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Original Contribution

Mediation of Firearm Violence and Preterm Birth by Pregnancy Complications and Health Behaviors: Addressing Structural and Postexposure Confounding

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Firearm violence may indirectly affect health among pregnant women living in neighborhoods where it is endemic. We used birth, death, emergency department, and hospitalization data from California from 2007–2011 to estimate the association between living in a neighborhood with high firearm violence and preterm delivery, and assessed whether there was mediation by diagnoses of pregnancy complications and health behaviors during pregnancy. We used an ensemble machine learning algorithm to predict the propensity for neighborhoods to be classified as having a high level of firearm violence. Risk differences for the total effect and stochastic direct and indirect effects were estimated using targeted maximum likelihood. Residence in high-violence neighborhoods was associated with higher prevalence of preterm birth (risk difference (RD) = 0.46, 95% confidence interval (CI): 0.13, 0.80), infections (RD = 1.34, 95% CI: −0.17, 2.86), asthma (RD = 0.76, 95% CI: 0.03, 1.48), and substance use (RD = 0.74, 95% CI: 0.00, 1.47). The largest indirect effects for the association between violence and preterm birth were observed for infection (stochastic indirect effect = 0.04, 95% CI: 0.00, 0.08) and substance use (stochastic indirect effect = 0.04, 95% CI: 0.01, 0.06). Firearm violence was associated with risk of preterm delivery, and this association was partially mediated by infection and substance use.

causal mediation analysis; firearm violence; pregnancy complications; preterm birth

Abbreviations: BMI, body mass index; CI, confidence interval; ICD-9, *International Classification of Diseases, Ninth Revision*; ZCTA, Zip Code Tabulation Area.

Firearm violence is a persistent problem in neighborhoods across the United States. In addition to causing premature death and imposing significant costs from immediate and long-term health-care needs, exposure to firearm violence can also affect health in the community overall (1–3). Experiencing firearm violence in one's community can increase risks of stress-responsive diseases (1) and may influence birth outcomes through similar stress mechanisms (4). In particular, exposure to high levels of firearm violence before and during pregnancy may increase maladaptive health behaviors or have direct physiological effects on maternal health, both of which can increase risk of preterm birth (5–10). Accordingly, previous research has found evidence that exposure to community violence is associated with increased risk of adverse pregnancy outcomes (4, 11).

However, structural confounding is a substantial challenge when studying firearm violence exposure and pregnancy outcomes. Because of historical policies of residential segregation and economic exclusion (12), communities that have high levels of violence also tend to have other features of social and economic inequality, such as elevated poverty, fewer economic opportunities, and reduced educational attainment. Disentangling these factors is difficult to accomplish using statistical adjustment because they are so correlated (13). Some previous studies have attempted to circumvent this issue by leveraging within-place variation in violence over time (14), rather than comparing people across communities. However, this approach typically focuses on acute changes in violence, and chronic violence is expected to have a much greater impact on health (15).

Chronic exposure to firearm violence may have physiological consequences that manifest over time as pregnancy complications (16). For example, studies have shown that chronic exposure to stressors like violence can dysregulate immune function (17), making pregnant women more susceptible to infection (18, 19). Evidence also suggests that altered immune function may be linked to preeclampsia (20, 21) and asthma (22, 23). In addition, chronic exposure to firearm violence could increase the likelihood that women adopt coping mechanisms for their own emotional well-being that may have negative implications for health. Violence exposure has previously been tied to altered health behaviors, including increased sexual risk-taking (24–26) and substance use (27–31). Diet and exercise patterns may also influence risk for gestational diabetes (32). These behavior modifications may affect maternal and fetal health, and understanding their role in pregnancy can help researchers better understand firearm violence as a potential driver of disparities in preterm birth.

In this study, we examined the association between community firearm violence and risk of preterm birth. To address issues of structural confounding, we used machine learning to predict the propensity of neighborhoods to have high levels of firearm violence and restricted our analysis to neighborhoods with similar propensities. We also investigated possible mediators of the relationship between firearm violence and preterm delivery, to identify potential mechanisms and improve our understanding of how features of the social environment, such as violence, can influence preterm birth.

METHODS

We used birth records linked to emergency department, hospitalization, and ambulatory surgery records during pregnancy; emergency department, hospitalization, and death records; and US Census data from 2007–2011 to estimate the association between living in a neighborhood with high firearm violence and preterm birth in California. In order to avoid fixed cohort bias, we removed any births with a conception week before January 1, 2007, or after March 1, 2011 (33). We defined preterm birth as delivery of a live singleton before 37 weeks' gestation, based on the clinical estimate of gestational age in the birth record. We stratified preterm births into spontaneous deliveries and indicated deliveries. Births were classified as spontaneously preterm if a woman delivered before 37 weeks' gestation and had a diagnosis code associated with premature labor or preterm premature rupture of the membranes, or if she had premature rupture of the membranes listed as a complication of labor or delivery or use of tocolytic agents in the birth record. Any preterm births that were not identified as spontaneous were classified as indicated. Individual-level covariates included maternal age, maternal age squared, educational attainment, race/ethnicity, health insurance type, and month-year of conception.

