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ORIGINAL RESEARCH

Occupational Exposures and Cardiac Structure and Function: ECHO-SOL (Echocardiographic Study of Latinos)

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BACKGROUND: Our objective was to determine associations of occupational exposures with cardiac structure and function in Hispanic/Latino adults.

METHODS AND RESULTS: Employed participants were included (n=782; 52% women, mean age 52.9 years). Occupational exposures to burning wood, vehicle exhaust, solvents, pesticides, and metals at the current and longest-held job were assessed by questionnaire. Survey multivariable linear regression analyses were used to model the relationship of each self-reported exposure with echocardiographic measures of cardiac structure and function. Exposure to burning wood at the current job was associated with decreased left ventricular (LV) ejection fraction (–3.1%; standard error [SE], 1.0 [*P*=0.002]). When the analysis was restricted to exposure at the longest-held job, occupational exposure to burning wood was associated with increased LV diastolic volume (6.7 mL; SE, 1.6 [*P*<0.0001]), decreased LV ejection fraction (–2.7%; SE, 0.6 [*P*<0.0001]), worse LV global longitudinal strain (1.0%; SE, 0.3 [*P*=0.0009]), and decreased right ventricular fractional area change (–0.02; SE, 0.004 [*P*<0.001]). Exposure to pesticides was associated with worse average global longitudinal strain (0.8%; SE, 0.2 [*P*<0.0001]). Exposure to metals was associated with worse global longitudinal strain in the 2-chamber view (1.0%; SE, 0.5 [*P*=0.04]), increased stroke volume (3.6 mL; SE, 1.6 [*P*=0.03]), and increased LV mass indexed to BSA (9.2 g/m^2; SE, 3.8 [*P*=0.01]) or height (4.4 g/m$^{2.7}$; SE, 1.9 [*P*=0.02]).

CONCLUSIONS: Occupational exposures to burning wood, vehicle exhaust, pesticides, and metals were associated with abnormal parameters of LV and right ventricular systolic function. Reducing exposures to toxic chemicals and particulates in the workplace is a potential opportunity to prevent cardiovascular disease in populations at risk.

Key Words: air pollution ■ echocardiography ■ environmental medicine ■ occupational medicine

Exposure to environmental toxicants, such as ambient air pollution, wood smoke, and heavy metals, has been recognized as a risk factor for cardiovascular disease (CVD).[1–3] Effects of particulate matter on CVD and mortality have been studied in China, Iran, United States, Canada, Brazil, United Kingdom, Italy, Australia/New Zealand, Japan, South Korea, and Hong Kong.[4–6] Particulate matter and gases are components of air pollution that have been associated with stroke, myocardial infarction, heart failure (HF), atrial fibrillation, and sudden cardiac death in multiple populations.[5,7] Cohort studies demonstrated an ≈10% increase in all-cause mortality and similar average but broader range cardiovascular mortality risk per 10-μg/m^3 elevation in particulate matter exposure. A decrease of particulate matter by 10 μg/m^3 reduced annual admissions of ischemic heart disease and HF in 204 counties by 1523 and 3156 cases per year, respectively, based on

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CLINICAL PERSPECTIVE

What Is New?

- Occupational exposure to wood smoke, vehicle exhaust, pesticides, and metals were associated with abnormal echocardiographic measures of cardiac function and structure in a population of US Hispanics.
- Exposure to wood and automobile combustion smoke was associated with many abnormal parameters of cardiac structure and function irrespective of tobacco smoking status.

What Are the Clinical Implications?

- Measures to reduce occupational and environmental exposures are potential important public health interventions that may decrease the risk of clinical and preclinical heart failure.

Nonstandard Abbreviations and Acronyms

CVD	cardiovascular disease
ECHO-SOL	Echocardiographic Study of Latinos
GBD	Global Burden of Disease Study
GLS	global longitudinal strain
HCHS/SOL	Hispanic Community Health Study/Study of Latinos
HF	heart failure
LV	left ventricular
MESA Air	Multi-Ethnic Study of Atherosclerosis and Air Pollution
RV	right ventricular
SE	standard error

US Medicare data.[8] Ambient air pollution, largely the result of fossil fuel combustion, as well as biomass fuel smoke exposure from the burning of wood, dung, and organic debris, have been studied individually in relation to CVD outcomes.[4,6,9] Additionally, exposure to heavy metals and metalloids, including lead, cadmium, arsenic, and mercury, have been associated with an increased risk of ischemic heart disease, peripheral heart disease, and HF.[10]

Many studies of environmental exposures and CVD focus on ambient exposures. For example, large epidemiological studies of air pollution exposure such as MESA Air (Multi-Ethnic Study of Atherosclerosis and Air Pollution) characterize the exposure of ambient air pollution at the location of the primary residence.[11] However, many individuals are exposed to toxicants in the workplace. Consequently, the global disability-adjusted life-years caused by occupational risk factors is significant.[12] Despite federal and state regulations that protect workers from hazardous occupational exposures, the potential cardiovascular risk associated with several common exposures has not been well characterized. Evaluating this risk is imperative particularly because upstream occupational risk factors for CVD may disproportionately affect low-income individuals.[13] Further, the intermediary cardiovascular pathway associated with occupational exposures such as pesticides is unclear despite the large proportion of exposed populations. As an example, 4.7% of 7404 US Hispanic/Latino workers enrolled in HCSL/SOL (Hispanic Community Health Study/Study of Latinos reported exposure to pesticides at their current job.[14,15] Thus, the objective of this study was to assess the relationship between occupational exposure to hazardous substances and cardiac structure and function in Hispanic/Latino participants in ECHO-SOL (Echocardiographic Study of Latinos).

METHODS

Data Sharing

The data, analytic methods, and study materials can be been made available to other researchers who apply to the HCHS/SOL Publications Committee for purposes of reproducing the results or replicating the procedure. Additional information about request of the data set may be found at the HCHS/SOL website (https://sites.cscc.unc.edu/hchs/).

Study Setting

HCHS/SOL is a population-based cohort study (N= 16 415, mean age 43 years) of self-identified Hispanic/Latino men and women aged 18 to 74 years,[16,17] living in 4 cities in the United States: Bronx, NY; Chicago, IL; Miami, FL; and San Diego, CA. Participants were recruited in communities surrounding 4 field centers in the respective cities. Details of the HCHS/SOL sampling method have been previously described.[16] Exclusion criteria included active-duty military service, not living at the residential address, planning to move from the area within 6 months, or physically unable to attend the clinic examination. The baseline HCHS/SOL assessment (2008–2011) included questionnaires, ECG, anthropometric measurements, and laboratory testing among other procedures.

ECHO-SOL is an ancillary study of HCHS/SOL, which included 1818 participants recruited through a stratified-sampling process representative of the parent study of Hispanic/Latino individuals across all 4 HCHS/SOL sites.[18] ECHO-SOL assessed cardiac structure and function using transthoracic echocardiography

performed from 2011 to 2014.[18] Inclusion criteria for ECHO-SOL included age ≥45 years; self-reported Hispanic/Latino of Mexican, Puerto Rican, Cuban, Dominican, Central American, or South American background; and enrollment ≤36 months from the date of the baseline HCHS/SOL visit. ECHO-SOL enrolled on average of 80% of eligible participants at each of the study sites.

The institutional review boards of all participating institutions approved the study and participants provided written informed consent.

For this cross-sectional analysis, we included participants who were employed at the time of the baseline HCHS/SOL questionnaire. All employed participants provided information about occupational exposure.

