Longitudinal Associations of Neighborhood Crime and Perceived Safety With Blood Pressure: The Multi-Ethnic Study of Atherosclerosis (MESA)

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BACKGROUND

High neighborhood crime and low perceptions of safety may influence blood pressure (BP) through chronic stress. Few studies have examined these associations using longitudinal data.

METHODS

We used longitudinal data from 528 participants of the Multi-Ethnic Study of Atherosclerosis (aged 45–84, nonhypertensive at baseline) who lived in Chicago, Illinois. We examined associations of changes in individual-level perceived safety, aggregated neighborhood-level perceived safety, and past-year rates of police-recorded crime in a 1, ½, or ¼ mile buffer per 1,000 population with changes in systolic and diastolic BPs using fixed-effects linear regression. BP was measured five times between 2000 and 2012 and was adjusted for antihypertensive medication use (+10 mm Hg added to systolic and +5 mm Hg added to diastolic BP for participants on medication). Models were adjusted for time-varying sociodemographic and health-related characteristics and neighborhood socioeconomic status. We assessed differences by sex.

RESULTS

A standard deviation increase in individual-level perceived safety was associated with a 1.54 mm Hg reduction in systolic BP overall (95% confidence interval [CI]: 0.25, 2.83), and with a 1.24 mm Hg reduction in diastolic BP among women only (95% CI: 0.37, 2.12) in adjusted models. Increased neighborhood-level safety was not associated with BP change. An increase in police-recorded crime was associated with a reduction in systolic and diastolic BPs among women only, but results were sensitive to neighborhood buffer size.

CONCLUSIONS

Results suggest individual perception of neighborhood safety may be particularly salient for systolic BP reduction relative to more objective neighborhood exposures.

Keywords: blood pressure; cohort study; crime; environment; hypertension; neighborhoods; safety.

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Research suggests that neighborhood characteristics influence cardiovascular health.[1] Neighborhood crime, or lack of perceived safety, may lead to adverse cardiovascular outcomes through chronic stress.[2] Chronic stress leads to prolonged activation of the sympathetic nervous system and secretion of stress hormones in response to repeated exposure to stressful situations.[3] Long-term dysregulation of stress hormones leads to inflammation and endothelial dysfunction, which may adversely impact blood pressure (BP).[3,4] In addition, exposure to neighborhood crime may adversely influence health behaviors, such as by discouraging residents of those neighborhoods from engaging in physical activity,[5–7] or promoting unhealthy behaviors as coping mechanisms to deal with stress.

Prior studies of neighborhood crime/safety and BP have primarily been cross-sectional,[8–11] and results have been mixed. Cross-sectional data are limited by the inability to establish a temporal association between crime and BP changes. Only one prior longitudinal study has evaluated associations of neighborhood safety with incident hypertension, and found no association.[12] Neighborhood crime/safety exposures may be operationalized in different ways, including individual-level perceptions of safety, neighborhood-level measures constructed by aggregating individual perceptions,[13] and objective measures of police-recorded crime. Prior studies have not examined associations of all three types of exposures with BP change over time, which would enable researchers to separate the potential influence

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of perceptions and objective neighborhood characteristics. In addition, prior studies have not examined associations of within-person changes in perceived safety or police-recorded crime with within-person changes in BP. This approach, accomplished by fixed-effects modeling,[14] controls for all participant characteristics (both measured and unmeasured) that remain constant over time.

This study examines longitudinal associations of within-person changes in individual- and neighborhood-level perceived safety and police-recorded crime rates with within-person changes in BP in the Multi-Ethnic Study of Atherosclerosis overall. We hypothesized that increases in individual-level perceived safety and neighborhood-level perceived safety would be associated with reductions in BP, and that increases in police-recorded crime would be associated with increases in BP. As some prior studies have found differences by sex in associations of crime/safety with other cardiometabolic outcomes,[15,16] we examined associations overall and by sex.

MATERIALS AND METHODS

Study population

The Multi-Ethnic Study of Atherosclerosis (MESA) is a multi-site cohort study of 6,814 US adults aged 45–84 at enrollment. The cohort includes self-identified White, African-American, Hispanic, and Chinese-American adults who were free of cardiovascular disease (CVD) at baseline and were recruited from six US sites.[17] Baseline exams were conducted between July 2000 and July 2002, with follow-up exams in 2002–2004 (exam 2), 2004–2005 (exam 3), 2005–2007 (exam 4), and 2010–2012 (exam 5). The Institutional Review Board at each site approved the study, and all participants provided written informed consent.

The MESA Neighborhood Study is an ancillary study which assessed neighborhood exposures and geocoded all residential addresses of MESA participants who agreed to participate. Our analysis included participants in the Neighborhood Study whose addresses were geocoded to the street-level or zip+4 centroid and who lived within the city limits of Chicago, as detailed police-recorded crime data were only available for this site (N = 855). Participant exam-years were excluded due to missing outcome (n = 4 exam-years), exposure (n = 39 exam-years), or covariate (n = 159 exam-years) data. In addition, we excluded those with hypertension at baseline to remove the potential for confounding by baseline hypertension status (N = 305), for a final sample size of 528 participants.

