Traffic pollution, reproductive health, and depressive symptoms in a healthy multiethnic sample of reproductive age women in the Ovarian Aging Study

Anwesha Pan, PhD,[1] Martha Grace Cromeens, JD, PhD, RN,[2] Marcelle I. Cedars, MD,[3] and Maria E. Bleil, PhD[2]

Abstract

Objective: This study aimed to determine whether exposure to traffic-related air pollution (TRAP) is associated with depressive symptoms while also characterizing the contribution of key explanatory factors related to sociodemographics and health. In addition, it aimed to also explore the role of reproductive health as a pathway through which exposure to TRAP may relate to depressive symptoms.

Methods: Participants were 688 healthy reproductive-age women in the Ovarian Aging Study. TRAP was derived from distance-weighted traffic counts using residential addresses. Depressive symptoms were assessed by the Center for Epidemiological Studies Depression scale. Explanatory factors were assessed by interview and clinic measures, including demographics (age, race/ethnicity), socioeconomic status (SES) (individual SES, neighborhood SES), general health (smoking, body mass index), and reproductive health (menarcheal age, contraceptive use, parity, menstrual cycle characteristics).

Results: In cross-sectional, step-wise multivariate regression analyses, greater exposure to TRAP was related to more depressive symptoms ($b = 0.779$, $P = 0.015$). Lower individual SES, longer menstrual cycle length, and experiencing change (vs no change) in menstrual cycle length were also related to more depressive symptoms (P's < 0.05). Examination of each model step showed that variance in depressive symptoms was attributable to TRAP (1.2%, $P = 0.004$), demographics (1.0%, $P = 0.217$), SES (1.4%, $P = 0.007$), general health (0.3%, $P = 0.356$), and reproductive health (2.0%, $P = 0.015$). Finally, menstrual cycle length, a marker of reproductive health status, partially mediated effects of TRAP on depressive symptoms (indirect effect: $b = 0.064$, $P = 0.020$).

Conclusions: Findings showed that exposure to TRAP is associated with depression, along with SES and reproductive health factors, and that reproductive health may be a pathway through which TRAP relates to depression.

Key Words: Depression, Menstrual cycle, Reproductive health, Traffic count, Traffic pollution, TRAP.

(*Menopause* 2025;32:00–00)

Nearly one quarter of the United States (US) population lives in proximity to high-volume roadways, exposing these individuals to hazardous traffic-related air pollution (TRAP) (eg, particulate matter, nitrogen oxides).[1] Such exposures have deleterious impacts on a wide range of health outcomes,[2] including psychiatric health conditions.[3,4] In recent years, studies have focused on TRAP in relation to depression specifically, due to the enormous health and economic burdens of depression in the US and worldwide.[5,6] In the Nurses' Health Study, among 41,844 middle-age and older women, ozone and particulate matter exposures predicted depression onset assessed by reports of a physician diagnosis of depression or use of an antidepressant medication.[7] In other studies, short-term TRAP exposures predicted depression-related emergency department visits and hospitalizations with evidence suggesting that women are more vulnerable to the psychiatric effects of TRAP exposures than men.[8–10] Finally, in studies examining indices of distance from roadways as a proxy for TRAP exposures, greater proximity to roadways related to increases in depressive symptomatology assessed by self-reports on questionnaire-based measures.[11,12] Affirming this pattern of results, a recent meta-analysis of 39 studies conducted in the US and abroad revealed an overall effect of TRAP on depression with respect to both long- and short-term TRAP exposures.[13]

As described above, the evidence base implicating TRAP as a risk factor for depression onset and symptom exacerbation has grown substantially, including studies of various methodological approaches for the assessment of TRAP exposures both in the short- and long-term and for the assessment of depression across markers of depression-related diagnoses, acute events, and self-reported symptoms. However, there remains a significant knowledge gap about whether such linkages are independent of key explanatory variables such as sociodemographic factors and relevant parameters of general and reproductive health. In this context, closer inspection of the relative contributions of such explanatory variables is an essential next step to begin to understand the potential mechanisms through which TRAP exposures may influence depression onset and symptom exacerbations.

First, with respect to sociodemographic factors, there are pronounced racial/ethnic and socioeconomic disparities in TRAP exposures. Racial and ethnic minority populations, including Hispanic, non-Hispanic Black, and non-Hispanic Asian (vs non-Hispanic White) are more likely to live in census blocks with higher TRAP exposures[14] and are more likely to be

Received July 24, 2024; revised and accepted September 30, 2024.

From the [1]Department of Anthropology, University of Washington, Seattle, WA; [2]Department of Child, Family, and Population Health Nursing, University of Washington, Seattle, WA; and [3]Department of Obstetrics, Gynecology, and Reproductive Sciences, University of California San Francisco, San Francisco, CA.

Funding/support: Preparation of this article and the research described here were supported by NIH/NIA (R01 AG053332 [Cedars]), NIH/NICHD and NIH/NIA (R01 HD044876 [Cedars]), NIH/UCSF-CTSI (UL1 RR024131), NIH/NIA (K08 AG035375 [Bleil]), NIH/NICHD (R03 HD080893 [Bleil]), NIH/NINR (T32 NR019761 [Cromeens]), and University of Washington, Research and Intramural Funding Program (RIFP [Bleil]).

Financial disclosure/conflicts of interest: Dr Cedars receives ongoing funding from ASRM — Presidential Chain and UpToDate for editorial duties. The other authors have nothing to disclose.

Address correspondence to: Anwesha Pan, PhD, Department of Anthropology, University of Washington, Seattle, 314 Denny Hall Box 353100, Seattle, WA 98195. E-mail: anweshap@uw.edu; Department of Sociology, Anthropology & Criminal Justice, Old Main 245B, Utah State University, Logan, UT 84322-0730. E-mail: anwesha.pan@usu.edu

ISSN: 1530-0374

DOI: 10.1097/GME.0000000000002483

exposed to higher concentrations of specific TRAP exposures such as particulate matter and nitrogen oxides.[14-17] A similar pattern is evident with respect to socioeconomic status (SES). In one study, individuals living in poverty had a 35% higher particulate matter emissions burden than the overall population.[16] In another study, there was a significant inverse association between household income and a variety of TRAP exposures.[14] Finally, race and ethnic minority populations, including Hispanic and non-Hispanic Black women, have a higher probability of being depressed than their non-Hispanic White counterparts.[18] As well, lower SES has been linked to increased depression risk,[19] with features of the environment such as higher racial segregation and lower neighborhood-level SES related to increases in depressive symptoms.[20,21]

Next, with respect to parameters of general health, TRAP exposures have been linked to body weight in children and adults as well as to associated cardiometabolic diseases. A recent meta-analysis revealed TRAP exposures were associated with an increased risk of overweight/obesity in children.[22] Other meta-analyses showed similar patterns in adults.[23,24] Notable findings from the Study of Women Across the Nation reported that TRAP exposures in midlife women also predicted specific aspects of body composition, including fat mass, proportional fat mass, and lower lean mass.[25] Beyond obesity, other studies showed that TRAP exposures alone, or in combination with features of neighborhoods, such as walkability, predicted risk for type 2 diabetes.[26,27] In parallel, findings in mice models showed diet and exposures to particulate matter together induced more visceral fat and insulin resistance compared to diet alone.[28] As well, growing evidence highlights the role of TRAP exposures in disrupting the regulation of appetite, metabolism, and basal metabolic rate—processes that underpin various cardiometabolic health conditions.[29] Finally, obesity and depression are strongly interrelated. A systematic review of longitudinal studies revealed that there are bidirectional associations between obesity and depression with studies showing that obesity at baseline predicted the onset of depression and studies showing that depression at baseline predicted the development of obesity.[30]

Finally, with respect to parameters of reproductive health, TRAP exposures have been linked to numerous adverse reproductive health outcomes such as accelerated pubertal development, reduced fecundability, and negative birth outcomes associated with fetal growth and preterm birth.[31-36] TRAP exposures have also been linked to menstrual cycle patterns regarded as a proxy for health more generally both with respect to reproductive fitness and associated health conditions in areas of cancer and cardiometabolic diseases.[37-39] In a large sample of women, TRAP predicted the onset of dysmenorrhea over a 12-month period.[40] In another study, short-term TRAP exposures predicted outpatient visits for menstrual cycle disorders.[41] Notable findings from the Nurses' Health Study II revealed that TRAP exposures were associated with menstrual cycle irregularity and a longer time to regularity among adolescent girls and young women.[42] In studies examining menstrual cycle length, TRAP exposures were related to luteal phase shortening, but not follicular phase or overall cycle length, in one study,[43] whereas TRAP exposures were related to longer follicular phase in another study.[44] In parallel, findings in mice models also showed adverse impacts on estrus cycle length and follicle formation.[45,46] Finally, menstrual cycles are related to depression risk.[47,48] Cyclic hormonal changes are associated with shifts in mood as a part of premenstrual syndrome and premenstrual dysphoric disorder.[49] Other time periods, marked by fluctuations in reproductive hormones, such as perimenopause, are also associated with depression risk.[50,51] At the same time, depression plays a role in the regulation of reproductive hormones and associated menstrual cycle abnormalities,[52] suggesting links between menstrual cycles and depression are bidirectional.