Study Procedures

Phillips iE33 or Sonos 5500/7500 ultrasound imaging platforms with a standard 2.5- to 3.5-MHz phased-array probe were used in the echocardiography examination. A comprehensive transthoracic echocardiography examination was performed including ECG-gated M-mode, 2-dimensional, spectral, color-flow, spectral, and tissue Doppler acquired in the parasternal long-axis and short-axis, as well as the apical 4-chamber and 2-chamber long-axis views. Left ventricular (LV) global longitudinal strain (GLS) analysis was performed using the vendor-independent Cardiac Performance Analysis software (TOMTEC) on acquired 2-dimensional images. All images were read by a registered diagnostic cardiac sonographer and over-read by a cardiologist (C.J.R.) with level 3 advanced echocardiography training. Inter-reader and intrareader variability were assessed and determined to have a high degree of interclass correlation for each measurement (0.80–0.99).[19]

Exposure Definitions

Based on questionnaires available in both English and Spanish, participants were asked about occupational exposures at both their current and longest-held jobs. Although we present only the wording for current jobs below, the question wording for both current and longest-held jobs were identical. These exposures were categorized as follows:

1. *Exposure to organic solvents*—In response to the question, "At the job you currently work the majority of your work hours per week, how often are you exposed to any type of organic solvents, for example styrene, trichloroethylene, toluene, or xylene?" Participants were allowed to choose one of the following: (1) none of the time; (2) 25% of the time; (3) 50% of the time; (4) 75% of the time; (5) 100% of the time; (6) occasionally; or (7) don't know. Participants who reported any degree of exposure were characterized as "exposed" and those who responded "none of the time" or "don't know" were characterized as "unexposed."
2. *Exposure to metals*—In response to the question, "At the job you currently work the majority of your work hours per week, how often are you exposed to metals such as manganese, lead, or mercury?" Participants were allowed to choose one of the following: (1) none of the time; (2) 25% of the time; (3) 50% of the time; (4) 75% of the time; (5) 100% of the time; (6) occasionally; or (7) don't know. Participants who reported any degree of exposure were characterized as "exposed" and those who responded "none of the time" or "don't know" were characterized as "unexposed."
3. *Exposure to burning wood, vehicle exhaust, and pesticides*—Participants were asked to respond "yes" or "no" to exposure to the following substances at their current and longest-held jobs: smoke from burning wood, vehicle exhaust, or pesticides.

Outcome Definitions

The echocardiographic measurements in this study included multiple measures of left and right heart structure and function.

1. LV mass was determined by subtracting the LV endocardial cavity volume from the volume encompassed by the LV epicardium and multiplying the resultant myocardial volume by the myocardial density. LV mass was indexed to body surface area.
2. LV systolic function and volumes. LV ejection fraction was derived from volumetric assessments using the method of discs from apical 4- and 2-chamber long-axis views to measure end-diastolic volume (EDV) and end-systolic volume (ESV). LV ejection fraction was calculated: (EDV–ESV)/EDV. We also utilized LV stroke volume to define systolic function.
3. LV diastolic function. Our algorithm for diastolic dysfunction utilized the following echocardiographic components: medial and lateral tissue Doppler E′ velocities, mitral inflow E/A ratio, E/E′ ratio, isovolumic relaxation time, and left atrial volume index.
4. Right ventricular (RV) systolic function measures included peak RV/right atrial pressure gradient, tricuspid annular plane systolic excursion, and RV fractional area change.
5. LV global longitudinal strain (GLS); LVGLS (4-chamber view, 2-chamber view, and average GLS).

Sociodemographic Characteristics

ECHO-SOL participant sociodemographic and lifestyle characteristics were obtained by questionnaires

conducted during the HCHS/SOL baseline visit. Hispanic/Latino background was determined by self-report and classified as Mexican, Puerto Rican, Cuban, Dominican, Central American, or South American. Alcohol use and tobacco use were determined by self-report and categorized as current, former, or never user. Education was described by 3 categories: less than high school, high school or equivalent, or greater than high school. Household income was categorized into 4 groups: <$20 000, $20 001 to $40 000, $40 001 to $75 000, or >$75 000. US-born was defined as born in the 50 United States, excluding US territories. Physical activity was determined using the Global Physical Activity Questionnaire (GPAQ) and was classified as low, moderate, or high.[20]

Statistical Analysis

The primary aim of this study was to compare echocardiographic measures of cardiac structure and function in participants with and without any self-reported occupational environmental exposures. The baseline characteristics of participants with and without self-reported occupational environmental exposures were compared. The corresponding distribution of all baseline sociodemographic and clinical characteristics was summarized for the overall population using mean±SE for continuous variables and proportions for categorical variables. Summary statistics were weighted to adjust for sampling probability and nonresponse. All analyses used complex survey methods that take into account the sampling weights and sampling strata of ECHO-SOL.[21,22]

Linear regression analyses were conducted comparing echocardiographic measures of cardiac structure and function in individuals who reported any current occupational exposure to burning wood, vehicle exhaust, pesticides, solvents, and metals with individuals who did not report exposure. Regression coefficients are reported amounting to the average increase/decrease in the respective cardiac parameter with the particular exposure. Additional linear regression analyses were conducted to compare participants who reported occupational/environmental exposures at the longest-held job with individuals who did not report occupational environmental exposures at the longest-held job. Multivariable models were sequentially adjusted for the following potential confounding variables: model 1—age and sex; and model 2—age, sex, study site, tobacco use, alcohol use, physical activity, and years of education. We performed a stratified analysis to assess the effect of wood smoke and auto exhaust on cardiac parameters across categories of tobacco smoke exposure. Last, we performed sensitivity analysis substituting number of pack-years of tobacco (a strong continuous measure of cumulative exposure to tobacco smoke) as a covariate in our multivariable models instead of categorized smoking status in multivariable models. SAS 9.3 (SAS Institute Inc.) survey procedures were utilized for all weighted analyses.

RESULTS

A total of 782 employed participants were included in this analysis, of which 504 participants reported their current job as their longest-held job (Figure). The mean age was 52.9 years (SE, 0.3) and 52% were women. Of the 782 individuals included in this sample, 168 (21%) reported an occupational/environmental exposure to ≥1 toxic substance at their current job. A total of 36 (4.6%) and 27 (3.4%) individuals reported that they did not know about exposure to organic solvents and metals, respectively, and they were excluded in all analyses. More participants reported exposure to vehicle exhaust compared with any other occupational exposure (Figure). Individuals who reported occupational exposures were more likely to be men. Additionally, high levels of physical activity, increased alcohol use, and lower educational attainment were reported by individuals with occupational exposures compared with those who reported they were not exposed (Table 1).

Overall, 778 individuals provided information regarding length of time at their longest-held job, with a mean of 17.2 years (SE, 0.3); 502 individuals reported their current job as their longest-held job, with a mean of 18.3 years (SE, 0.6). A total of 276 participants reported that their longest-held job was not their current job and they spent a mean of 16.7 years (SE, 0.5) at their longest-held job, which was 1.7 years (SE, 0.8) less compared with participants who reported that their current job was their longest job (P=0.03).

Among occupational exposures at their current job, patient exposure to burning wood was associated with decreased LV systolic function. Individuals who reported occupational exposure to burning wood had a 3.1% decrease in LV ejection fraction (SE, 1.0) compared with individuals who did not report exposure to burning wood, after adjusting for potentially confounding variables. Occupational exposure to vehicle exhaust was associated with a statistically significant increase in isovolumic relaxation time (0.01; SE, 0.003) compared with individuals who did not report any exposure to vehicle exhaust (Table S1). Exposure to solvents was associated with increase in RV fractional area change (0.02; SE, 0.005) but exposures to pesticides and metals at current job were not associated with differences in measures of cardiac structure and function (Table S2).