Blood pressure

Systolic and diastolic BP (SBP, DBP) were measured at each exam following a standard protocol. Participants rested for 5 minutes and then three measurements were taken at 2-minute intervals using an automated oscillometric sphygmomanometer.[18] The second and third measurements were averaged and this value was used for analysis. To account for treatment effects of antihypertensive medication use, we added 10 mm Hg to the observed SBP and 5 mm Hg to the observed DBP values among participants reporting antihypertensive medication use. This approach was found in simulation studies to reduce bias and loss of power relative to other strategies for handling treatment effects.[19] In a sensitivity analysis, we used the observed BP values and adjusted for antihypertensive medication use as a covariate.

Neighborhood perceived safety

Neighborhood perceived safety was assessed via questionnaire. Respondents rated an area within a 20-minute walk (approximately 1 mile) of their residence using two questions: "I feel safe walking in my neighborhood, day or night" and "Violence is not a problem in my neighborhood". Response options were Likert-scaled from 1 (strongly agree) to 5 (strongly disagree), and the scale was found to have acceptable internal consistency and reliability.[13] These measures were assessed twice from MESA participants (in 2003–2005 and 2010–2011). For exams at which perceived safety was not assessed, the score was imputed from the exam closest in time. To examine associations of individual-level perceived safety with outcomes, we averaged the responses to these two survey questions.

We aggregated individual-level perceived safety ratings to create summary measures at the neighborhood (census tract)-level. Aggregating individual-level neighborhood perceptions avoids the issue of same-source bias, in which individuals self-report both exposure and health outcomes and their health status affects how they report the exposure or vice versa.[20] To create neighborhood measures, an independent sample of community raters living in the same census tracts as MESA participants were recruited using random digit dialing or list-based sampling.[13] These community raters completed the neighborhood safety ratings in 2004 and 2011–2012. Neighborhood safety ratings of MESA participants and community raters were aggregated to the census tract-level using empirical Bayesian estimation.[13] Standardized z-scores for individual-level and neighborhood-level perceived safety were calculated for each participant by centering at the mean and dividing by the standard deviation (SD) across all time points.

Neighborhood crime

Police-recorded crime data from 2001–2012 was obtained from the City of Chicago Data Portal,[21] which contains data on all police-recorded crimes occurring within the Chicago city limits. Crime locations are geocoded to 100th block centerlines, and information on the date and crime type are available. For 1999–2000, similar police-recorded crime data were obtained from the Chicago police department. As described in previous work,[5,15,22] crime types were categorized based on Illinois Uniform Crime Reporting codes into four categories: homicide, assault/battery, criminal offenses (e.g., robbery, sexual assault), and incivilities (e.g., vandalism, drug crimes). Crimes occuring in an airport/airplane were excluded.

At each exam, 1-year normalized crime rates were calculated. Using ArcGIS version 9.1 (Esri, Redlands, CA), the total number of crime incidents within a 1 mile buffer around participant addresses in the year before the exam date was calculated (numerator). This rate was divided by the total buffer population (based on census block-level population). For each block, a weight was calculated reflecting the percentage of the block area that fell within the participant buffer. This weight was multiplied by the total population within the block, and the weighted block populations were summed to calculate the total population within the 1 mile buffer. Population counts were obtained from the US census. Crime rates were multiplied by 1,000 to reflect the crime rate per 1,000 persons. We assessed sensitivity of results to alternative buffer sizes of a ½ and ¼ mile (a ¼ mile is equivalent to a 2-block radius in Chicago).

Covariates

Time-invariant covariates included baseline age, sex, race/ethnicity, education, and duration of residence in the neighborhood (Table 1). Time-varying covariates included marital status, income, alcohol use, smoking status, waist circumference, physical activity,[23] diabetes,[24] hyperlipidemia, whether participants have moved since the last exam, and neighborhood socioeconomic status[12] (Table 1).

Statistical analysis

We used Spearman correlation coefficients to calculate correlations of individual-level perceived safety, neighborhood-level perceived safety, and police-recorded crime at each exam. In statistical models, the three exposures were modeled separately, then subsequently included together in fully-adjusted models. To examine associations of within-person changes in individual-level perceived safety, neighborhood-level perceived safety, and police-recorded crime with within-person changes in BP, we used econometric fixed-effects models. Fixed-effects models use only within-person variation in exposures and outcomes and tightly control for all time-invariant person-specific characteristics (measured and unmeasured).[14] As

Table 1. Operationalization and measurement of key socio-demographic, health-related, and neighborhood covariates