The current study builds on the literature described above by leveraging a large, ethnically diverse sample of healthy, reproductive age women in the Ovarian Aging (OVA) Study to examine the cross-sectional association between TRAP exposure and self-reported depressive symptoms. The current study is unique due to the availability of a distance-weighted measure of traffic volume in a sample that is also well characterized on parameters relevant to understanding pollution-depression links in women. Specifically, the current study is well positioned to evaluate the association between TRAP exposure and depressive symptoms while also considering the contribution of key explanatory factors, including demographic factors, individual and neighborhood SES indicators, and general and reproductive health status indicators. In addition, exploratory analyses were conducted to consider whether menstrual cycle characteristics, indexing reproductive health more broadly, may be a pathway through which TRAP exposure is associated with depressive symptoms. This work is expected to add new knowledge to the current literature by offering insights into the mechanisms by which TRAP exposure may impact psychological health.

METHODS

Participants

The current sample included participants in the OVA Study, a community-based, cross-sectional investigation of ovarian aging conducted between 2006 and 2011. Participants were recruited through Kaiser Permanente (KP) of Northern California, which provides health care to more than 30% of the population in Northern California. The KP membership is generally representative of the Northern California population with respect to its sociodemographic and health-related characteristics.

Women were included in the OVA Study based on selection criteria, including ages between 25 and 45 years; self-identification as White, Black, Latina, Chinese, or Filipina; and ability to speak/read English, Spanish, or Cantonese. Women were also required to have regular menstrual cycles (ie, able to predict the start of menses within 5 d) and have their uterus and both ovaries intact. Women were excluded based on self-reports of major medical illnesses (ie, cardiovascular diseases, chronic kidney or liver disease, diabetes, invasive cancer, chemotherapy or radiation therapy, epilepsy, systemic lupus erythematosus, or HIV-positive status), use of medications affecting the menstrual cycle in the 3 months before study participation, and current pregnancy or breastfeeding.

The OVA Study protocol entailed a single in-person study visit to the University of California San Francisco campus located in San Francisco, California. It included a medical history interview, transvaginal ultrasound, anthropometric assessment,

blood draw, and self-report questionnaires. The study visits were led by trained staff who were bilingual in English/Spanish or English/Cantonese. Of the 1,019 women who completed the OVA Study protocol, 688 are included in the current analysis. Of the 331 women missing data, 307 did not complete the self-report questionnaires from which the main outcome variable, depressive symptoms, is derived. This was due to 179 women who were never administered the questionnaires because the questionnaires were not originally included in the study protocol and 128 women who were provided the questionnaires but did not complete them. Finally, an additional 24 women did not have traffic pollution data due to an error with their self-reported residential address or a lack of available traffic data for a particular geographical location.

Institutional review board approval was obtained from KP of Northern California, the University of California San Francisco, and the University of Washington. Written informed consent was obtained from all study participants.

Measures

Primary exposure variable

Traffic-related air pollution

At the study visit, participants reported their current residential address. All participant addresses were then geocoded and imported (in batch) into a traffic linkage service on the California Environmental Health Tracking Program web portal to derive a distance-weighted index of traffic pollution exposure for each participant. Specifically, the TrafficMetrix data set (US version 14.0) was used to derive traffic counts, representing the annual averages of daily traffic on weekdays.[53] The traffic counts were then conflated to TeleAtlas street networks and linked to the provided geocoded residential addresses using a 500-m buffer around each residence. The sum of all traffic counts, both length and Gaussian adjusted, within the buffer was used as the index of TRAP exposure in the current study. Support for the use of such an index of TRAP exposure is demonstrated by studies showing that traffic is an important source of exposure to chemical toxicants such as particulate matter and nitrogen oxides.[54] In addition, distance to roadways and traffic density have been found to correlate with nitrogen dioxide levels in households.[55] In this way, distance-weighted traffic density is a suitable index of exposure to traffic pollutants of concern. Moreover, participants in the current study resided in the San Francisco Bay Area. Traffic exposure in California is the highest in the US with 40% of the population living near (within 300 m) busy roads (>10,000 cars/d).[56] As well, there is a high prevalence of exposure to TRAP in those living in the urban Bay Area counties as the population proportion of those living near busy roads is 82% for San Francisco County and 72% for Alameda County.[57]

Primary outcome variable

Depressive symptoms

At the study visit, participants were given a packet of self-report questionnaires and instructed to complete the packet at the visit with the option of completing it at home and returning it by mail. Included in this packet was the Center for Epidemiological Studies Depression Scale (CESD)[58,59] used to assess current depressive symptoms. The CESD includes 20 items each scored on a 0- to 3-point scale. Response choices indicate the frequency with which each symptom (or item) is experienced over the past week, ranging from "rarely or none of the time (<1 d)" scored 0 to "most or all of the time (5-7 d)" scored 3. After the reversal of four positively worded items, responses are summed to produce a total score (ranging from 0 to 60) with higher values reflecting more depressive symptoms. In addition, four subscale scores are calculated including (1) depressed affect (example item: "I thought my life had been a failure"), (2) low positive affect (example item: "I felt hopeful about the future" [reverse scored]), (3) somatic and retarded activity (example item: "my sleep was restless"), and (4) interpersonal difficulties (example item: "I felt that people disliked me"). Prior studies support use of the subscales based on the results of a confirmatory factor analysis.[60] Psychometric evaluation of the CESD showed high internal reliability across psychiatric and nonpsychiatric samples[61,62] and adequate validity as indicated by differences in CESD scores between patient and nonpatient samples, correlation of CESD scores with clinician ratings of depression, reduction in CESD scores with depression treatment, and correspondence with other measures of depression.[59,62–66] A factor analysis performed in the OVA Study sample replicated the original CESD four-factor structure.[67] As well, in the OVA Study sample, internal consistency was high for the CESD total score ($\alpha = 0.88$), depressed affect subscale ($\alpha = 0.86$), and the positive affect subscale ($\alpha = 0.76$) but was lower for the somatic and retarded activity subscale ($\alpha = 0.66$) and the interpersonal difficulties subscale ($\alpha = 0.55$).[67]

Explanatory factors

Demographics

Participants reported their date of birth, which was used to calculate their age (in years) at the date of study participation. Participants reported their race/ethnicity in categories: White (self-identification as White, non-Hispanic), Black (self-identification as Black or African American, non-Hispanic), Latina (self-identification as White or Black Hispanic/Latina of Mexican or Central American origin), Chinese (self-identification as Chinese or Chinese American), and Filipina (self-identification as Filipina or Filipina American). Participants' biological parents were required to be in the same race/ethnic group as the participant, preventing the inclusion of women who identified as "mixed" or "multiple" race/ethnicity. The race/ethnicity variable was dummy coded (0 vs 1) into four variables ($k - 1$) using White as the reference group. Age and race/ethnicity were the main demographic variables examined in the current study.

Individual SES

Participants reported their educational level in categories (1, <HS/some HS; 2, HS grad/GED; 3, some college/AA/vocational school; 4, college graduate; 5, graduate school [PhD, MS]; 6, professional degree [MD, JD, DDS, MBA]) as well as their household income in categories (1, <$5,000; 2, $5,000-$15,999; 3, $16,000-$24,999; 4, $25,000-$34,999; 5, $35,000-$49,999; 6, $50,000-$74,999; 7, $75,000-$99,999; 8, $100,000-$149,999; 9, $150,000-$199,999; 10, $200,000 +), which was then divided by the number of individuals in the household who were dependent on the income. The sample

distributions of the individual education and household income variables were standardized and then summed, and the result was restandardized to create a single individual SES composite with a sample mean of 0 and a standard deviation of 1. This composite was used to index "individual SES" in the current study with higher composite scores reflecting higher individual SES.