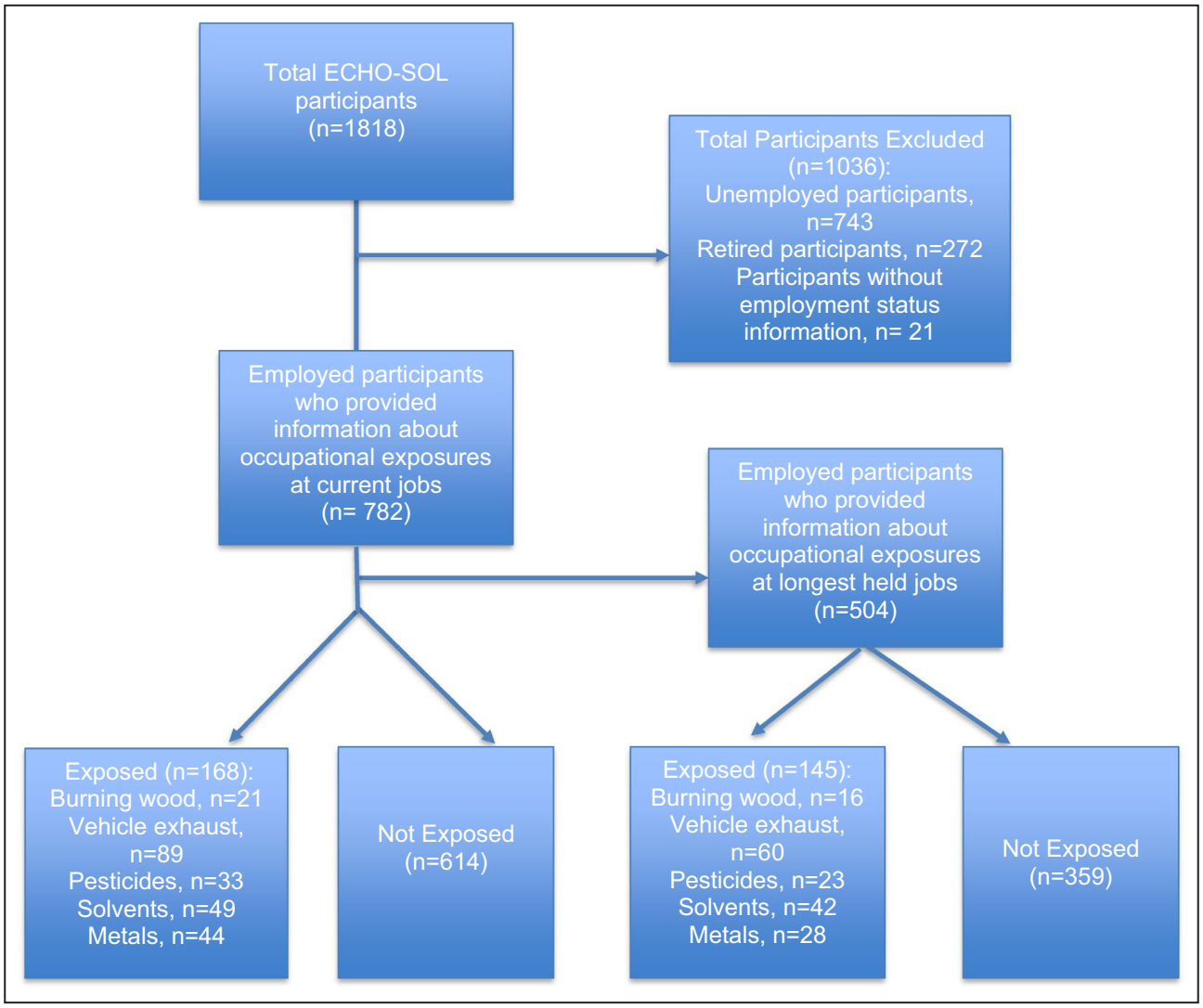

Figure. Occupational exposure of participants in ECHO-SOL (Echocardiographic Study of Latinos).
All employed participants provided information about occupational exposures. Occupational exposure at the longest-held job applies to participants whose current job was also the longest-held job.

Occupational exposures at the longest-held job were more strongly associated with differences in echocardiographic measures of cardiac structure and function. Of note, exposure to burning wood was associated with differences in multiple parameters of cardiac structure and function. After full adjustment for potential confounders, exposure to burning wood at the longest-held job was associated with increased LV end-diastolic volume (6.7 mL; SE, 1.6), increased LV end-systolic volume (4.6 mL; SE, 0.9), decreased LV ejection fraction (–2.7%; SE, 0.6), and worse LVGLS (1.0%; SE, 0.3). Exposure to burning wood was associated with increased medial and lateral E′ velocities (0.7 cm/s [SE, 0.2] and 0.7 cm/s [SE, 0.3], respectively), which is a marker of increased diastolic function. In terms of the right heart, exposure to burning wood was associated with an increase (3.7 mm Hg; SE, 0.3) in peak right atrial/RV gradient and a decrease (–0.02; SE, 0.004) in RV fractional area change (Table 2).

Differences in measures of cardiac structure and function were also noted in association with occupational exposure to other toxic substances in the longest-held job. Individuals with occupational exposure to vehicle exhaust at the longest-held job was associated with a decrease (–0.1 cm; SE, 0.04) in tricuspid annular plane systolic excursion compared with individuals who did not report any exposure to vehicle exhaust. LVGLS was worse in the apical 2-chamber view only (0.5%; SE, 0.2). Exposure to pesticides at the longest-held job was associated with worse LVGLS (0.8%; SE, 0.2) and smaller left atrial volume index (–2.5 mL; SE, 0.8). Additionally, increased medial and lateral E′ velocities (0.6 cm/s [SE, 0.1] and 0.9 cm/s [SE, 0.4], respectively)

Table 1. Characteristics of Individuals With and Without Occupational Exposures to Heavy Metals, Solvents, Pesticides, Burning Wood, and Vehicle Exhaust in ECHO-SOL

	Any Occupational Exposure (n=168)	No Occupational Exposure (n=614)
Age, mean (SE)	51.6 (0.5)	53.3 (0.3)
Women, %	21.8	60.2
National background, %		
Dominican	24.8	20.9
Puerto Rican	12.7	10.4
Mexican	25.9	25.9
Cuban	28.2	28.2
Central American	7.2	7.7
South American	4.6	6.9
Low physical activity, %	29.3	44.5
Body mass index, mean (SE)	29.2 (0.4)	29.8 (0.3)
Current tobacco use, %	19.8	12.1
Current alcohol use, %	62.0	50.1
Less than high school education	35.6	22.0
Household income <$20 000 per y	39.2	37.9
US mainland nativity, %	11.4	8.4

Values presented are unweighted counts of total participants in HCHS/SOL (Hispanic Community Health Study/Study of Latinos) with respective characteristic. Percentages are weighted row percentages. ECHO-SOL indicates Echocardiographic Study of Latinos; and SE, standard error.

were observed for individuals reporting occupational exposure to pesticides compared with individuals who did not report pesticide exposure (Table 3).