Covariate	Years assessed[a]	Operationalization	Assessment method
Baseline age	0	In years	Questionnaire
Sex	0	Male, female	Questionnaire
Race/ethnicity	0	White, Black, Chinese American	Questionnaire
Educational attainment	0	High school degree or less, some college, bachelor's degree or higher	Questionnaire
Duration of residence in neighborhood	0	In years	Questionnaire
Marital status[b]	0, 3, 10	Married/living as married vs. not	Questionnaire
Household income[c]	0, 2, 3, 10	<$40,000, $40,000–$75,000, ≥$75,000	Questionnaire
Alcohol use	0, 2, 3, 5, 10	Current, not current	Questionnaire
Smoking status	0, 2, 3, 5, 10	Never, former, current smoker	Questionnaire
Waist circumference	0, 2, 3, 5, 10	Centimeters	Measured using a steel measuring tape of standard four-ounce tension in centimeters at the minimum abdominal girth
Physical activity[c]	0, 2, 3, 10	Metabolic equivalents per week of moderate-to-vigorous physical activity	Questionnaire[d]
Diabetes	0, 2, 3, 5, 10	Yes, no	Fasting plasma glucose level ≥ 126 mg/dl or use of insulin or antihyperglycemics[e]
Hyperlipidemia	0, 2, 3, 5, 10	Yes, no	Triglycerides ≥150 mg/dl or high density lipoprotein cholesterol (HDL) <40 mg/dl for men or <50 mg/dl for women
Moving since last exam	0, 2, 3, 5, 10	Yes, no	Questionnaire
Neighborhood socioeconomic status	0, 2, 3, 5, 10	Factor score, with a higher value indicating lower socioeconomic status	Data taken from US Census (2000) and American Community Surveys (2005–2009, 2007–2011). Factor score included % adult residences with bachelor degree, % with management/professional occupations, median household income, % with interest, dividends, or rental income, and median housing value[f]

The Multi-Ethnic Study of Atherosclerosis (MESA), Chicago, Illinois, 2000–2012.
[a]Year 0 corresponds to the baseline exam; year 2 to exam 2; year 3 to exam 3; year 5 to exam 4; year 10 to exam 5.
[b]Marital status in years 2 and 5 were imputed from the closest exam.
[c]Household income and physical activity in year 5 were imputed from the closest exam.
[d]Reference for physical activity questionnaire: Bertoni *et al.*[23]
[e]Based on 2003 criteria of the American Diabetes Association: Genuth *et al.*[24]
[f]Neighborhood socioeconomic status factor score reference: Kaiser *et al.*[12]

BP trajectories demonstrated substantial departures from linearity (Supplementary Figure 1), the relationship between BP and follow-up time was modeled using piecewise linear splines with knots at 1.6 years (average follow-up time at exam 2) and 4.8 years (average follow-up time at exam 4). Model fit statistics indicated this relationship fit the data better than other parameterizations (Supplementary Table 1). As fixed-effects models inherently control for time-invariant covariates, models included only time-varying covariates (follow-up time, marital status, income, alcohol use, smoking, waist circumference, physical activity, diabetes, hyperlipidemia, moving since last exam, and neighborhood SES). However, interactions between time-invariant covariates (baseline age, sex, race, education, and neighborhood duration) and the time splines were tested to determine whether BP trajectories varied by these factors. As none were found to be significant (all $P > 0.05$), we did not retain them in final models.

We tested for differences by sex in all models by including an interaction between each neighborhood exposure and sex. As significant interactions were found, we present sex-stratified results. We also tested for an interaction by whether or not participants moved during the study period, and found none (P-interaction ≥ 0.5 for all models). All analyses were completed in Stata version 14.2 (StataCorp, College Station, TX).

RESULTS

The study population of 528 participants was followed for an average of 9.0 years. At baseline, the study population was 63.5% non-Hispanic white, 24.2% non-Hispanic black, and 12.3% non-Hispanic Chinese, and 54.9% women (Table 2). The population-level mean SBP increased from 114.4 mm Hg at baseline to 120.1 mm Hg by year 10 (2010–2012). Mean DBP increased from 69.0 mm Hg to 70.6 mm Hg. Total crime rates per 1,000 persons within a 1 mile radius of participants' home declined from 91.2 at baseline to 65.9 by year 10. The average individual-level perceived safety declined from 3.7 to 3.6 (scaled 1–5 with higher values reflecting greater perceived safety), while mean neighborhood-level perceived safety score declined from 3.6 to 3.5. A total of 113 participants (21.4%) had at least a 1 SD change in individual-level perceived safety, while 57 (10.8%) had at least a 1 SD change in neighborhood-level perceived safety, and 350 (66.3%) had a change in police-recorded crime rate of at least 10 per 1,000 persons per year. Spearman correlation coefficients ranged from 0.48 to 0.58 for individual-level and neighborhood-level perceived safety, −0.09 to −0.26 for individual-level perceived safety and police-recorded crime, and −0.11 to −0.41 for neighborhood-level safety and crime.

A 1 SD increase in individual-level perceived safety was associated with a within-person reduction in SBP of −1.54 mm Hg (95% confidence interval [CI]: −2.83, −0.25) (Table 3). The association was stronger for women than for men (P-interaction: 0.03), with a reduction of −3.06 mm Hg (95% CI: −4.95, −1.17) among women and −0.61 mm Hg (95% CI: −2.35, 1.13) among men. For DBP, an increase in individual-level perceived safety was associated with a reduction for women only (P-interaction: 0.003). For neighborhood-level perceived safety, a 1 SD increase was associated with a reduction in SBP of −0.78 mm Hg (95% CI: −2.26, 0.69) and an increase in DBP of 0.14 mm Hg (95% CI: −0.59, 0.88), although confidence intervals were wide. Results did not differ significantly by sex (P-interaction: 0.6 and 0.09, respectively).