Neighborhood SES

Participants' current residential addresses (described above in reference to the ascertainment of the TRAP exposure variable) were also used to derive the indicated neighborhood SES variables. Addresses were geocoded to the 2010 Census tracts, and crosswalks were used to map to the earlier 2000 Census to encompass the full range of dates of the study data collection period (2006-2010). Census tracts were mapped, and census tract data were standardized using the Longitudinal Tract Database,[68] which leverages population and area weighting to account for changes in the geographical boundaries of census tracts over time. Decennial census tract data for the indicated neighborhood variables of interest were extracted, census tract data involving US dollars were adjusted for inflation (using the Consumer Price Index of the US Bureau of Labor Statistics) to reflect 2010 dollars, and linear interpolation was used to estimate annual values from the decennial data.

The extracted neighborhood SES variables included the following: (1) neighborhood education (percentage of individuals with a high school diploma among individuals 25+ years of age), (2) neighborhood income (median household income), (3) neighborhood unemployment (percentage of individuals unemployed among individuals in the workforce 16+ years of age), (4) neighborhood home values (median home values), and (5) neighborhood poverty (% of families below the poverty line). Values for neighborhood unemployment and neighborhood poverty were reversed (so higher values reflected higher SES). The sample distributions of all the neighborhood variables were standardized and then summed, and the result was restandardized to create a single neighborhood SES composite with a sample mean of 0 and a standard deviation of 1. This composite was used to index "neighborhood SES" in the current study with higher composite scores reflecting higher neighborhood SES.

General health status

Participants responded to a set of standard interview-based questions regarding their history of smoking cigarettes. From this, cigarette smoking was coded in categories (1, current/past smoking; 0, never smoked). Participants also completed a standard anthropometric assessment performed by a study nurse. From this, weight and height were used to calculate body mass index (BMI) (weight [kg]/height [m^2]). Smoking status and BMI were used to index "general health status" in the current study.

Reproductive health status

Participants responded to a set of standard interview-based questions regarding their medical history in areas of reproductive health. Menarcheal age was assessed by participants' reports of the age of their first menstrual period, coded in years. Hormone contraceptive use was assessed by participants' reports of lifetime use of all hormonal methods of contraception (eg, pills, patch, shot, ring), then coded dichotomously in categories (1, positive history of use; 0, no history of use). Parity was assessed by participants' reports of lifetime live births and then coded dichotomously in categories (1, 1+ live births; 0, no live births). Menstrual cycle length was assessed by participants' reports of their typical menstrual cycle length in the past 12 months in categories (1, less than 21 d; 2, 22-24 d; 3, 25-27 d; 4, 28-32 d; 5, 33-35 d; 6, greater than 35 d). Change in menstrual cycle length was assessed by participants' reports of whether their typical menstrual cycle length reflected a change (ie, becoming shorter, longer, more variable, or more regular) in the past 12 months and then coded dichotomously in categories (1, any change in menstrual cycle length; 0, no change in menstrual cycle length). Menarcheal age, hormone contraception use, parity, menstrual cycle length, and change in menstrual cycle length were used to index "reproductive health status" in the current study.

Statistical analysis plan

Linear regression models were fit to examine TRAP exposure in relation to depressive symptoms. The TRAP exposure variable was first standardized (with a sample mean of 0 and a standard deviation of 1) to aid in the interpretation of the results. In total, five separate linear regression models were fit for each of five outcome variables: the CESD total score and the four CESD subscale scores (depressed affect, low positive affect, somatic and retarded activity, and interpersonal difficulties). The independent variables were entered into each regression equation stepwise to allow for the examination of the model change statistics at each step, reflecting the relative contribution of each set of explanatory factors (demographics, SES, general health status, reproductive health status). TRAP exposure was entered on step 1, demographic variables (age, race/ethnicity) were entered on step 2, SES variables (individual SES, neighborhood SES) were entered on step 3, general health status variables (smoking, BMI) were entered on step 4, and reproductive health status variables (menarcheal age, contraceptive use, parity, menstrual cycle length, change in menstrual cycle length) were entered on step 5. Results are reported for the final linear regression models in which all the variables are examined simultaneously, and the change statistics are reported for each step. The primary exposure variable, the explanatory variables, and the outcome variables were derived and coded as described above in the Measures section. In exploratory analyses, whether reproductive health status, indexed by menstrual cycle characteristics, may partially mediate the association between TRAP exposure and depressive symptoms was explored by examining the indirect effect of menstrual cycle length on depressive symptoms.

RESULTS

Sample characteristics

In Table 1, sample descriptives are reported showing that women were 34.8 (5.6) years of age on average and were race/ethnically diverse, including 24.4% White, 22.5% Black, 20.6% Latina, 27.8% Chinese, and 4.7% Filipina. Regarding individual SES, 40.1% of women did not receive a college degree, and 68.1% reported an annual household income <$75,000 per year. Regarding neighborhood SES, the mean percent of individuals with a HS diploma was 82.3 (11.3), the mean median home

TABLE 1. Descriptive statistics examining demographic, socioeconomic, general and reproductive health, and depressive symptom information for the full sample (N = 688)

	Mean (SD) or %
Age (y)	34.8 (5.6)
White	24.4%
Black	22.5%
Latina	20.6%
Chinese	27.8%
Filipina	4.7%
Individual education (% < college graduate)	40.1%
Household income (% < $75,000)	68.1%
Neighborhood, % with HS diploma	82.3 (11.3)
Neighborhood, median home value	$568,975.53 ($222,821.84)
Neighborhood, median household income	$67,952.37 ($26,532.77)
Neighborhood, % unemployed for age 25+ y	9.6 (4.7)
Neighborhood, % families below poverty line	7.6 (7.8)
Smoking (% current/past)	20.6%
BMI (kg/m^2)	26.6 (6.7)
Menarcheal age (y)	12.6 (1.6)
Hormone contraception (% past use)	67.2%
Parity (% 1+ live birth)	41.3%
Menstrual cycle length <28 d	16.6%
Menstrual cycle length 28-32 d	76.2%
Menstrual cycle length >32 d	7.2%
Menstrual cycle length change (% any change)	32.8%
Depressive symptoms (CESD total)	11.4 (8.3)
Depressive symptoms (CESD score 16+)	26.7%

BMI, body mass index; CESD, Center for Epidemiological Studies Depression Scale; HS, high school.

values was $568,975.53 ($22,821.84), the mean median household income was $67,952.37 ($26,532.77), the mean percent unemployed was 9.6 (4.7), and the mean percent of families below the poverty line was 7.6 (7.8). Regarding general health status, 20.6% of women smoked cigarettes currently or in the past, and the mean BMI was 26.6 (6.7) kg/m^2. Regarding reproductive health status, mean menarcheal age was 12.6 (1.6) years, 67.2% of women used hormone contraception in the past, 41.3% of women had one or more live births, the mean menstrual cycle length was in the category "28-32 d," and 32.8% of women reported a change (vs no change) in menstrual cycle length in the past 12 months. Regarding depressive symptoms, the mean CESD total score was 11.4 (8.3), and 26.7% of women scored in the clinical range (16+) on the CESD depression scale.

Bivariate correlations

In Table 2, bivariate correlations between TRAP exposure and the explanatory factors and depressive symptom outcomes showed significant associations between higher TRAP exposure and current/past smoking versus never smoking (r = 0.173, P < 0.001), longer menstrual cycle length (r = 0.104, P = 0.006), and more depressive symptoms, indexed by the CESD total score (r = 0.111, P = 0.004), the CESD depressed affect subscale score (r = 0.123, P = 0.001), and the CESD low positive affect subscale (r = 0.095, P = 0.013).