Exposure to metals was associated with worse longitudinal strain in the 2-chamber view only (1.0%; SE, 0.5) and increased stroke volume (3.6 mL; SE, 1.6), lateral E′ velocity (1.2 cm/s; SE, 0.4), LV mass indexed to body surface area (9.2 g/m^2; SE, 3.8) or indexed to height (4.4 g/m$^{2.7}$; SE, 1.9), and isovolumic relaxation time (7 ms; SE, 2) (Table 3). Exposure to solvents had a different pattern of association with measures of cardiac structure and function including increased LV ejection fraction (0.7%; SE, 0.3), more favorable LVGLS (–0.6%; SE, 0.1), increased tricuspid annular plane systolic excursion (0.1 cm; SE, 0.02), and increased RV fractional area change (0.02; SE, 0.005). Additionally, occupational solvent exposure was also associated with increased LV end-diastolic volume (5.4 mL; SE, 2.6), E/E′ ratio (0.6; SE, 0.1), and peak right atrial/RV gradient (0.8 mm Hg; SE, 0.4).

Use of pack-years smoking as a covariate in our models instead of categorized smoking status did not significantly change our main results (Table S3).

In stratified analysis, participants exposed to burning wood who never smoked had better 4-chamber LVGLS (–0.8; SE, 0.2), 2-chamber LVGLS (–1.8; SE, 0.4), and average LVGLS (–1.2; SE, 0.2) compared with former and current smokers. Additionally, only current smokers exposed to burning wood had an increase in E/A ratio (0.1; SE, 0.02). Only current smokers had worse 4-chamber LVGLS (0.7; SE, 0.3), 2-chamber LVGLS (1.2; SE, 0.3), and average LVGLS (0.9; SE, 0.3) in terms of exposure to vehicle exhaust (Table S4).

DISCUSSION

In a representative sample of US Hispanics/Latinos, occupational exposure to burning wood, vehicle exhaust, pesticides, solvents, and metals were associated with differences in cardiac structure and function, particularly when the exposure occurred at the longest-held job. Occupational exposure to burning wood was associated with decreased LV systolic function and RV systolic function. Occupational exposure to vehicle exhaust was associated with decreased RV function and decreased LV strain. Decreased LV strain was observed in association with pesticide exposure. Occupational solvent and metal exposure were also associated with differences in LV and RV structure and function.

These results are supported by data from prior studies of HCHS/SOL in which pesticide exposure was associated with increased prevalence of coronary heart disease and atrial fibrillation.[15] Our current study extends this previous study in examining a broader set of occupational exposures in relation to cardiac structure and function. Among the occupational exposures examined in this study, exposure to burning wood was associated with abnormal trends in multiple measures of LV and RV systolic function. These results are similar to data from our prior work in which we examined cardiac structure and function in biomass fuel users and nonusers in a rural, high-altitude region of Peru, in that GLS was worse and E′ velocities were increased in biomass fuel users.[23] The decrease in LV strain suggests that the exposure to biomass fuel smoke likely alters LV function through a direct myopathic process. One significant difference in the results of the current study and the Peruvian study is that RV systolic function was lower in individuals exposed to burning wood in this study but not in the Peruvian study. Differences in the composition of biomass fuels in Peru compared with the United States and the effect of chronic high-altitude exposure potentially explain the discrepancy in the findings with regard to the right ventricle. However, the changes observed in the left ventricle are similar in both studies.

In a study that looked at the effect of smoking on cardiac structure and function in ECHO-SOL

Table 2. Association of Occupational Exposure to Burning Wood and Vehicle Exhaust at Longest-Held Job With Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL

	Burning Wood				Vehicle Exhaust			
	Adjusted Model 1	*P* Value	Adjusted Model 2	*P* Value	Adjusted Model 1	*P* Value	Adjusted Model 2	*P* Value
LV structure								
LV mass index, g/m^2	7.2 (4.1)	0.08	7.1 (4.6)	0.12	0.5 (2.0)	0.80	1.3 (2.0)	0.54
LV mass index, g/m$^{2.7}$	4.3 (1.8)	0.02	3.9 (2.2)	0.08	−0.2 (0.9)	0.86	0.6 (1.0)	0.56
LV end-diastolic volume, mL	6.6 (1.4)	<0.0001	6.7 (1.6)	<0.0001	2.2 (1.6)	0.16	2.8 (1.6)	0.07
LV end-systolic volume, mL	4.3 (0.9)	<0.0001	4.6 (0.9)	<0.0001	0.8 (0.7)	0.27	1.2 (0.7)	0.08
LV systolic function								
LV ejection fraction, %	−2.5 (0.6)	<0.0001	−2.7 (0.6)	<0.0001	−0.4 (0.5)	0.43	−0.5 (0.4)	0.24
LV stroke volume, mL	1.4 (0.8)	0.07	1.8 (0.9)	0.04	1.4 (1.3)	0.26	1.9 (1.2)	0.11
LV longitudinal strain (4-chamber), %	1.2 (0.3)	0.0003	1.1 (0.3)	0.0003	−0.05 (0.2)	0.84	−0.09 (0.2)	0.71
LV longitudinal strain (2-chamber), %	1.0 (0.3)	0.0002	0.6 (0.3)	0.04	0.5 (0.2)	0.03	0.5 (0.2)	0.03
LV longitudinal strain (average), %	1.2 (0.3)	<0.0001	1.0 (0.3)	0.0009	0.3 (0.2)	0.19	0.3 (0.2)	0.20
LV diastolic function								
Medial E′ velocity, cm/s	0.7 (0.2)	0.0001	0.7 (0.2)	0.0001	−0.2 (0.2)	0.27	−0.04 (0.2)	0.82
Lateral E′ velocity, cm/s	0.8 (0.4)	0.02	0.7 (0.3)	0.04	0.04 (0.3)	0.87	0.1 (0.3)	0.59
E/E′ ratio	−0.03 (0.1)	0.78	0.07 (0.2)	0.66	0.3 (0.1)	0.01	0.3 (0.2)	0.11
E/A ratio	0.0008 (0.03)	0.98	−0.0004 (0.3)	0.99	0.02 (0.03)	0.50	0.02 (0.03)	0.38
Isovolumic relaxation time, s	0.008 (0.001)	<0.0001	0.008 (0.001)	<0.0001	0.003 (0.002)	0.06	0.0004 (0.002)	0.79
LA volume index, mL/m^2	0.8 (0.3)	0.008	0.8 (0.4)	0.05	0.1 (0.6)	0.82	−0.1 (0.6)	0.84
RV function								
Peak RA/RV gradient, mm Hg	3.7 (0.3)	<0.0001	3.7 (0.3)	<0.0001	−1.6 (0.7)	0.03	−1.3 (0.7)	0.05
TAPSE, cm	−0.02 (0.03)	0.58	−0.03 (0.03)	0.34	−0.1 (0.04)	0.004	−0.1 (0.04)	0.001
RV fractional area change	−0.02 (0.004)	0.0003	−0.02 (0.004)	<0.0001	0.006 (0.06)	0.35	0.004 (0.007)	0.59

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed patients. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure. Model 1: age and sex; and model 2: age, sex, study site, tobacco use, alcohol use, physical activity, and years of education. ECHO-SOL indicates Echocardiographic Study of Latinos; LA, left atrial; LV, left ventricular; RA, right atrial; RV, right ventricular; and TAPSE, tricuspid annular plane systolic excursion.