For police-recorded crime, an increase of 10 crimes per 1,000 persons in a 1 mile buffer was associated with within-person reductions in SBP and DBP of −0.25 mm Hg (95% CI: −0.60, 0.10) and −0.08 mm Hg (95% CI: −0.25, 0.10), respectively, although confidence intervals overlapped the null (Table 3). Associations differed by sex (P-interaction <0.001 for SBP and 0.001 for DBP). Among men, an increase in crime was associated with increases in both SBP and DBP with wide confidence intervals. Among women, an increase in crime was associated with a reduction of −0.83 mm Hg (95% CI: −1.36, −0.30) in SBP and −0.25 mm Hg (95% CI: −0.50, −0.01) in DBP. However, results were sensitive to the size of the neighborhood buffer used. When the crime area buffer was reduced to a ½ or ¼ mile, an increase in crime was no longer associated with a significant reduction in BP among women (Table 4).

Results were similar in models that simultaneously included all three neighborhood exposures (Tables 3 and 4). In addition, patterns were similar in sensitivity analyses that used the original recorded BP and adjusted for antihypertensive medication use (Supplementary Tables 2 and 3).

DISCUSSION

Neighborhood- and individual-level perceived safety and police-recorded crime rates may influence BP through chronic stress, yet few studies have examined these associations. In a multiethnic cohort, an increase in individual-level perceived safety was associated with a decrease in SBP for the overall population, and with a decrease in DBP among women only. In contrast, change in neighborhood-level perceived safety was not associated with BP change. An increase in police-recorded crime was associated with a reduction in SBP and DBP among women, in contrast to the study hypothesis. However, this finding was attenuated when altering the neighborhood buffer.

Few studies have examined associations of neighborhood crime/safety with BP or hypertension. Prior work in MESA found no association of neighborhood-level safety with prevalent or incident hypertension.[10,12] However, neither study examined individual-level perceived safety or police-recorded crime. Two prior studies found individual-level perceived crime/safety were not associated with cross-sectional differences in BP among African Americans.[9,11] Our findings that an increase in individual-level perceived safety was associated with within-person reductions in SBP suggests that improvements in perceived safety may be particularly relevant for BP changes. It is possible that individuals may adapt to a stressful environment, but that a change in the environment (due to moving to a new neighborhood or due to changes in their present neighborhood) may affect stress and downstream health outcomes. More research

Table 2. Characteristics of study participants over follow-up

Characteristic	Year 0, exam 1 N (%)	Year 2, exam 2 N (%)	Year 3, exam 3 N (%)	Year 5, exam 4 N (%)	Year 10, exam 5 N (%)	*P*-value[a]
Total *N*	528	478	457	418	367	—
Time since baseline, years, Mean (SD)	N/A	1.6 (0.3)	3.1 (0.3)	4.8 (0.4)	9.4 (0.5)	—
Outcomes[b]						
Systolic blood pressure, mm Hg, mean (SD)	114.4 (13.8)	114.2 (15.8)	114.8 (16.4)	118.1 (17.4)	120.1 (18.9)	<0.001
Diastolic blood pressure, mm Hg, mean (SD)	69.0 (9.1)	68.9 (9.5)	69.0 (10.0)	69.9 (9.9)	70.6 (10.6)	0.06
Neighborhood exposures						
Individual perceived safety (SD)[c]	3.7 (0.9)	3.6 (0.9)	3.7 (0.9)	3.7 (0.9)	3.6 (0.9)	0.7
Neighborhood perceived safety, mean (SD)[c]	3.6 (0.4)	3.6 (0.4)	3.6 (0.4)	3.5 (0.5)	3.5 (0.5)	<0.001
Total crime per 1,000 persons within 1 mile radius, mean (SD)	91.2 (34.6)	86.9 (31.8)	88.2 (32.3)	87.9 (40.5)	65.9 (36.3)	<0.001
Total crime per 1,000 persons within ½ mile radius, mean (SD)	72.3 (44.3)	70.7 (42.9)	73.1 (43.1)	76.0 (52.1)	56.3 (42.4)	<0.001
Total crime per 1,000 persons within ¼ mile radius, mean (SD)	59.8 (42.0)	59.7 (42.3)	62.6 (42.5)	64.5 (49.0)	49.9 (41.7)	<0.001
Sociodemographics						
Age, years, mean (SD)	60.4 (9.6)	61.6 (9.4)	63.4 (9.5)	65.3 (9.4)	69.2 (9.3)	<0.001
Sex						0.9
Men	238 (45.1)	210 (43.9)	193 (42.2)	175 (41.9)	157 (42.8)	
Women	290 (54.9)	268 (56.1)	264 (27.8)	243 (58.1)	210 (57.2)	
Race						0.9
Non-Hispanic White	335 (63.5)	302 (63.2)	294 (64.3)	277 (66.3)	234 (63.8)	
Non-Hispanic Black	128 (24.2)	117 (24.5)	111 (24.3)	93 (22.2)	88 (24.0)	
Non-Hispanic Chinese	65 (12.3)	59 (12.3)	52 (11.4)	48 (11.5)	45 (12.2)	
Education						0.9
High school or less	55 (10.4)	49 (10.3)	43 (9.4)	38 (9.1)	31 (8.5)	
Some college/ associate's degree	123 (23.3)	110 (23.0)	104 (22.8)	88 (21.0)	79 (21.5)	
Bachelor's degree or less	350 (66.3)	319 (66.7)	310 (67.8)	292 (69.9)	257 (70.0)	
Household income, $						0.9
<40,000	120 (22.7)	105 (22.0)	106 (23.2)	92 (22.0)	91 (24.8)	
40,000–74,999	127 (24.1)	114 (23.8)	108 (23.6)	98 (23.4)	83 (22.6)	
≥75,000	281 (53.2)	259 (54.2)	243 (53.2)	228 (54.6)	193 (52.6)	
Married/living as married	319 (60.4)	291 (60.9)	274 (60.0)	249 (59.6)	202 (55.0)	0.5