Multivariate analyses

In Table 3, results are reported depicting a linear regression model estimating the association between TRAP exposure and depressive symptoms indexed by the CESD total score. In Table 4, in a parallel set of analyses, results are reported depicting four separate linear regression models estimating the association between TRAP exposure and depressive symptoms indexed by each of the four CESD subscale scores (depressed affect, positive affect, somatic and retarded activity, and interpersonal difficulties). Results are reported from the final step of the regression models in which associations between TRAP exposure and the explanatory factors (demographics, SES, general health status, and reproductive health status) in relation to each of the indicated dependent variables are estimated simultaneously.

Depressive symptoms (CESD total score)

In Table 3, results showed a significant association between TRAP exposure and depressive symptoms (b = 0.779; 95% CI, 0.153 to 1.405; P = 0.015), indicating that greater TRAP exposure was associated with more depressive symptoms, independently of the explanatory factors included in the model (demographics, SES, general health status, and reproductive health status). Each one standard deviation greater level of TRAP exposure was associated with a 0.8-point higher mean score on the CESD depression scale (total score) while holding constant the other modeled variables. In this model,

TABLE 2. Bivariate correlations between TRAP exposure and variables, including demographics, SES, general health status, reproductive health status, and depressive symptoms

TRAP exposure correlates	*r*	*P*
Demographics		
Age	−0.032	0.407
Black (vs White)	−0.070	0.066
Latina (vs White)	−0.020	0.602
Asian (vs White)	−0.006	0.868
Filipina (vs White)	−0.059	0.125
SES		
Individual SES composite	0.016	0.671
Neighborhood SES composite	0.007	0.846
General health status		
Smoking	0.173	<0.001
BMI	−0.044	0.245
Reproductive health		
Menarcheal age	0.016	0.679
Hormone contraception	0.011	0.779
Parity	−0.056	0.140
Menstrual cycle length	0.104	0.006
Menstrual cycle length change	−0.014	0.720
CESD depressive symptoms		
Total score	0.111	0.004
Depressed affect subscale	0.123	0.001
Low positive affect subscale	0.095	0.013
Somatic subscale	0.048	0.211
Interpersonal subscale	0.065	0.087

BMI, body mass index; CESD, Center for Epidemiological Studies Depression Scale; SES, socioeconomic status; TRAP, traffic-related air pollution.

TABLE 3. Results from the final model of a linear regression equation show the association between TRAP exposure and the CESD depressive symptom total score, adjusted for key explanatory factors in domains of demographics, SES, general health status, and reproductive health status

					Change statistics:			
	b	95% CI for *b*	β	*P*	R^2	ΔR^2	ΔF	ΔF *sig*
DV: Depressive symptoms (CESD total score)								
Exposure					1.2%	1.2%	8.554	0.004
TRAP	0.779	0.153 to 1.405	0.094	0.015				
Demographics					2.2%	1.0%	1.414	0.217
Age	−0.064	−0.184 to 0.055	−0.044	0.291				
Black (vs White)	−0.125	−2.265 to 2.014	−0.006	0.908				
Latina (vs White)	−1.223	−3.400 to 0.955	−0.060	0.271				
Asian (vs White)	0.628	−1.306 to 2.561	0.034	0.524				
Filipina (vs White)	−1.716	−4.871 to 1.440	−0.044	0.286				
SES					3.6%	1.4%	4.942	0.007
Individual SES composite	−1.101	−1.974 to −0.228	−0.133	0.014				
Neighborhood SES composite	−0.504	−1.230 to 0.222	−0.061	0.173				
General health status					3.9%	0.3%	1.035	0.356
Smoking (1 = current/past vs 0 = never)	0.578	−1.046 to 2.202	0.028	0.485				
BMI	0.048	−0.064 to 0.160	0.039	0.399				
Reproductive health status					5.9%	2.0%	2.828	0.015
Menarcheal age (y)	−0.054	−0.466 to 0.358	−0.010	0.797				
Hormone contraception (1 = past use vs 0 = never)	0.197	−1.190 to 1.585	0.011	0.780				
Parity (1 = 1+ live births vs 0 = none)	−1.080	−2.813 to 0.652	−0.064	0.221				
Menstrual cycle length	1.186	0.119 to 2.253	0.085	0.029				
Menstrual cycle length change (1 = any change vs none)	1.802	0.492 to 3.113	0.102	0.007				

BMI, body mass index; CESD, Center for Epidemiological Studies Depression Scale; DV, dependent variable; SES, socioeconomic status; TRAP, traffic-related air pollution.

significant independent associations between explanatory factors, individual SES ($b = -1.101$; 95% CI, −1.974 to −0.228; $P = 0.014$), menstrual cycle length ($b = 1.186$; 95% CI, 0.119 to 2.253; $P = 0.029$), change in menstrual cycle length ($b = 1.802$; 95% CI, 0.492 to 3.113; $P = 0.007$), and depressive symptoms were also observed. Each one standard deviation higher level of individual SES was associated with a 1.1-point lower mean score on the CESD depression scale, each 1-unit increase in menstrual cycle length was associated with a 1.2-point higher mean score on the CESD depression scale, and experiencing a change in menstrual cycle length versus no change was associated with a 1.8-point higher mean score on the CESD depression scale, while holding constant the other modeled variables.

TABLE 4. Results from the final models of four separate regression equations show the association between TRAP exposure and each CESD depressive symptom subscale score, adjusted for key explanatory factors in domains of demographics, SES, general health status, and reproductive health status (results associated with the explanatory factors are not shown)

	b	95% CI for *b*	β	*P*
1. DV: CESD subscale, depressed affect				
Exposure				
TRAP	0.353	0.076 to 0.630	0.097	0.013
2. DV: CESD subscale, low positive affect				
Exposure				
TRAP	0.212	0.019 to 0.404	0.082	0.031
3. DV: CESD subscale, somatic and retarded activity				
Exposure				
TRAP	0.124	−0.112 to 0.361	0.040	0.302
4. DV: CESD subscale, interpersonal activities				
Exposure				
TRAP	0.078	0.001 to 0.155	0.076	0.048

CESD, Center for Epidemiological Studies Depression Scale; DV, dependent variable; TRAP, traffic-related air pollution.

In Table 3, change statistics are reported for each step of the linear regression model showing that TRAP exposure accounted for 1.2% of the variance in depressive symptoms. With the addition of the demographic variables (age, race/ethnicity) on step 2, an additional 1% of the variance in depressive symptoms was explained, but this contribution was not statistically significant (ΔF $P = 0.217$). With the addition of the SES variables (individual SES, neighborhood SES) on step 3, an additional 1.4% of the variance in depressive symptoms was explained, and in contrast, this contribution was statistically significant (ΔF $P = 0.007$). Finally, with respect to the addition of the general health status variables (smoking, BMI) on step 4, an additional 0.3% of the variance in depressive symptoms was explained but was not a significant contribution (ΔF $P = 0.356$), and with respect to the addition of the reproductive health status variables (menarcheal age, contraceptive use, parity, menstrual cycle length, change in menstrual cycle length) on step 5, an additional 2.0% of the variance in depressive

symptoms was explained and this was a significant contribution (ΔF $P = 0.015$). In sum, TRAP exposure, along with the explanatory factors, accounted for 5.9% of the variance in depressive symptoms. The explanatory factors that contributed to the model significantly, based on the model change statistics for the indicated step, included the SES variables and the reproductive health status variables.

Depressive symptoms (CESD subscale scores)

In Table 4, results showed a significant association between TRAP exposure and depressive symptoms for three of the four subscales examined, including depressed affect ($b = 0.353$; 95% CI, 0.076 to 0.630; $P = 0.013$), low positive affect ($b = 0.212$; 95% CI, 0.019 to 0.404; $P = 0.031$), and interpersonal difficulties ($b = 0.078$; 95% CI, 0.001 to 0.155; $P = 0.048$), indicating that greater TRAP exposure was associated with more depressive symptoms in these areas, independently of the explanatory factors included in the model (demographics, SES, general health status, and reproductive health status). Each one standard deviation greater level of TRAP exposure was associated with a 0.4-point higher mean score on the depressed affect subscale, a 0.2-point higher mean score on the low positive affect subscale, and a 0.1-point higher mean score on the interpersonal difficulties subscale, while holding constant the other modeled variables.