Table 3. Association of Occupational Exposure to Solvents, Pesticides, and Metals at Longest-Held Job With Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL

	Solvents				Pesticides				Metals			
	Adjusted Model 1	*P* Value	Adjusted Model 2	*P* Value	Adjusted Model 1	*P* Value	Adjusted Model 2	*P* value	Adjusted Model 1	*P* Value	Adjusted Model 2	*P* Value
LV structure												
LV mass index, g/m^2	−2.2 (1.0)	0.03	−1.4 (1.0)	0.14	4.6 (2.3)	0.047	3.0 (2.5)	0.23	8.5 (3.3)	0.09	9.2 (3.8)	0.01
LV mass index, g/m$^{2.7}$	−0.6 (0.9)	0.51	−0.1 (0.6)	0.89	3.1 (1.2)	0.009	1.9 (1.2)	0.11	4.7 (1.6)	0.003	4.4 (1.9)	0.02
LV end-diastolic volume, mL	5.7 (3.7)	0.12	5.4 (2.6)	0.04	−2.9 (1.7)	0.09	−3.3 (1.8)	0.07	2.6 (1.9)	0.16	2.6 (2.9)	0.38
LV end-systolic volume, mL	1.4 (1.5)	0.33	1.4 (1.0)	0.17	−1.2 (0.6)	0.0498	−0.8 (0.6)	0.22	0.1 (0.9)	0.89	−0.1 (1.3)	0.92
LV systolic function												
LV ejection fraction, %	0.7 (0.3)	0.01	0.7 (0.3)	0.008	0.1 (0.4)	0.80	−0.08 (0.5)	0.87	0.04 (0.7)	0.95	0.4 (0.6)	0.54
LV stroke volume, mL	0.3 (1.6)	0.84	0.2 (1.3)	0.88	4.8 (2.0)	0.02	4.3 (2.4)	0.08	2.9 (1.4)	0.04	3.6 (1.6)	0.03
LV longitudinal strain (4-chamber), %	−0.4 (0.2)	0.07	−0.4 (0.2)	0.047	0.9 (0.2)	0.0001	0.8 (0.3)	0.001	−0.1 (0.3)	0.72	−0.4 (0.4)	0.28
LV longitudinal strain (2-chamber), %	−0.9 (0.2)	0.0002	−0.9 (0.2)	<0.0001	1.1 (0.2)	<0.0001	0.7 (0.2)	0.009	1.5 (0.4)	0.0002	1.0 (0.5)	0.04
LV longitudinal strain (average), %	−0.6 (0.2)	0.0001	−0.6 (0.1)	<0.0001	1.0 (0.2)	<0.0001	0.8 (0.2)	<0.0001	0.8 (0.3)	0.02	0.4 (0.4)	0.28
LV diastolic function												
Medial E′ velocity, cm/s	0.3 (0.1)	0.003	0.4 (0.09)	<0.0001	0.7 (0.1)	<0.0001	0.6 (0.1)	<0.0001	−0.04 (0.2)	0.87	0.1 (0.3)	0.68
Lateral E′ velocity, cm/s	−0.2 (0.2)	0.40	−0.08 (0.19)	0.66	1.2 (0.3)	<0.0001	0.9 (0.3)	0.0009	0.9 (0.4)	0.02	1.2 (0.4)	0.006
E/E′ ratio	0.7 (0.1)	<0.0001	0.6 (0.1)	<0.0001	0.05 (0.1)	0.70	0.2 (0.2)	0.38	0.2 (0.3)	0.54	0.1 (0.3)	0.73
E/A ratio	−0.008 (0.02)	0.69	−0.009 (0.02)	0.66	0.03 (0.03)	0.31	0.03 (0.03)	0.40	−0.3 (0.06)	0.65	−0.0004 (0.06)	0.99
Isovolumic relaxation time, s	−0.001 (0.001)	0.26	−0.002 (0.001)	0.054	−0.001 (0.001)	0.30	−0.001 (0.001)	0.28	0.01 (0.002)	<0.0001	0.007 (0.002)	0.0003
LA volume index, mL/m^2	0.6 (0.7)	0.40	0.2 (0.6)	0.75	−2.3 (0.6)	0.0003	−2.5 (0.8)	0.0009	1.1 (0.7)	0.14	1.4 (0.9)	0.13
RV function												
Peak RA/RV gradient, mm Hg	0.6 (0.4)	0.16	0.8 (0.4)	0.03	1.6 (0.7)	0.02	1.1 (0.6)	0.09	0.2 (0.7)	0.78	0.4 (0.8)	0.56
TAPSE, cm	0.1 (0.03)	<0.0001	0.1 (0.02)	<0.0001	−0.04 (0.04)	0.27	−0.06 (0.04)	0.13	−0.02 (0.05)	0.63	−0.06 (0.06)	0.35
RV fractional area change	0.02 (0.005)	<0.0001	0.02 (0.005)	0.0002	0.02 (0.007)	0.025	−0.002 (0.008)	0.75	0.004	0.51	0.002 (0.009)	0.80

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed patients. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure. Model 1: age and sex; and model 2: age, sex, study site, tobacco use, alcohol use, physical activity, and years of education. ECHO-SOL indicates Echocardiographic Study of Latinos; LA, left atrial; LV, left ventricular; RA, right atrial; RV, right ventricular; and TAPSE, tricuspid annular plane systolic excursion.

participants, 25.7% were former smokers and 17.7% were current smokers, with a median of 16 pack-years of smoking history. Smoking duration and intensity were associated in a dose-dependent manner with multiple adverse parameters of RV and LV function and structure.[24] In our current study, most of the effect of occupational exposures in the combustion category, burning wood and automobile exhaust, on measures of cardiac function and structure did not change in sensitivity analyses adjusted for pack-years of smoking or smoking exposure categories, which supports independent adverse effects of these occupational exposures on cardiac structure and function. However, tobacco smoke may have a moderating effect on the association of environmental exposures with cardiac parameters given our stratified analysis results where the effect of burning wood and vehicle exhaust on GLS was worse among smokers compared with those who never smoked.

Exposure to burning wood occurs in a number of diverse occupations; however, the cardiovascular health of firefighters is the most often studied.[25,26] Cardiovascular events are more frequent in firefighters who are at risk for CVD while on duty; however, there are limited data to support that exposure to mixtures of particulate matter and gases from burning debris are actually the cause.[26,27] A controlled experiment of endothelial function and thrombosis in firefighters after acute exposure to burning wood smoke did not find increased endothelial dysfunction or increased ex vivo thrombus formation after smoke exposure.[28] However, to our knowledge, no prior study has examined the relationship between chronic occupational exposure to burning wood and cardiac function. Although the data on occupational exposure to burning wood are limited, household exposure to biomass fuels smoke, which included wood, dung, and organic debris, has been robustly associated with increased cardiovascular mortality in several large international studies.[4,6] On a cellular level, exposure to smoke from burning wood is associated with autonomic dysfunction, decreased endothelial function, and a proinflammatory, prothrombotic state.[2,7,29–31] However, additional longitudinal studies are needed to better understand the progression from subclinical cardiac dysfunction and incident clinical HF as a result of occupational exposures to burning wood.