Table 2. *Continued*

Characteristic	Year 0, exam 1 N (%)	Year 2, exam 2 N (%)	Year 3, exam 3 N (%)	Year 5, exam 4 N (%)	Year 10, exam 5 N (%)	P-value[a]
Health behaviors/clinical factors						
Smoking status						0.1
Never smoker	248 (47.0)	213 (44.6)	203 (44.4)	179 (42.8)	158 (43.0)	
Former smoker	211 (40.0)	208 (43.5)	207 (45.3)	199 (47.6)	180 (49.1)	
Current smoker	69 (13.0)	57 (11.9)	47 (10.3)	40 (9.6)	29 (7.9)	
Current alcohol use	412 (78.0)	350 (73.2)	328 (71.8)	282 (67.5)	232 (63.2)	<0.001
Moderate/vigorous physical activity, MET-minutes/week, mean (SD)	5453.3 (4783.1)	4854.0 (4445.7)	5148.2 (5050.4)	5043.1 (4892.0)	5024.6 (4720.1)	0.4
Waist circumference, mean (SD)	92.9 (13.8)	94.0 (14.0)	94.1 (14.2)	93.9 (13.9)	95.1 (15.7)	0.3
Diabetes	24 (4.6)	22 (4.6)	20 (4.4)	24 (5.7)	34 (9.3)	0.01
Hyperlipidemia	173 (32.8)	158 (33.1)	139 (30.5)	123 (29.6)	74 (20.2)	<0.001
On antihypertensive medication	38 (7.2)	66 (13.8)	82 (17.9)	97 (23.2)	112 (30.5)	<0.001
Neighborhood covariates						
Length of residence in neighborhood at baseline, years, mean (SD)	18.9 (14.4)	19.5 (14.2)	19.7 (14.4)	19.8 (14.3)	19.2 (13.8)	0.9
Neighborhood socioeconomic status factor score, mean (SD)[d]	−2.1 (1.5)	−2.0 (1.5)	−2.1 (1.4)	−2.3 (1.4)	−2.0 (1.3)	0.003
Moved before visit	N/A	31 (6.5)	21 (4.6)	23 (5.5)	29 (7.9)	0.2

The Multi-Ethnic Study of Atherosclerosis (MESA), Chicago, Illinois, 2000–2012.
[a]*P*-values from chi-squared tests for categorical variables and analysis of variance (ANOVA) for continuous variables.
[b]For participants who reported antihypertensive medication use, 10 mm Hg was added to the observed systolic blood pressure and 5 mm Hg was added to the observed systolic blood pressure to account for treatment effects.
[c]Higher value indicates greater safety.
[d]Higher value indicates lower socioeconomic status.

is needed to elucidate the specific mechanisms of effect of neighborhood change.

Our finding that increases in police-recorded crime rates were associated with reductions in BP among women was contrary to our hypothesis and surprising given the strong association of individual-level safety with SBP reduction. The reason for this association is unclear, but its attenuation upon reducing the neighborhood buffer size suggests this finding is not very robust. Objectively measured crime may not align well with individuals' perceptions of neighborhood safety, and individual perception of safety may be more strongly linked to stress-related cardiometabolic effects than actual crime rates. Prior studies have found low levels of agreement between perceived and objective measures of crime/safety,[25–27] and these measures were not highly correlated in our study. While individual perceptions are potentially subject to same-source bias,[20] their importance for health outcomes is supported by prior work in MESA, where changes in perceived individual-level safety were more strongly associated with changes in BMI and waist circumference than police-recorded crime,[15] and more strongly associated with changes in depressive symptoms than neighborhood-level safety.[28]

The mechanism by which perceived safety may influence BP is not explicitly known. One potential pathway is through prolonged activation of the hypothalamic-pituitary-adrenal axis and secretion of stress hormones.[3] Long-term dysregulation of stress hormones can result in inflammation and endothelial dysfunction, and subsequently higher BP levels.[3,4] Perceptions of an unsafe neighborhood may also deter residents from engaging in physical activity in their neighborhood or could encourage unhealthy coping mechanisms like smoking. We found associations of perceived safety with reduced SBP among MESA participants after controlling for physical activity, smoking, and alcohol use. However, more longitudinal research on stress-related biomarkers is needed to fully support the biological stress mechanism.

The stronger association between individual-level perceived safety and BP among women than men in our study might be explained by sex differences in stress response.