Exploratory mediation analyses

In exploratory analyses examining whether the association between TRAP exposure and depressive symptoms is mediated by menstrual cycle length, adjusted for explanatory factors, results showed that the path between TRAP exposure and menstrual cycle length (path A) was significant ($b = 0.054$; 95% CI, 0.010 to 0.098; $P = 0.017$), with greater TRAP exposure related to longer menstrual cycle length. The path between menstrual cycle length and depressive symptoms (path B) was also significant ($b = 1.304$; 95% CI, 0.232 to 2.376; $P = 0.017$), with longer menstrual cycle length related to more depressive symptoms. In addition, the path between TRAP exposure and depressive symptoms, unadjusted for menstrual cycle length, (total effect, path C) was significant ($b = 0.809$; 95% CI, 0.117 to 1.480; $P = 0.012$), and the path between TRAP exposure and depressive symptoms, adjusted for menstrual cycle length, (direct effect, path C′) attenuated slightly but was also significant ($b = 0.745$; 95% CI, 0.056 to 1.440; $P = 0.024$), with greater TRAP exposure related to more depressive symptoms. Finally, inspection of the indirect effect showed that menstrual cycle length partially mediated the effect of TRAP exposure on depressive symptoms ($b = 0.064$; 95% CI, 0.003 to 0.160; $P = 0.020$), with 7.9% of the effect of TRAP exposure on depressive symptoms mediated by menstrual cycle length. Results of the mediation analyses are depicted in Figure 1.

DISCUSSION

The purpose of the current study was to examine the association between TRAP exposure and depressive symptoms in a large, ethnically diverse sample of healthy, reproductive age women in the OVA Study. The sample was well characterized with respect to sociodemographic and health variables, allowing TRAP exposure to be examined in a multivariate model adjusted for key explanatory factors. This analytic approach supported the rigorous examination of the association between TRAP exposure and depression independent of these explanatory factors, as well as the rigorous examination of the extent to which each of these explanatory factors contributed to variance in depression. Finally, in exploratory analyses, the potential mediational role of reproductive health was examined as a pathway through which TRAP exposure may "get into the body" to influence depression, offering new knowledge about possible mechanisms.

Findings revealed that women with greater TRAP exposure were significantly more likely to experience depression according to self-reports on an established questionnaire measure of depressive symptoms. This association was independent of adjustment for other key explanatory factors entered step-wise in the final multivariate model, including demographics (age, race/ethnicity), SES (individual SES, neighborhood SES), general health (smoking, BMI), and reproductive health (menarcheal age, contraceptive use, parity, menstrual cycle length, change in menstrual cycle length). Specifically, each one standard deviation greater level of TRAP exposure was associated with an approximately 1-point higher total score on the depression questionnaire, adjusted for these other factors. Inspection of the explanatory factors themselves revealed that there were significant independent associations of individual SES and two of the reproductive health indicators, menstrual cycle length and change in menstrual cycle length, in relation to depression. That is, higher individual SES, indexed by a composite of education level and household income, was significantly related to lower depression, whereas longer menstrual cycle length and change (vs no change) in menstrual length in the prior 12 months were both significantly related to higher depression. In addition, inspection of the model change statistics for each step in the final multivariate model revealed that steps that included the SES and reproductive health factors, but not the demographic or general health factors, made a significant contribution, beyond TRAP, to the final model. That is, the predictors overall explained 5.9% of the variance in depression, with TRAP exposure accounting for 1.2% of the variance in depression, and SES and reproductive health factors accounting for an additional 1.4% ($P < 0.01$) and 2.0% ($P < 0.05$) of the variance in depression, respectively. Finally, examination of the depression questionnaire subscales showed that TRAP exposure was also significantly related to higher depressed affect, lower positive affect, and higher interpersonal difficulties, but not to the subscale reflecting somatic symptoms of depression.

The primary finding that greater TRAP exposure was associated with experiencing more depressive symptoms is consistent with a relatively robust literature linking TRAP exposures to depression risk.[7–13] The current study adds to the literature by examining this association in a large, ethnically diverse sample of healthy, reproductive age women, building on a series of findings pertaining to women specifically. Prior studies showed that women are not only at increased risk for depression,[69,70] but effects of TRAP on depression may be stronger in women,[9] making continued study of this association in women especially important. The current study also adds to the literature by systemically evaluating the contribution of key explanatory factors to the final multivariate model. This approach revealed that effects of TRAP on depression were independent of these factors but that SES and reproductive health factors were themselves

also significant independent contributors to depression risk. This pattern is consistent with prior studies showing that SES is inversely related to depression,[18,19] including findings based on US population data from the Public Health Questionnaire and the National Health and Nutrition Examination Survey in which women from lower-income groups were at greater risk for depression compared to women in the middle and higher income groups.[18] Such SES-depression links are especially troublesome insofar as TRAP exposures disproportionately burden lower SES individuals and lower SES neighborhoods,[14,16] potentially setting the stage for a clustering of risk factors for poor psychological health in vulnerable individuals. In addition to SES, reproductive health factors also emerged as significant, independent contributors to depression risk. This pattern is also consistent with prior studies showing that reproductive health factors are related to depression. In particular, studies showed that cyclic hormonal changes are associated with depressed mood, such as in premenstrual syndrome or premenstrual dysphoric disorder, as are hormonal fluctuations such as during perimenopause.[49-51] As well, irregular menstrual cycles and menstrual cycle symptoms have been associated with developing depressive symptoms.[71,72] Studies also showed reciprocal impacts of depression on the regulation of reproductive hormones.[52]

Exploratory analyses were also conducted to further examine reproductive health status as a potential pathway through which TRAP exposures may influence depression. Specifically, menstrual cycle length, regarded as a general marker of reproductive health and fertility, was examined.[33,73] In these exploratory analyses, TRAP exposure was significantly related to having a longer menstrual cycle length (path A) and having a longer menstrual cycle length was significantly related to higher depression (path B). Additionally, there was a significant indirect effect showing that TRAP effects on depression were mediated by menstrual cycle length. That is, greater TRAP exposure was related to higher depression through the effect of TRAP exposure on having a longer menstrual cycle and through the subsequent effect of having a longer menstrual cycle on experiencing higher depression. Although no prior studies have tested this mediation model, findings related to the individual paths are partially consistent with prior studies. First, several studies reported that TRAP exposures impacted menstrual cycle characteristics, but the pattern of association was not consistent. In one study, TRAP exposures were related to a shorter luteal phase,[43] and, in another study, TRAP exposures were related to a longer follicular phase,[44] but neither study showed associations with overall menstrual cycle length. In addition, as described above, greater TRAP exposures have been related to depression[7-13] and indicators of menstrual cycle function have been related to depression.[49-51] In summary, although the analyses were exploratory, it is possible that part of the effect of TRAP exposures on depression is through the impact that TRAP has on menstrual cycle function, which itself impacts mood.

It is also worth noting that the examined demographic factors, including age and race/ethnicity, did not contribute to the final multivariate model, accounting for only 1.0% of the variance in depression, which was nonsignificant. Bivariate correlations showed that there were no significant associations between age and TRAP exposure or between race/ethnicity and TRAP exposure, although identifying as Black (vs White) was marginally associated with greater TRAP exposure ($P = 0.066$). Age and race/ethnicity examined individually were also unrelated to depression in the multivariate model. In parallel, the general health factors, including smoking and BMI, did not contribute to the final multivariate model, accounting for only 0.3% of the variance in depression, which was nonsignificant. Interestingly, bivariate correlations showed that TRAP exposure was significantly related to current/past smoking status versus never smoking, but TRAP exposure was not related to BMI, and both smoking and BMI examined individually were unrelated to depression in the multivariate model. Null findings among these variables are somewhat unexpected, especially for BMI, based on prior studies reporting consistent associations between TRAP exposures and body weight[22-25] and between obesity and depression.[30]

There are several strengths of the current study. First, the sample was unique in its racial/ethnic composition, representing approximately equal numbers of women identifying as White, Black, Latina, and Chinese, as well as a smaller group of women identifying as Filipina. In addition, the sample was recruited to be generally healthy and regularly cycling, and not using hormone medications affecting the menstrual cycle, which may eliminate potential confounding due to specific health conditions or abnormal menstrual cycles. The sample was also well characterized in general, enabling the examination of key explanatory factors in the model. For example, SES was assessed by interview-based self-reports of education and income at the individual level as well as census-derived indicators of socioeconomic conditions at the neighborhood level. Similarly, general health and reproductive health were assessed by clinic and interview-based methods, including self-reports of relevant reproductive factors pertaining to pubertal development, fertility, and menstrual cycle characteristics. Finally, a gold standard approach for the creation of the distance-weighted marker of TRAP was taken by leveraging a traffic linkage service provided through the California Environmental Health Tracking Program. This service merged traffic counts available through the TrafficMetrix data set with TeleAtlas street