Prior literature on the association between exposure to pesticides and CVD has focused on ischemic heart disease outcomes. Specifically, a large prospective study of agricultural workers in North Carolina and Iowa found no relationship between pesticide exposure and incident myocardial infarction or myocardial mortality, yet a retrospective study of survivors of organophosphorous pesticide poisoning in Taiwan reported an increased risk of coronary heart disease and cardiac arrhythmia.[32,33] Another study of female pesticide applicators and the female spouses of pesticide applicators found that a number of pesticides, including chlorpyrifos, coumaphos, carbofuran, metalaxyl, pendimethalin, and trifluralin, were associated with increased odds of nonfatal myocardial infarction.[34] However, these data were limited by a case-control study design and the few number of myocardial infarction cases linked with exposure to these pesticides. Organochlorine pesticide exposure has been associated with increased peripheral arterial disease and cardiovascular mortality.[35–37] Pesticides potentially increase risk for coronary heart disease and other CVDs through elevated blood pressure, alteration in serum lipid profile, and increased obesity and insulin resistance.[38–42] DNA methylation, epigenetic modification, and increased oxidative stress are among several possible mechanisms by which pesticide exposure impairs cardiovascular health.[42–44] To our knowledge, there are no published studies of the association of pesticide use with HF or asymptomatic cardiac dysfunction.

(GBD) Global Burden of Disease Study identified occupational exposures as a worldwide public health threat and risk factor for chronic disease.[12] While understanding that the health consequences of exposures at the workplace should be a priority for public health, it is also important to recognize that some occupational exposures such as exposure to burning wood during wildfires affect not only firefighters but also large communities and geographical areas.[25,45] Large wildfires, such as the wildfires that occurred in Northern and Southern California in 2017, exposed millions of people to wood smoke with high concentrations of fine particulate matter and other air pollutants, yet the full cardiovascular impact of these exposures has not been fully described.[46,47] Additionally, pesticide exposure can extend beyond agricultural workers. Communities adjacent to farms and consumers of agricultural products can be exposed to varying amounts of pesticides from commercial agriculture.[14,48] Understanding any potential relationship between pesticide exposure and cardiovascular function and ultimately CVD will have significant implications for public health.

This study has several limitations that are worth considering. First, this is a cross-sectional, observational study and therefore causal inference cannot be determined based on these data. Second, the occupational exposures were self-reported and thus are subject to recall bias. However, any misclassification of the exposure would bias the results towards the null and thus underestimate the true relationship between occupational exposures and cardiac measures. Third, although we asked about time at current job and longest-held job, it is difficult to explicitly assess the frequency of exposure as most people would not be aware that they are being exposed or know the exact

toxicant of exposure. Additionally, we restricted our sample to people who are currently employed, most likely a healthier population, and may have underestimated the relationship between exposures and outcome. Fourth, this study was undertaken in Hispanic/Latino populations across 4 major US cities, thus limiting the generalizability beyond the study population. Here, we chose not to adjust the *P* value for multiple comparisons because each outcome was selected based on a priori hypothesis and a unique mechanism between exposure and each cardiac parameter. We were interested in controlling the type I error rate per outcome of interest rather than per group of outcome variables. Nevertheless, the results should be interpreted cautiously and validated in other studies. Future studies with a longitudinal design are needed to better elucidate the mechanisms of how occupational exposures impact progression of cardiac function from subclinical disease to clinical HF. However, the long-term public health importance of our study is likely high given the potential for accumulation of cardiac damage over the life course with lifetime occupational/environmental exposure coupled with the fact that cardiac dysfunction is an independent risk factor for future development of clinical HF.[49–54]

CONCLUSIONS

In US Hispanics/Latinos, occupational/environmental exposure to burning wood, vehicle exhaust, metals, and pesticides was associated with abnormal parameters of cardiac structure and function. Occupational/environmental exposures to toxic substances potentially pose a threat to the cardiovascular health of working-aged individuals who are exposed. Moreover, reducing exposure to these environmental toxicants, particularly burning wood and pesticides, in the general public is potentially an opportunity for primordial prevention of CVD.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Materials

Tables S1-S4

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SUPPLEMENTAL MATERIAL

Table S1. Association of Occupational Exposure to Burning Wood and Vehicle Exhaust at the Current Job with Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL.

	Burning wood				Vehicle Exhaust			
	Adjusted Model 1	**P-value**	**Adjusted Model 2**	**P-value**	**Adjusted Model 1**	**P-value**	**Adjusted Model 2**	**P-value**
LV STRUCTURE								
LV mas index, g/m^2	4.8 (4.1)	0.24	5.7 (5.3)	0.28	-1.3 (2.8)	0.64	-0.2 (2.8)	0.94
LV mass index, g/m$^{2.7}$	3.3 (2.0)	0.10	3.4 (2.4)	0.17	-1.1 (1.4)	0.43	-0.2 (1.3)	0.86
LV End diastolic volume, mL	5.2 (4.4)	0.24	6.4 (5.0)	0.20	1.4 (2.5)	0.58	2.1 (2.6)	0.43
LV End systolic volume, mL	4.4 (1.9)	0.02	5.3 (2.3)	0.03	0.2 (1.4)	0.88	0.9 (1.6)	0.60
LV SYSTOLIC FUNCTION								
LVEF, %	-2.8 (1.1)	0.01	-3.1 (1.0)	0.002	-0.1 (0.8)	0.89	-0.6 (0.8)	0.46
LV Stroke volume, mL	1.6 (3.1)	0.60	1.5 (2.7)	0.59	1.2 (2.5)	0.65	0.02 (2.6)	0.99
LV longitudinal strain (4 Chamber), %	0.5 (0.6)	0.38	1.2 (0.6)	0.049	-0.7 (0.5)	0.19	-0.4 (0.5)	0.46
LV longitudinal strain (2-Chamber), %	0.9 (0.7)	0.21	1.1 (0.7)	0.10	0.3 (0.4)	0.52	0.4 (0.4)	0.37
LV longitudinal strain (average), %	0.8 (0.6)	0.18	1.3 (0.6)	0.03	-0.2 (0.4)	0.69	0.1 (0.4)	0.86
LV DIASTOLIC FUNCTION								
Medial E' velocity, cm/sec	0.6 (0.6)	0.33	0.6 (0.5)	0.27	0.02 (0.4)	0.95	-0.1 (0.3)	0.79
Lateral E' velocity, cm/sec	0.6 (1.3)	0.63	0.6 (1.4)	0.68	0.3 (0.5)	0.57	0.1 (0.4)	0.80

E/E' ratio	-0.2 (0.6)	0.69	-0.1 (0.5)	0.83	-0.1 (0.3)	0.75	-0.05 (0.3)	0.86
E/A ratio	-0.02 (0.1)	0.73	-0.02 (0.1)	0.81	0.1 (0.05)	0.22	0.04(0.04)	0.33
Iso-volumic Relaxation time, sec	0.01 (0.005)	0.07	0.01 (0.005)	0.07	0.01 (0.003)	0.006	0.01 (0.003)	0.03
LA volume index, mL/m2	0.5 (2.0)	0.82	0.1 (2.1)	0.98	0.2 (1.0)	0.85	-1.0 (1.1)	0.48
RV FUNCTION								
Peak RA-RV gradient, mmHg	2.3 (1.4)	0.10	3.1 (1.2)	0.009	-1.0 (1.0)	0.36	-1.0 (1.0)	0.47
TAPSE	-0.03 (0.1)	0.77	-0.1 (0.1)	0.58	-0.1 (0.1)	0.31	-0.1 (0.1)	0.13
RV Fractional area change	-0.004 (0.02)	0.81	-0.02 (0.02)	0.27	0.01 (0.01)	0.24	0.01 (0.01)	0.47

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed subjects. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure.
Model 1: age, sex; Model 2: age, sex, study site, tobacco use, alcohol use, physical activity, and years of education.

Table S2. Association of Occupational Exposure to Solvents, Pesticides and Metals at the Current Job with Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL.