Table 3. Mean within-person changes in blood pressure associated with within-person changes in crime and neighborhood safety[a]

	Systolic blood pressure (mm Hg)			Diastolic blood pressure (mm Hg)		
	Overall, $N = 528$	Men, $N = 238$	Women, $N = 290$	Overall, $N = 528$	Men, $N = 238$	Women, $N = 290$
Single exposure models						
Individual perceived safety score[b]	−1.54 (−2.83, −0.25)*	−0.61 (−2.35, 1.13)	−3.06 (−4.95, −1.17)*	−0.23 (−0.87, 0.42)	0.59 (−0.39, 1.56)	−1.24 (−2.12, −0.37)*
Neighborhood perceived safety score[b]	−0.78 (−2.26, 0.69)	−1.38 (−3.43, 0.67)	−0.30 (−2.37, 1.77)	0.14 (−0.59, 0.88)	0.45 (−0.70, 1.60)	−0.12 (−1.08, 0.84)
Total crime per 1,000 persons within 1 mile[c]	−0.25 (−0.60, 0.10)	0.32 (−0.13, 0.78)	−0.83 (−1.36, −0.30)*	−0.08 (−0.25, 0.10)	0.11 (−0.15, 0.36)	−0.25 (−0.50, −0.01)*
Fully adjusted models with neighborhood exposures modeled together						
Individual perceived safety score[b]	−1.53 (−2.85, −0.21)*	−0.27 (−2.06, 1.52)	−3.13 (−5.04, −1.21)*	−0.28 (−0.94, 0.39)	0.59 (−0.41, 1.60)	−1.27 (−2.16, −0.38)*
Neighborhood perceived safety score[b]	−0.79 (−2.33, 0.75)	−1.06 (−3.20, 1.08)	−0.70 (−2.88, 1.48)	0.12 (−0.65, 0.90)	0.45 (−0.75, 1.65)	−0.18 (−1.19, 0.84)
Total crime per 1,000 persons within 1 mile[c]	−0.34 (−0.70, 0.02)	0.26 (−0.21, 0.73)	−0.94 (−1.49, −0.38)*	−0.08 (−0.26, 0.10)	0.15 (−0.11, 0.42)	−0.29 (−0.54, −0.03)*

The Multi-Ethnic Study of Atherosclerosis (MESA), Chicago, Illinois, 2000–2012. *$P < 0.05$.
[a]Estimated using linear fixed-effects models with subject-specific fixed effects. Models adjusted for time since baseline as two-knot piecewise linear splines, and the following time-varying covariates: marital status, household income, smoking status, alcohol use, waist circumference, total physical activity, diabetes, hyperlipidemia, neighborhood socioeconomic status, and moving before the exam. Neighborhood exposures were first modeled separately ("single exposure models") and subsequently models were run including all three neighborhood exposures ("fully adjusted models…").
[b]Per standard deviation increase. Higher score indicates greater perceived neighborhood safety.
[c]Per 10 crime increase.
[d]P values for neighborhood exposure × sex interactions: Systolic blood pressure: individual perceived safety: $P = 0.03$, neighborhood safety: $P = 0.6$, total crime: $P < 0.0001$. Diastolic blood pressure: individual perceived safety: $P = 0.003$, neighborhood safety: $P = 0.09$, total crime: $P = 0.001$.

Psychological distress has been shown to mediate associations between neighborhood safety and obesity,[29] and a similar process might be at work for BP. Women may experience greater fear of crime in response to perceived neighborhood risks,[30] which may increase the level of psychological distress experienced due to living in a neighborhood perceived to be unsafe. In addition, sex hormones regulate the hypothalamic-pituitary-adrenal axis response to psychological stress differently between men and women,[31] which might explain the differences observed in our study.

The magnitude of SBP reduction associated with an increase in individual-level perceived safety in our study suggests that interventions that increase individuals' perceived neighborhood safety could have a meaningful impact on CVD. SBP is more strongly related to CVD incidence than DBP among middle-aged and older adults.[32] In addition, a prior study evaluating the impact of a hypothetical population-level intervention estimated that a 1 mm Hg reduction of SBP would reduce incidence of coronary heart disease by approximately 10 events per 100,000 population.[33] Thus, even relatively small changes in SBP may be clinically meaningful in terms of CVD prevention.

Strengths of this study include longitudinal data with multiple domains of neighborhood safety and crime measured at multiple time points, and the diverse sample of middle-aged to older adults. This study is also subject to several limitations. First, while fixed-effects models prevent confounding by unmeasured time-invariant factors, they do not eliminate residual confounding due to time-varying unmeasured factors (e.g., other neighborhood characteristics such as the built environment). Second, selection bias may have occurred if loss to follow-up differed by both BP and neighborhood safety/crime. Third, the survey-based neighborhood safety measures were only available at two time points. While this enabled us to estimate changes, we assigned measures at exams where this information was not collected based on the closest time point. This may have led to misspecification of the neighborhood environment in these unmeasured time points and may have reduced the amount of change we were able to capture. The crime data in this study did not capture crime incidents that were not reported to the police. In addition, reasons for the unexpected association of police-recorded crime with a reduction in BP among women remained unclear. Finally, as our analysis included only MESA participants in Chicago, results may not generalize to other geographic locations.