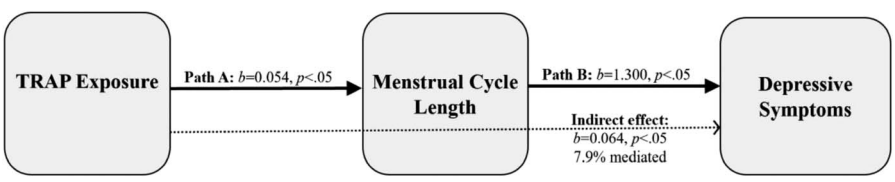

FIG. 1. Results are reported from regression models adjusted for explanatory factors (demographics, SES, general health status, and reproductive health status). The solid arrows represent direct paths between TRAP exposure and menstrual cycle length (path A) and between menstrual cycle length and depressive symptoms (path B). The dotted arrow represents the indirect (mediated) path, showing menstrual cycle length mediated effects of TRAP exposure on depressive symptoms. SES, socioeconomic status; TRAP, traffic-related air pollution.

networks, summing traffic counts within a 500-m buffer around each participant's residential address. Taken together, an additional strength of the current study was to leverage these data with a novel focus on understanding TRAP in relation to depression while also considering key explanatory factors and whether TRAP effects on depression were mediated by reproductive health status.

There are also several weaknesses of the current study. Most notably, the current study was cross-sectional in design, limiting knowledge about the direction of association between TRAP and depression and precluding the opportunity to draw causal inferences. In fact, it remains plausible that depression influences TRAP exposure insofar as individuals who are depressed may face challenges that constrain their options for employment, housing, and other factors related to the likelihood of TRAP exposure. Moreover, the cross-sectional design of the study is especially problematic with respect to the interpretation of the mediational analyses that were conducted in the current study, although these analyses were considered exploratory. In addition, the current study used a distance-weighted proxy measure of TRAP exposure based on the current residential locations of the participants. Although prior studies have substantiated that proximity to roadways is associated with traffic-related pollutants,[55] actual pollutants were not measured, and the distance-weighted proxy measure may represent some error or misclassification. The measure of depression that was used may also be criticized. Although the CESD questionnaire is well established with sound psychometric properties,[59,61-66] other measures using interview-based methods or that describe clinical indicators of depression would provide a stronger basis for distinguishing features of depression uniquely versus symptoms of general distress. Similarly, only overall menstrual cycle length was available for analysis in the current study. Greater resolution regarding menstrual phase and the length of each phase is needed to provide more detailed information about how TRAP exposures disrupt menstrual cycle function. Finally, the current study only considered traffic-related pollution and did not characterize neighborhoods with respect to other relevant variables, such as greenspace or walkability, which might offset negative exposures. In addition, other environmental variables, such as light, noise, and water-related pollution, may be relevant to understanding mental health outcomes, either alone or in combination with other neighborhood variables.[74]

Future studies should address the weaknesses of the current study by employing longitudinal study designs and improved measurement strategies that elaborate on assessments of TRAP, depression, and menstrual cycle characteristics as well as other features of neighborhoods and other sources of pollution. In addition, the finding that TRAP effects on depression may be partially mediated by reproductive health status requires additional investigation. This mediation model, although cross-sectional, is supported by prior evidence showing that some TRAP exposures mimic estrogens, which impact hormonal pathways. Such disruptions may be reflected by menstrual cycle characteristics, including menstrual cycle length, which itself is a marker of reproductive health associated with ovarian follicle growth, ovulation, and the potential for conception, implantation, and embryo development[73,75] as well as other areas of cancer and cardiometabolic disease.[37-39] Specifically, TRAP exposures, including components of particulate matter such as polycyclic aromatic hydrocarbons,[76] are related to estrogen levels and risk for estrogen related cancers.[77-79] Polycyclic aromatic hydrocarbons are common in the environment as they are produced from car exhaust and industrial emissions and smoke from wildfires and cigarette smoking. In this context, it is possible that such chemical exposures are impacting hormones associated with menstrual cycle function, which, in turn, has a concomitant or sequential effect on depression. In fact, estrogen levels and fluctuations in estrogen levels have been associated with depression risk,[80] although it is also noteworthy that depression has reciprocal effects on the regulation of reproductive hormones and hormone-depression links are likely bidirectional. In sum, to move the current work forward, future studies are needed to test whether TRAP-related disruptions in the regulation of hormones affecting menstrual cycle function may be a mechanism leading to the onset or worsening of depressive symptoms.

CONCLUSIONS

In conclusion, the current study found that TRAP exposure is related to depression in women, and this association is independent of a host of sociodemographic and health factors, whereas individual-level SES and menstrual cycle characteristics are also independently related to depression. In addition, the association between TRAP exposure and depression may be partially mediated by menstrual cycle characteristics, reflecting reproductive health status more broadly. However, future studies are needed to clarify the direction of association between these constructs using longitudinal data and incorporating more detailed assessments to help delineate these pathways.

Acknowledgments

We would like to thank Paul English and Jhaqueline Valle at the Public Health Institute, Tracking California Program, who contributed to the data collection efforts related to the neighborhood SES variables and the TRAP variable used in the current manuscript.

REFERENCES

1. Antonczak B, Thompson TM, DePaola MW, Rowangould G. 2020 Near-roadway population census, traffic exposure and equity in the United States. *Transportation Res Part D: Transport Environ* 2023;125:103965. doi: https://doi.org/10.1016/j.trd.2023.103965
2. HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution. Systematic review and meta-analysis of selected health effects of long-term exposure to Traffic-Related Air Pollution: Special Report 23. 2022., Health Effects Institute.
3. Tzivian L, Winkler A, Dlugaj M, et al. Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults. *Int J Hyg Environ Health* 2015;218:1-11. doi: 10.1016/j.ijheh.2014.08.002
4. Braithwaite I, Zhang S, Kirkbride JB, Osborn DPJ, Hayes JF. Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: a systematic review and meta-analysis. *Environ Health Perspect* 2019;127:126002. doi: 10.1289/ehp4595
5. Stewart WF, Ricci JA, Chee E, Hahn SR, Morganstein D. Cost of lost productive work time among US workers with depression. *JAMA* 2003;289:3135-3144. doi: 10.1001/jama.289.23.3135
6. Murray CJL, Vos T, Lozano R, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012;380:2197-2223. doi: 10.1016/s0140-6736(12)61689-4
7. Kioumourtzoglou M-A, Power MC, Hart JE, et al. The association between air pollution and onset of depression among middle-aged and older women. *Am J Epidemiol* 2017;185:801-809. doi: 10.1093/aje/kww163