	Solvents				Pesticides				Metals			
	Adjusted Model 1	P-value	Adjusted Model 2	P-value	Adjusted Model 1	P-value	Adjusted Model 2	P-value	Adjusted Model 1	P-value	Adjusted Model 2	P-value
LV STRUCTURE												
LV mas index, g/m^2	-3.9 (2.9)	0.17	-3.4 (2.8)	0.22	0.1 (3.1)	0.98	-0.6 (3.2)	0.86	6.3 (4.3)	0.14	6.6 (4.2)	0.12
LV mass index, g/m$^{2.7}$	-1.6 (1.7)	0.32	-1.2 (1.4)	0.38	0.5 (1.7)	0.77	0.2 (1.4)	0.87	3.2 (2.1)	0.13	2.9 (1.9)	0.14
LV End diastolic volume, mL	3.3 (4.5)	0.46	2.2 (4.1)	0.60	-2.7 (3.5)	0.43	-2.2 (3.3)	0.50	3.2 (2.9)	0.27	3.4 (3.3)	0.30
LV End systolic volume, mL	0.5 (2.1)	0.80	0.4 (1.9)	0.82	-1.7 (2.0)	0.38	-1.6 (1.9)	0.40	0.9 (1.3)	0.50	1.2 (1.6)	0.46
LV SYSTOLIC FUNCTION												
LVEF, %	1.0 (0.9)	0.23	0.5 (0.9)	0.56	1.3 (1.3)	0.35	1.4 (1.3)	0.30	-0.3 (1.2)	0.78	-0.6 (1.1)	0.58
LV Stroke volume, mL	1.1 (2.9)	0.71	-0.3 (2.8)	0.92	4.0 (2.7)	0.14	4.5 (2.9)	0.11	4.6 (3.3)	0.17	3.4 (3.7)	0.36
LV longitudinal strain (4 Chamber), %	0.6 (0.6)	0.37	-0.5 (0.6)	0.39	0.4 (0.7)	0.59	0.4 (0.7)	0.57	-0.04 (0.6)	0.95	0.1 (0.6)	0.86
LV longitudinal strain (2-Chamber), %	-0.6 (0.5)	0.24	-0.7 (0.6)	0.21	0.3 (0.8)	0.72	-0.03 (0.7)	0.97	1.3 (0.6)	0.04	0.9 (0.7)	0.22

LV longitudinal strain (average), %	-0.5 (0.5)	0.26	-0.5 (0.5)	0.26	0.4 (0.6)	0.53	0.2 (0.5)	0.70	0.7 (0.5)	0.18	0.6 (0.5)	0.29
LV DIASTOLIC FUNCTION												
Medial E' velocity, cm/sec	0.4 (0.4)	0.20	0.4 (0.3)	0.16	0.5 (0.3)	0.12	0.5 (0.3)	0.09	0.03 (0.4)	0.94	0.1 (0.4)	0.85
Lateral E' velocity, cm/sec	0.3 (0.5)	0.48	0.3 (0.5)	0.50	1.0 (0.9)	0.29	0.9 (0.9)	0.32	0.7 (0.8)	0.37	0.8 (0.8)	0.31
E/E' ratio	0.5 (0.4)	0.27	0.4 (0.4)	0.38	0.1 (0.4)	0.90	0.1 (0.4)	0.76	-0.1 (0.5)	0.84	-0.2 (0.4)	0.70
E/A ratio	0.01 (0.04)	0.77	-0.003 (0.05)	0.95	0.1 (0.1)	0.23	0.1 (0.1)	0.35	-0.01 (0.1)	0.94	0.01 (0.1)	0.93
Iso-volumic Relaxation time, sec	-0.003 (0.003)	0.28	-0.004 (0.002)	0.09	0.003 (0.04)	0.43	0.003 (0.004)	0.51	0.01 (0.03)	0.04	0.005 (0.003)	0.12
LA volume index, mL/m2	0.8 (1.2)	0.50	0.02 (1.1)	0.99	-0.5 (1.4)	0.74	-0.8 (1.5)	0.61	1.0 (1.2)	0.40	0.2 (1.1)	0.87
RV FUNCTION												
Peak RA-RV gradient, mmHg	-0.01 (1.4)	0.99	0.01 (1.5)	0.99	-0.1 (1.4)	0.94	-0.3 (1.3)	0.81	0.2 (1.2)	0.88	0.5 (1.3)	0.70
TAPSE, cm	0.1 (0.1)	0.12	0.1 (0.1)	0.21	-0.05 (0.1)	0.49	-0.04 (0.1)	0.53	-0.1 (0.1)	0.24	-0.1 (0.1)	0.09
RV Fractional area change	0.02 (0.01)	0.28	0.02 (0.005)	0.0008	-0.01 (0.01)	0.57	-0.02 (0.02)	0.35	0.002 (0.01	0.89	-0.01 (0.01)	0.64

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed subjects. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure.
Model 1: age, sex; Model 2: age, sex, study site, tobacco use, alcohol use, physical activity, and years of education.

Table S3. Association of Occupational Exposures at the Longest Job with Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL (Sensitivity Analysis using Pack-Years of Smoking in Adjusted Models).

	Burning wood		Vehicle Exhaust		Solvents		Pesticides		Metals	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**
LV STRUCTURE										
LV mas index, g/m^2	6.3 (4.5)	0.17	1.4 (2.1)	0.52	-1.6 (0.9)	0.08	2.6 (2.4)	0.27	8.7 (3.6)	0.01
LV mass index, g/m$^{2.7}$	3.7 (2.2)	0.09	0.6 (1.0)	0.58	-0.2 (0.6)	0.75	1.7 (1.2)	0.16	4.1 (1.8)	0.01
LV End diastolic volume, mL	7.1 (1.6)	<. 0001	3.2 (1.6)	0.049	5.1 (2.9)	0.08	-3.0 (1.9)	0.11	2.9 (2.9)	0.31
LV End systolic volume, mL	4.8 (0.9)	<. 0001	1.4 (0.7)	0.06	1.2 (1.0)	0.25	-0.9 (0.7)	0.19	-0.2 (1.2)	0.86
LV SYSTOLIC FUNCTION										
LVEF, %	-2.7 (0.6)	<. 0001	-0.6 (0.5)	0.23	0.7 (0.3)	0. 01	0.04 (0.5)	0.93	0.5 (0.6)	0.45
LV Stroke volume, mL	1.5 (0.9)	0.09	2.3 (1.2)	0.047	0.4 (1.4)	0. 79	4.8 (2.4)	0.043	3.8 (1.6)	0.01
LV longitudinal strain (4 Chamber), %	1.2 (0.3)	0.0002	-0.1 (0.2)	0.81	-0.5 (0.2)	0.03	0.8 (0.2)	0.0002	-0.5 (0.4)	0.22
LV longitudinal strain (2-Chamber), %	0.6 (0.3)	0.052	0.6 (0.2)	0.02	-0.9 (0.2)	<. 0001	0.6 (0.2)	0.01	0.9 (0.5)	0.055
LV longitudinal strain (average), %	1.0 (0.3)	0.0009	0.3 (0.2)	0.17	-0.6 (0.1)	<. 0001	0.7 (0.2)	0.0001	0.4 (0.4)	0.36
LV DIASTOLIC FUNCTION										
Medial E' velocity, cm/sec	0.7 (0.2)	0.0002	-0.1 (0.2)	0.66	0.5 (0.1)	<. 0001	0.6 (0.1)	<. 0001	0.2 (0.3)	0.47