CONCLUSIONS

In a multi-ethnic cohort of middle-aged to older adults, increases in individual-level perceived safety were associated with within-person reductions in SBP overall, and with DBP among women. Associations for police-recorded crime were

Table 4. Mean within-person changes in blood pressure associated with within-person changes in total crime-sensitivity to neighborhood buffer sizes[a,c]

	Systolic blood pressure (mm Hg)			Diastolic blood pressure (mm Hg)		
	Overall, $N = 528$	Men, $N = 238$	Women, $N = 290$	Overall, $N = 528$	Men, $N = 238$	Women, $N = 290$
Single exposure models						
Total crime per 1,000 persons within 1 mile[b]	−0.25 (−0.60, 0.10)	0.32 (−0.13, 0.78)	−0.83 (−1.36, −0.30)*	−0.08 (−0.25, 0.10)	0.11 (−0.15, 0.36)	−0.25 (−0.50, −0.01)*
Total crime per 1,000 persons within ½ mile[b]	−0.03 (−0.30, 0.23)	0.22 (−0.14, 0.58)	−0.25 (−0.64, 0.14)	0.02 (−0.11, 0.16)	0.10 (−0.10, 0.30)	−0.03 (−0.22, 0.15)
Total crime per 1,000 persons within ¼ mile[b]	0.10 (−0.17, 0.37)	0.22 (−0.13, 0.57)	0.01 (−0.40, 0.42)	0.07 (−0.06, 0.21)	0.04 (−0.15, 0.24)	0.11 (−0.08, 0.30)
Fully adjusted models with neighborhood exposures modeled together						
Total crime per 1,000 persons within 1 mile[b]	−0.34 (−0.70, 0.02)	0.26 (−0.21, 0.73)	−0.94 (−1.49, −0.38)*	−0.08 (−0.26, 0.10)	0.15 (−0.11, 0.42)	−0.29 (−0.54, −0.03)*
Total crime per 1,000 persons within ½ mile[b]	−0.08 (−0.35, 0.19)	0.18 (−0.19, 0.55)	−0.26 (−0.66, 0.14)	0.02 (−0.11, 0.16)	0.13 (−0.07, 0.34)	−0.04 (−0.22, 0.15)
Total crime per 1,000 persons within ¼ mile[b]	0.05 (−0.22, 0.32)	0.18 (−0.18, 0.54)	−0.01 (−0.43, 0.40)	0.07 (−0.06, 0.21)	0.08 (−0.12, 0.28)	0.11 (−0.09, 0.30)

The Multi-Ethnic Study of Atherosclerosis (MESA), Chicago, Illinois, 2000–2012. *$P < 0.05$.

[a]Estimated using linear fixed-effects models with subject-specific fixed effects. Models adjusted for time since baseline as two-knot piecewise linear splines, and the following time-varying covariates: marital status, household income, smoking status, alcohol use, waist circumference, total physical activity, diabetes, hyperlipidemia, neighborhood socioeconomic status, and moving before the exam. Neighborhood exposures were first modeled separately ("single exposure models") and subsequently models were run including all three neighborhood exposures ("fully adjusted models…").

[b]Per 10 crime increase.

[c]P values for neighborhood exposure × sex interactions: Systolic blood pressure: 1 mile radius: $P < 0.0001$; ½ mile radius: $P = 0.007$; ¼ mile radius: $P = 0.1$. Diastolic blood pressure: 1 mile radius: $P = 0.001$; ½ mile radius: $P = 0.1$; ¼ mile radius: $P = 0.9$.

inconsistent. Results suggest individual perceptions of safety differ from police-recorded crime, and support the development of evidence-based approaches to improve neighborhood safety and engage residents in the process order to improve their perceptions of neighborhood safety.

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DISCLOSURE

The authors declared no conflict of interest.

REFERENCES

1. Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obes Rev* 2011; 12:217–230.
2. Chandola T. The fear of crime and area differences in health. *Health Place* 2001; 7:105–116.
3. McEwen BS, Stellar E. Stress and the individual. Mechanisms leading to disease. *Arch Intern Med* 1993; 153:2093–2101.
4. Pickering TG. Stress, inflammation, and hypertension. *J Clin Hypertens (Greenwich)* 2007; 9:567–571.
5. Evenson KR, Block R, Diez Roux AV, McGinn AP, Wen F, Rodríguez DA. Associations of adult physical activity with perceived safety and police-recorded crime: the Multi-Ethnic Study of Atherosclerosis. *Int J Behav Nutr Phys Act* 2012; 9:146.