8. Gu X, Guo T, Si Y, et al. Association between ambient air pollution and daily hospital admissions for depression in 75 Chinese cities. *Am J Psychiatry* 2020; 177:735-743. doi: 10.1176/appi.ajp.2020.19070748
9. Szyszkowicz M. Air pollution and emergency department visits for depression in Edmonton, Canada. *Int J Occup Med Environ Health* 2007;20:241-245. doi: 10.2478/v10001-007-0024-2
10. Szyszkowicz M, Kousha T, Kingsbury M, Colman I. Air pollution and emergency department visits for depression: a multicity case-crossover study. *Environ Health Insights* 2016;10:155-161. doi: 10.4137/ehi.S40493
11. Nguyen AM, Malig BJ, Basu R. The association between ozone and fine particles and mental health-related emergency department visits in California, 2005-2013. *PloS One* 2021;16:e0249675. doi: 10.1371/journal.pone.0249675
12. Pun VC, Manjourides J, Suh HH. Close proximity to roadway and urbanicity associated with mental ill-health in older adults. *Sci Total Environ* 2019;658: 854-860. doi: 10.1016/j.scitotenv.2018.12.221
13. Borroni E, Pesatori AC, Bollati V, Buoli M, Carugno M. Air pollution exposure and depression: a comprehensive updated systematic review and meta-analysis. *Environ Pollut* 2022;292(Pt A):118245. doi: 10.1016/j.envpol.2021.118245
14. Liu J, Clark LP, Bechle MJ, et al. Disparities in air pollution exposure in the united states by race/ethnicity and income, 1990-2010. *Environ Health Perspect* 2021;129:127005. doi: 10.1289/ehp8584
15. Rosofsky A, Levy JI, Zanobetti A, Janulewicz P, Fabian MP. Temporal trends in air pollution exposure inequality in Massachusetts. *Environ Res* 2018;161: 76-86. doi: 10.1016/j.envres.2017.10.028
16. Mikati I, Benson AF, Luben TJ, Sacks JD, Richmond-Bryant J. Disparities in distribution of particulate matter emission sources by race and poverty status. *Am J Public Health* 2018;108:480-485. doi: 10.2105/ajph.2017.304297
17. Tessum CW, Paolella DA, Chambliss SE, Apte JS, Hill JD, Marshall JD. $PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States. *Sci Adv* 2021;7:eabf4491. doi: 10.1126/sciadv.abf4491
18. Zare H, Fugal A, Azadi M, Gaskin DJ. How income inequality and race concentrate depression in low-income women in the US; 2005-2016. *Healthcare (Basel)* 2022;10:1424. doi: 10.3390/healthcare10081424
19. Miech RA, Shanahan MJ. Socioeconomic status and depression over the life course. *J Health Soc Behav.* 2000 April 17, 2024 2000;41:162-176. doi: 10. 2307/2676303
20. Generaal E, Timmermans EJ, Dekkers JEC, Smit JH, Penninx BWJH. Not urbanization level but socioeconomic, physical and social neighbourhood characteristics are associated with presence and severity of depressive and anxiety disorders. *Psychol Med* 2019;49:149-161. doi: 10.1017/ s0033291718000612
21. Martz CD, Hunter EA, Kramer MR, et al. Pathways linking census tract typologies with subjective neighborhood disorder and depressive symptoms in the Black Women's Experiences Living with Lupus (BeWELL) Study. *Health Place* 2021;70:102587. doi: 10.1016/j.healthplace.2021.102587
22. Zheng J, Zhang H, Shi J, et al. Association of air pollution exposure with overweight or obesity in children and adolescents: a systematic review and meta-analysis. *Sci Total Environ* 2024;910:168589. doi: 10.1016/j.scitotenv.2023. 168589
23. Huang S, Zhang X, Huang J, Lu X, Liu F, Gu D. Ambient air pollution and body weight status in adults: a systematic review and meta-analysis. *Environ Pollut* 2020;265(Pt A):114999. doi: 10.1016/j.envpol.2020.114999
24. Lin L, Li T, Sun M, et al. Global association between atmospheric particulate matter and obesity: a systematic review and meta-analysis. *Environ Res* 2022; 209:112785. doi: 10.1016/j.envres.2022.112785
25. Wang X, Karvonen-Gutierrez CA, Gold EB, et al. Longitudinal associations of air pollution with body size and composition in midlife women: the Study of Women's Health Across the Nation. *Diabetes Care* 2022;45:2577-2584. doi: 10. 2337/dc22-0963
26. Sørensen M, Poulsen AH, Hvidtfeldt UA, et al. Air pollution, road traffic noise and lack of greenness and risk of type 2 diabetes: a multi-exposure prospective study covering Denmark. *Environ Int* 2022;170:107570. doi: 10.1016/j.envint. 2022.107570
27. Howell NA, Tu JV, Moineddin R, et al. Interaction between neighborhood walkability and traffic-related air pollution on hypertension and diabetes: the CANHEART cohort. *Environ Int* 2019;132:104799. doi: 10.1016/j.envint.2019. 04.070
28. Sun Q, Yue P, Deiuliis JA, et al. Ambient air pollution exaggerates adipose inflammation and insulin resistance in a mouse model of diet-induced obesity. *Circulation* 2009;119:538-546. doi: 10.1161/circulationaha.108.799015
29. Jerrett M, McConnell R, Wolch J, et al. Traffic-related air pollution and obesity formation in children: a longitudinal, multilevel analysis. *Environ Health* 2014; 13:49. doi: 10.1186/1476-069x-13-49
30. Luppino FS, de Wit LM, Bouvy PF, et al. Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Arch Gen Psychiatry* 2010;67:220-229. doi: 10.1001/archgenpsychiatry.2010.2
31. Hood RB, Hart JE, Laden F, Rosner B, Chavarro JE, Gaskins AJ. Exposure to particulate matter air pollution and age of menarche in a nationwide cohort of U. S. girls. *Environ Health Perspect* 2023;131:107003. doi: 10.1289/ehp12110
32. Gaskins AJ, Hart JE, Mínguez-Alarcón L, et al. Residential proximity to major roadways and traffic in relation to outcomes of in vitro fertilization. *Environ Int* 2018;115:239-246. doi: 10.1016/j.envint.2018.03.029
33. Wesselink AK, Kirwa K, Hatch EE, et al. Residential proximity to major roads and fecundability in a preconception cohort. *Environ Epidemiol* 2020;4:e112. doi: 10.1097/ee9.0000000000000112
34. Yu Z, Zhang X, Zhang J, et al. Gestational exposure to ambient particulate matter and preterm birth: an updated systematic review and meta-analysis. *Environ Res* 2022;212(Pt C):113381. doi: 10.1016/j.envres.2022.113381
35. Stieb DM, Chen L, Eshoul M, Judek S. Ambient air pollution, birth weight and preterm birth: a systematic review and meta-analysis. *Environ Res* 2012;117: 100-111. doi: 10.1016/j.envres.2012.05.007
36. Costello JM, Steurer MA, Baer RJ, Witte JS, Jelliffe-Pawlowski LL. Residential particulate matter, proximity to major roads, traffic density and traffic volume as risk factors for preterm birth in California. *Paediatr Perinat Epidemiol* 2022;36: 70-79. doi: 10.1111/ppe.12820
37. Solomon CG, Hu FB, Dunaif A, et al. Long or highly irregular menstrual cycles as a marker for risk of type 2 diabetes mellitus. *JAMA* 2001;286:2421-2426. doi: 10.1001/jama.286.19.2421
38. Solomon CG, Hu FB, Dunaif A, et al. Menstrual cycle irregularity and risk for future cardiovascular disease. *J Clin Endocrinol Metab* 2002;87:2013-2017. doi: 10.1210/jcem.87.5.8471
39. Whelan EA, Sandler DP, Root JL, Smith KR, Weinberg CR. Menstrual cycle patterns and risk of breast cancer. *Am J Epidemiol* 1994;140:1081-1090. doi: 10.1093/oxfordjournals.aje.a117208
40. Lin S-Y, Yang Y-C, Lin C-C, et al. Increased incidence of dysmenorrhea in women exposed to higher concentrations of NO, NO_2, NO_x, CO, and $PM_{2.5}$: a nationwide population-based study. *Front Public Health* 2021;9:682341. doi: 10.3389/fpubh.2021.682341
41. Liang Z, Xu C, Fan YN, et al. Association between air pollution and menstrual disorder outpatient visits: a time-series analysis. *Ecotoxicol Environ Saf* 2020; 192:110283. doi: 10.1016/j.ecoenv.2020.110283
42. Mahalingaiah S, Missmer SE, Cheng JJ, Chavarro J, Laden F, Hart JE. Perimenarchal air pollution exposure and menstrual disorders. *Hum Reprod* 2018;33:512-519. doi: 10.1093/humrep/dey005
43. Merklinger-Gruchala A, Jasienska G, Kapiszewska M. Effect of air pollution on menstrual cycle length—a prognostic factor of women's reproductive health. *Int J Environ Res Public Health* 2017;14:816. doi: 10.3390/ijerph14070816
44. Giorgis-Allemand L, Thalabard JC, Rosetta L, Siroux V, Bouyer J, Slama R. Can atmospheric pollutants influence menstrual cycle function? *Environ Pollut* 2020;257:113605. doi: 10.1016/j.envpol.2019.113605
45. Zhou S, Xi Y, Chen Y, et al. Ovarian dysfunction induced by chronic whole-body PM2.5 exposure. *Small* 2020;16:e2000845. doi: 10.1002/smll.202000845
46. Veras MM, Damaceno-Rodrigues NR, Guimarães Silva RM, et al. Chronic exposure to fine particulate matter emitted by traffic affects reproductive and fetal outcomes in mice. *Environ Res* 2009;109:536-543. doi: 10.1016/j.envres. 2009.03.006
47. Soares CN, Zitek B. Reproductive hormone sensitivity and risk for depression across the female life cycle: a continuum of vulnerability? *J Psychiatry Neurosci* Jul 2008;33:331-343.
48. Smeeth DM, Dima D, Jones L, et al. Polygenic risk for circulating reproductive hormone levels and their influence on hippocampal volume and depression susceptibility. *Psychoneuroendocrinology* 2019;106:284-292. doi: 10.1016/ j.psyneuen.2019.04.011
49. Hartlage SA, Freels S, Gotman N, Yonkers K. Criteria for premenstrual dysphoric disorder: secondary analyses of relevant data sets. *Arch Gen Psychiatry* 2012;69:300-305. doi: 10.1001/archgenpsychiatry.2011.1368
50. Cohen LS, Soares CN, Vitonis AF, Otto MW, Harlow BL. Risk for new onset of depression during the menopausal transition: the Harvard study of moods and cycles. *Arch Gen Psychiatry* 2006;63:385-390. doi: 10.1001/archpsyc.63.4.385
51. Freeman EW, Sammel MD, Lin H, Nelson DB. Associations of hormones and menopausal status with depressed mood in women with no history of depression. *Arch Gen Psychiatry* 2006;63:375-382. doi: 10.1001/archpsyc.63.4.375
52. Young EA, Midgley AR, Carlson NE, Brown MB. Alteration in the hypothalamic-pituitary-ovarian axis in depressed women. *Arch Gen Psychiatry* 2000;57:1157-1162. doi: 10.1001/archpsyc.57.12.1157
53. Kalibrate. TrafficMetrix, US Version 14.0. 2024. Available at: https://kalibrate.com/products/data/trafficmetrix/. Accessed September 2, 2017.
54. Zhang K, Batterman S. Air pollution and health risks due to vehicle traffic. *Sci Total Environ* 2013;450-451:307-316. doi: 10.1016/j.scitotenv.2013.01.074
55. Rijnders E, Janssen NA, van Vliet PH, Brunekreef B. Personal and outdoor nitrogen dioxide concentrations in relation to degree of urbanization and traffic density. *Environ Health Perspect* 2001;109(Suppl 3(Suppl 3)):411-417. doi: 10. 1289/ehp.01109 s3411

