. https://doi.org/10.1152/jappl.2000.89.1.81.
68. Li J, Siegrist J. The role of compensation in explaining harmful effects of overtime work on self-reported heart disease: preliminary evidence from a Germany prospective cohort study. *Am J Ind Med.* 2018;61(10):861–868. https://doi.org/10.1002/ajim.22895.
69. Pampel FC, Krueger PM, Denney JT. Socioeconomic disparities in health behaviors. *Annu Rev Sociol.* 2010;36(1):349–370. https://doi.org/10.1146/annurev.soc.012809.102529.
70. Grintsova O, Maier W, Mielck A. Inequalities in health care among patients with type 2 diabetes by individual socio-economic status (SES) and regional deprivation: a systematic literature review. *Int J Equity Health.* 2014;13(1):43. https://doi.org/10.1186/1475-9276-13-43.
71. Stringhini S, Dugravot A, Shipley M, et al. Health behaviours, socioeconomic status, and mortality: further analyses of the British Whitehall II and the French GAZEL prospective cohorts. *PLoS Med.* 2011;8(2):e1000419. https://doi.org/10.1371/journal.pmed.1000419.
72. Mengesha MM, Roba HS, Ayele BH, Beyene AS. Level of physical activity among urban adults and the socio-demographic correlates: a population-based cross-sectional study using the global physical activity questionnaire. *BMC Public Health.* 2019;19(1):1160. https://doi.org/10.1186/s12889-019-7465-y.
73. Ellis G, Hunter RF, Hino AAF, et al. Study protocol: healthy urban living and ageing in place (HULAP): an international, mixed methods study examining the associations between physical activity, built and social environments for older adults the UK and Brazil. *BMC Public Health.* 2018;18(1):1135. https://doi.org/10.1186/s12889-018-6018-0.
74. Hoos T, Espinoza N, Marshall S, Arredondo EM. Validity of the Global Physical Activity Questionnaire (GPAQ) in adult latinas. *J Phys Act Health.* 2012;9(5):698–705. https://doi.org/10.1123/jpah.9.5.698.