6. Harrison RA, Gemmell I, Heller RF. The population effect of crime and neighbourhood on physical activity: an analysis of 15,461 adults. *J Epidemiol Community Health* 2007; 61:34–39.
7. Piro FN, Noss O, Claussen B. Physical activity among elderly people in a city population: the influence of neighbourhood level violence and self perceived safety. *J Epidemiol Community Health* 2006; 60:626–632.
8. Agyemang C, van Hooijdonk C, Wendel-Vos W, Ujcic-Voortman JK, Lindeman E, Stronks K, Droomers M. Ethnic differences in the effect of environmental stressors on blood pressure and hypertension in the Netherlands. *BMC Public Health* 2007; 7:118.
9. Coulon SM, Wilson DK, Alia KA, Van Horn ML. Multilevel associations of neighborhood poverty, crime, and satisfaction with blood pressure in African-American adults. *Am J Hypertens* 2016; 29:90–95.
10. Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan TE, Cooper RS, Ni H, Shea S. Neighborhood characteristics and hypertension. *Epidemiology* 2008; 19:590–598.
11. Clark CR, Ommerborn MJ, Hickson DA, Grooms KN, Sims M, Taylor HA, Albert MA. Neighborhood disadvantage, neighborhood safety and cardiometabolic risk factors in African Americans: biosocial associations in the Jackson Heart Study. *PLoS One* 2013; 8:e63254.
12. Kaiser P, Diez Roux AV, Mujahid M, Carnethon M, Bertoni A, Adar SD, Shea S, McClelland R, Lisabeth L. Neighborhood environments and incident hypertension in the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol* 2016; 183:988–997.
13. Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan T. Assessing the measurement properties of neighborhood scales: from psychometrics to ecometrics. *Am J Epidemiol* 2007; 165:858–867.
14. Allison PD. *Fixed Effects Regression Models,* 1st edn. SAGE Publications: Thousand Oaks, CA, 2009.
15. Powell-Wiley TM, Moore K, Allen N, Block R, Evenson KR, Mujahid M, Diez Roux AV. Associations of neighborhood crime and safety and with changes in body mass index and waist circumference: the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol* 2017; 186:280–288.
16. Pham do Q, Ommerborn MJ, Hickson DA, Taylor HA, Clark CR. Neighborhood safety and adipose tissue distribution in African Americans: the Jackson Heart Study. *PLoS One* 2014; 9:e105251.
17. Bild DE, Bluemke DA, Burke GL, Detrano R, Diez Roux AV, Folsom AR, Greenland P, Jacob DR Jr, Kronmal R, Liu K, Nelson JC, O'Leary D, Saad MF, Shea S, Szklo M, Tracy RP. Multi-Ethnic Study of Atherosclerosis: objectives and design. *Am J Epidemiol* 2002; 156:871–881.
18. Perloff D, Grim C, Flack J, Frohlich ED, Hill M, McDonald M, Morgenstern BZ. Human blood pressure determination by sphygmomanometry. *Circulation* 1993;88:2460–2470.
19. Tobin MD, Sheehan NA, Scurrah KJ, Burton PR. Adjusting for treatment effects in studies of quantitative traits: antihypertensive therapy and systolic blood pressure. *Stat Med* 2005; 24:2911–2935.
20. Raudenbush SW, Sampson RJ. Ecometrics: toward a science of assessing ecological settings, with application to the systematic social observation of neighborhoods. *Sociol Methodol* 1999; 29:1–41.
21. City of Chicago. Chicago Data Portal. 2017, published online 8 May 2017 <https://data.cityofchicago.org/>.
22. Kerr Z, Evenson KR, Moore K, Block R, Diez Roux AV. Changes in walking associated with perceived neighborhood safety and police-recorded crime: the Multi-Ethnic Study of Atherosclerosis. *Prev Med* 2015; 73:88–93.
23. Bertoni AG, Whitt-Glover MC, Chung H, Le KY, Barr RG, Mahesh M, Jenny NS, Burke GL, Jacobs DR. The association between physical activity and subclinical atherosclerosis: the Multi-Ethnic Study of Atherosclerosis. *Am J Epidemiol* 2009; 169:444–454.
24. Genuth S, Alberti KG, Bennett P, Buse J, Defronzo R, Kahn R, Kitzmiller J, Knowler WC, Lebovitz H, Lernmark A, Nathan D, Palmer J, Rizza R, Saudek C, Shaw J, Steffes M, Stern M, Tuomilehto J, Zimmet P; Expert Committee on the Diagnosis and Classification of Diabetes Mellitus. Follow-up report on the diagnosis of diabetes mellitus. *Diabetes Care* 2003; 26:3160–3167.
25. McGinn AP, Evenson KR, Herring AH, Huston SL, Rodriguez DA. The association of perceived and objectively measured crime with physical activity: a cross-sectional analysis. *J Phys Act Health* 2008; 5:117–131.
26. Kirtland KA, Porter DE, Addy CL, Neet MJ, Williams JE, Sharpe PA, Neff LJ, Kimsey CD Jr, Ainsworth BE. Environmental measures of physical activity supports: perception versus reality. *Am J Prev Med* 2003; 24:323–331.
27. Luo F, Ren L, Zhao JS. Location-based fear of crime: a case study in Houston, Texas. *Crim Justice Rev* 2015; 41:75–97.
28. Moore KA, Hirsch JA, August C, Mair C, Sanchez BN, Diez Roux AV. Neighborhood social resources and depressive symptoms: longitudinal results from the Multi-Ethnic Study of Atherosclerosis. *J Urban Health* 2016; 93:572–588.
29. Burdette AM, Hill TD. An examination of processes linking perceived neighborhood disorder and obesity. *Soc Sci Med* 2008; 67:38–46.
30. Snedker KA. Neighborhood conditions and fear of crime: a reconsideration of sex differences. *Crime Delinq* 2015; 61:45–70.
31. Pasquali R. The hypothalamic-pituitary-adrenal axis and sex hormones in chronic stress and obesity: pathophysiological and clinical aspects. *Ann N Y Acad Sci* 2012; 1264:20–35.
32. Franklin SS, Larson MG, Khan SA, Wong ND, Leip EP, Kannel WB, Levy D. Does the relation of blood pressure to coronary heart disease risk change with aging? The Framingham Heart Study. *Circulation* 2001; 103:1245–1249.
33. Hardy ST, Loehr LR, Butler KR, Chakladar S, Chang PP, Folsom AR, Heiss G, MacLehose RF, Matsushita K, Avery CL. Reducing the blood pressure-related burden of cardiovascular disease: impact of achievable improvements in blood pressure prevention and control. *J Am Heart Assoc* 2015; 4:e002276.