56. Rowangould GM. A census of the US near-roadway population: public health and environmental justice considerations. *Transportation Res Part D: Transport Environ* 2013;25:59-67. doi: https://doi.org/10.1016/j.trd.2013.08.003
57. California Department of Public Health. California Environmental Health Tracking Program (CEHTP). 2024. Available at: https://trackingcalifornia.org/#gsc.tab=0. Accessed September 2, 2017.
58. Radloff LS. The CES-D Scale: a self-report depression scale for research in the general population. *Appl Psychol Measur* 1977;1:385-401. doi: 10.1177/014662167700100306
59. Weissman MM, Sholomskas D, Pottenger M, Prusoff BA, Locke BZ. Assessing depressive symptoms in five psychiatric populations: a validation study. *Am J Epidemiol* 1977;106:203-214. doi: 10.1093/oxfordjournals.aje.a112455
60. Hales DP, Dishman RK, Motl RW, Addy CL, Pfeiffer KA, Pate RR. Factorial validity and invariance of the center for epidemiologic studies depression (CES-D) scale in a sample of Black and White adolescent girls. *Ethn Dis* Winter 2006;16:1-8.
61. Nunnally JC. *Psychometric Theory. McGraw-Hill Series in Psychology.* New York: McGraw-Hill; 1967.
62. Radloff LS, Teri L. Use of the Center for Epidemiological Studies—Depression Scale with older adults. *Clin Gerontol: J Aging Mental Health* 1986;5(1-2): 119-136. doi: 10.1300/J018v05n01_06
63. Blazer DG, Landerman LR, Hays JC, Simonsick EM, Saunders WB. Symptoms of depression among community-dwelling elderly African-American and white older adults. *Psychol Med* 1998;28:1311-1320. doi: 10.1017/s0033291798007648
64. Clark VA, Aneshensel CS, Frerichs RR, Morgan TM. Analysis of effects of sex and age in response to items on the CES-D scale. *Psychiatry Res* 1981;5: 171-181. doi: 10.1016/0165-1781(81)90047-0
65. Hertzog C, Van Alstine J, Usala PD, Hultsch DF, Dixon R. Measurement properties of the Center for Epidemiological Studies Depression Scale (CES-D) in older populations. *Psychol Assess: J Consult Clin Psychol* 1990;2:64-72. doi: 10.1037/1040-3590.2.1.64
66. Knight RG, Williams S, McGee R, Olaman S. Psychometric properties of the Centre for Epidemiologic Studies Depression Scale (CES-D) in a sample of women in middle life. *Behav Res Ther* 1997;35:373-380. doi: 10.1016/s0005-7967(96)00107-6
67. Bleil ME, Bromberger JT, Latham MD, et al. Disruptions in ovarian function are related to depression and cardiometabolic risk during premenopause. *Menopause* 2013;20:631-639. doi: 10.1097/GME.0b013e31827c5c45
68. Logan JR, Xu Z, Stults B. Interpolating U.S. decennial census tract data from as early as 1970 to 2010: a longtitudinal tract database. *Prof Geogr* 2014;66: 412-420. doi: 10.1080/00330124.2014.905156
69. Albert PR. Why is depression more prevalent in women? *J Psychiatry Neurosci* 2015;40:219-221. doi: 10.1503/jpn.150205
70. Brody DJ, Pratt LA, Hughes JP. Prevalence of depression among adults aged 20 and over: United States, 2013-2016. *NCHS Data Brief* 2018;303:1-8.
71. Klusmann H, Kapp C, Engel S, et al. Higher depressive symptoms in irregular menstrual cycles: converging evidence from cross-sectional and prospective assessments. *Psychopathology* 2024;57:1-8. doi: 10.1159/000535565
72. Kullik L, Stork M, Kiel A, Kellmann M, Jakowski S. The prevalence of menstrual cycle symptoms and their association with mental health and sleep in German exercising women and athletes. *J Sci Med Sport* 2024;27:362-367. doi: 10.1016/j.jsams.2024.02.008
73. Xiping L, Xiaqiu WU, Lirong B, Jin P, Hui K-K. Menstrual cycle characteristics as an indicator of fertility outcomes: evidence from prospective birth cohort study in China. *J Tradit Chin Med* 2022;42:272-278. doi: 10.19852/j.cnki.jtcm.2022.02.010
74. Tota M, Karska J, Kowalski S, et al. Environmental pollution and extreme weather conditions: insights into the effect on mental health. *Front Psych* 2024; 15:1389051. doi: 10.3389/fpsyt.2024.1389051
75. Wesselink AK, Wise LA, Hatch EE, et al. Menstrual cycle characteristics and fecundability in a North American preconception cohort. *Ann Epidemiol* 2016; 26:482-487.e1. doi: 10.1016/j.annepidem.2016.05.006
76. Ravindra, Mittal AK, Van Grieken R. Health risk assessment of urban suspended particulate matter with special reference to polycyclic aromatic hydrocarbons: a review. *Rev Environ Health* 2001;16:169-189. doi: 10.1515/reveh.2001.16.3.169
77. Santodonato J. Review of the estrogenic and antiestrogenic activity of polycyclic aromatic hydrocarbons: relationship to carcinogenicity. *Chemosphere* 1997;34: 835-848. doi: 10.1016/s0045-6535(97)00012-x
78. Merklinger-Gruchala A, Jasienska G, Thune I, Kapiszewska M. Joint effect of particulate matter and cigarette smoke on women's sex hormones. *BMC Womens Health* 2022;22:3. doi: 10.1186/s12905-021-01586-w
79. White AJ, Bradshaw PT, Hamra GB. Air pollution and breast cancer: a review. *Curr Epidemiol Rep* 2018;5:92-100. doi: 10.1007/s40471-018-0143-2
80. Sun Q, Li G, Zhao F, et al. Role of estrogen in treatment of female depression. *Aging (Albany NY)* 2024;16:3021-3042. doi: 10.18632/aging.205507