Lateral E' velocity, cm/sec	0.9 (0.3)	0.009	0.1 (0.3)	0.58	-0.01 (0.2)	0.95	1.1 (0.2)	<. 0001	1.5 (0.4)	0.0006
E/E' ratio	-0.05 (0.2)	0.77	0.3 (0.2)	0.08	0.5 (0.1)	0.0003	0.1 (0.2)	0.51	-0.01 (0.3)	0.98
E/A ratio	0.001 (0.03)	0.98	0.03 (0.03)	0.32	-0.01 (0.02)	0.51	0.02 (0.03)	0.50	0.002 (0.06)	0.97
Iso-volumic Relaxation time, sec	0.01 (0.001)	<. 0001	0.0004 (0.002)	0.79	-0.002 (0.001)	0.056	-0.002 (0.001)	0.17	0.01 (0.002)	0.002
LA volume index, mL/m2	0.7 (0.4)	0.09	-0.2 (0.7)	0.81	0.2 (0.6)	0.73	-2.8 (0.7)	<. 0001	1.2 (0.9)	0.19
RV FUNCTION										
Peak RA-RV gradient, mmHg	4.0 (0.3)	<. 0001	-1.2 (0.6)	0.051	0.9 (0.4)	0.03	1.3 (0.6)	0.03	0.9 (0.7)	0.23
TAPSE	-0.02 (0.03)	0.53	-0.1 (0.04)	0.0003	0.1 (0.03)	<. 0001	-0.05 (0.04)	0.22	-0.04 (0.06)	0.54
RV Fractional area change	-0.02 (0.005)	<. 0001	0.004 (0.01)	0.54	0.02 (0.005)	< .0001	-0.0004 (0.01)	0.95	0.002 (0.01)	0.83

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed subjects. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure.
Adjusted model: age, sex, study site, tobacco use (number of pack-years), alcohol use, physical activity, and years of education.

Table S4. Association of Occupational Exposure to burning wood and vehicle exhaust at the Longest Job with Echocardiographic Measures of Cardiac Structure and Function in ECHO-SOL Stratified by Smoking Status.

	Burning wood						Vehicle exhaust					
	Never smoker		Former smoker		Current smoker		Never smoker		Former smoker		Current smoker	
	Estimate (SE)	P-value	Estimate (SE)	P-value	Estimate (SE)	P-value	Estimate (SE)	P-value	Estimate (SE)	P-value	Estimate (SE)	P-value
LV STRUCTURE												
LV mas index, g/m^2	8.9 (1.2)	<0.001	19.5 (12.1)	0.11	8.3 (1.3)	<. 0001	10.4 (1.8)	<0.001	9.4 (4.7)	0.045	-2.3 (1.8)	0.20
LV mass index, g/m$^{2.7}$	2.1 (0.6)	0.0005	8.2 (5.3)	0.13	2.8 (0.7)	<. 0001	1.0 (0.9)	0.29	2.8 (2.1)	0.18	-2.7 (0.9)	0.006
LV End diastolic volume, mL	36.1 (1.7)	<. 0001	9.8 (4.6)	0.035	15.3 (1.3)	<. 0001	18.3 (3.4)	<. 0001	13.2 (2.4)	<. 0001	6.3 (2.3)	0.007
LV End systolic volume, mL	15.6 (0.6)	<. 0001	8.0 (3.4)	0.01	9.0 (0.7)	<. 0001	4.8 (1.6)	0.002	7.6 (1.2)	<. 0001	3.4 (1.0)	0.001
LV FUNCTION												
LVEF, %	-3.2 (0.3)	<. 0001	-3.0 (2.4)	0.20	-4.2 (0.4)	<. 0001	0.1 (0.6)	0.79	-2.5 (0.9)	0.0045	-1.1 (0.7)	0.09
LV Stroke volume, mL	22.8 (0.8)	<. 0001	6.2 (1.4)	<. 0001	1.9 (0.9)	0.03	9.1 (2.0)	<. 0001	6.1 (1.0)	<. 0001	3.5 (1.4)	0.01
LV longitudinal strain (4 Chamber), %	-0.8 (0.2)	<. 0001	2.8 (0.8)	0.0003	2.2 (0.2)	<. 0001	-0.4 (0.5)	0.40	0.7 (0.5)	0.12	0.7 (0.3)	0.044
LV longitudinal strain (2-Chamber), %	-1.8 (0.4)	<. 0001	2.5 (0.6)	0.0001	2.5 (0.2)	<. 0001	1.1 (0.4)	0.01	1.1 (0.5)	0.03	1.2 (0.3)	0.0003

LV longitudinal strain (average), %	-1.2 (0.2)	<. 0001	2.6 (0.7)	<. 0001	2.5 (0.2)	<0.001	0.4 (0.4)	0.30	0.9 (0.4)	0.03	0.9 (0.3)	0.001
LV DIASTOLIC FUNCTION												
Medial E' velocity, cm/sec	2.4 (0.2)	<. 0001	0.7 (0.3)	0.01	0.6 (0.2)	0.0004	1.8 (0.7)	0.008	-0.2 (0.1)	0.01	-0.2 (0.2)	0.26
Lateral E' velocity, cm/sec	-0.1 (0.2)	0.61	-1.8 (0.2)	<. 0001	2.7 (0.3)	<. 0001	1.9 (0.8)	0.01	0.5 (0.3)	0.14	-0.2 (0.3)	0.63
E/E' ratio	-1.2 (0.2)	<. 0001	-0.8 (0.2)	<. 0001	-0.5 (0.1)	<. 0001	-1.7 (0.5)	0.001	0.2 (0.2)	0.21	-0.2 (0.2)	0.42
E/A ratio	-0.1 (0.04)	0.01	-0.1 (0.02)	<. 0001	0.1 (0.02)	<. 0001	0.2 (0.2)	0.17	0.04 (0.03)	0.20	-0.02 (0.03)	0.55
Iso-volumic Relaxation time, sec	0.005 (0.001)	<. 0001	0.02 (0.001)	<. 0001	0.003 (0.001)	0.03	0.02 (0.003)	<. 0001	-0.001 (0.002)	0.55	0.003 (0.002)	0.13
LA volume index, mL/m^2	5.5 (0.4)	<. 0001	-4.9 (1.2)	<. 0001	1.2 (0.4)	0.002	3.7 (1.2)	0.003	-1.8 (1.1)	0.09	-0.9 (0.6)	0.15
RV FUNCTION												
Peak RA-RV gradient, mmHg	3.1 (0.2)	<. 0001	2.6 (1.3)	0.045	2.4 (0.2)	<. 0001	0.7 (1.1)	0.57	-1.7 (0.9)	0.06	-3.9 (1.1)	0.0004
TAPSE, cm	0.5 (0.03)	<. 0001	-0.3 (0.02)	<. 0001	-0.004 (0.04)	0.92	0.3 (0.04)	<. 0001	-0.4 (0.1)	<. 0001	0.03 (0.1)	0.59
RV Fractional area change	-0.01 (0.005)	0.03	-0.05 (0.01)	<. 0001	-0.01 (0.01)	0.25	-0.002 (0.02)	0.92	0.002 (0.01)	0.88	0.001 (0.01)	0.92

Linear regression analyses are reported comparing the respective outcome variable cardiac parameter between exposed and unexposed subjects. Regression coefficients are presented amounting to the average increase (positive numbers) or decrease (negative numbers) (with standard error) in the respective cardiac parameter with the particular exposure.
Adjusted model: age, sex, study site, alcohol use, physical activity, and years of education.