Rates of firearm violence were calculated for Zip Code Tabulation Areas (ZCTAs) using emergency department and hospitalization records from California's Office of Statewide Health Planning and Development and death records from the Center for Health Statistics and Informatics, California Department of Public Health, for 2007–2011. Incidents of firearm violence were defined as any firearm-related assault or fatality that was recorded in the emergency department, hospitalization, or mortality data and were geocoded to the victim's home address. People who went to the emergency department before being admitted to the hospital only had a hospitalization record, and people who died after seeking care at the emergency department or hospital were only included via the death records; thus, any duplicates of incidents across data sources were removed so they were not double-counted. The firearm violence rate was calculated by dividing the total number of firearm violence deaths and injuries by the estimated person-time. Neighborhoods were classified as "high firearm violence" if the average rate of firearm violence exceeded the 90th percentile of firearm violence rates (37.97 deaths/injuries per 100,000 person-years). To rigorously control for neighborhood-level factors associated with firearm violence that could influence risk of preterm birth, we used a set of community covariates that have been shown to optimally predict levels of firearm violence in California (34). These data were obtained from the 2007–2011 American Community Survey, the Census Topologically Integrated Geographic Encoding and Referencing (TIGER) files, and the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) database.

Pregnancy complications and health behaviors were examined as potential mediators. We identified pregnancy complications as adverse events or comorbid conditions occurring during pregnancy that may plausibly be affected by firearm violence and have been associated with increased risk of preterm birth in previous studies (35–38). Early-onset preeclampsia, gestational diabetes, substance use, asthma, and infection were identified using *International Classification of Diseases, Ninth Revision* (ICD-9), codes from the maternal hospitalization, emergency department, or ambulatory surgery records for the duration of pregnancy that were linked via a probabilistic linkage algorithm to the birth records. ICD-9 codes were chosen on the basis of prior research that used linked birth and hospitalization records to identify pregnancy complications (38–46). We focused on early-onset preeclampsia (diagnosis before 34 weeks' gestation) because previous literature suggested that late-onset preeclampsia may have a distinct etiology (47). We determined the timing of preeclampsia on the basis of the date of the first record that indicated a preeclampsia diagnosis during pregnancy.

Mediation analyses present difficulties in questions like this, because one key assumption of most methods is that no mediator-outcome confounder is affected by prior exposure. In particular, natural direct and indirect effects are not identified when there is postexposure confounding. However, chronic exposure to firearm violence may influence health behaviors and/or chronic conditions that both increase the likelihood of pregnancy complications and may affect preterm delivery. Violation of this assumption has required previous mediation analyses of social exposures and pregnancy outcomes to focus on controlled direct effects, in which the mediator values are set to the same level for everyone, blocking the mediated pathway (37, 48). These effects are often difficult to interpret, given that our understanding of why women develop complications is incomplete; therefore, setting the complication status to a certain value for all women is infeasible in reality. Furthermore, if the goal is to understand the indirect pathway—that is, the extent to which the exposure influences the outcome through the mediator—then estimating controlled direct effects is insufficient. To address this issue, we estimated stochastic direct and indirect effects, which allowed us to estimate indirect effects, rely on fewer assumptions, and have the option of including postexposure confounders. When no postexposure confounders exist, stochastic direct and indirect effects are the same in expectation as natural direct and indirect effects.

Previous literature has suggested that preexisting chronic conditions are important to consider when evaluating the relationship between pregnancy complications and risk of preterm birth (49). Living in a neighborhood with high firearm violence could affect diet and exercise habits or induce stress-related coping behaviors that affect weight gain or increase the prevalence of certain chronic conditions (50); therefore, prepregnancy body mass index (BMI; weight (kg)/height (m)^2), preexisting hypertension, and preexisting diabetes were identified as postexposure confounders (Figure 1). These conditions were identified from the linked hospitalization and birth record files. All ICD-9 and *International Classification of Diseases, Tenth Revision*, codes used in this analysis are listed in Web Table 1 (available at https://academic.oup.com/aje).

This study was reviewed and approved by the California Health and Human Services Agency Committee for the Protection of Human Subjects and the University of California, Berkeley, Committee for the Protection of Human Subjects.

Statistical analysis

Propensity score estimation for neighborhood-level firearm violence. We estimated propensity scores to identify neighborhoods with similar characteristics but differing levels of firearm violence. We used SuperLearner, an ensemble machine learning algorithm (51), along with a set of neighborhood covariates that included measures related to residential segregation, poverty, educational attainment, and environmental characteristics (Web Table 2), to estimate the propensity for a neighborhood to be classified as having a high level of violence (see Web Appendix 1 for the list of algorithms included in the SuperLearner). Neighborhoods were retained in the analysis if the propensity score fell between the 2.5th percentile of the values for neighborhoods that were observed to have high violence and the 97.5th percentile of values for neighborhoods that were not observed to have high violence, in accordance with prior recommendations (52). We used stabilized inverse probability of treatment weights to account for remaining confounding by the community covariates (53).

Estimation of total effects. We used targeted maximum likelihood estimation to estimate risk differences (54). The outcome and exposure models were estimated using logistic regression. Targeted maximum likelihood estimation is a double-robust substitution estimator, meaning that if the exposure or the outcome model is correct, then the estimate will be consistent. The exposure model captures the individual-level characteristics associated with living in a neighborhood with high firearm violence, and it is weighted by the inverse probability of treatment weights constructed using the community covariates; therefore, both the individual- and community-level covariates are incorporated in its estimation. To account for the clustering of women within ZCTAs, we used a nonparametric clustered bootstrap with Wald-style confidence intervals for inference.

Estimation of stochastic direct and indirect effects. We believed that the assumption of no postexposure confounding was violated in this study (see Figure 1 and Web Appendix 2 for additional discussion); therefore, we opted to estimate stochastic direct and indirect effects (55). We define our variables as follows: Y is preterm birth; A is living in a neighborhood with high firearm violence; M is a pregnancy

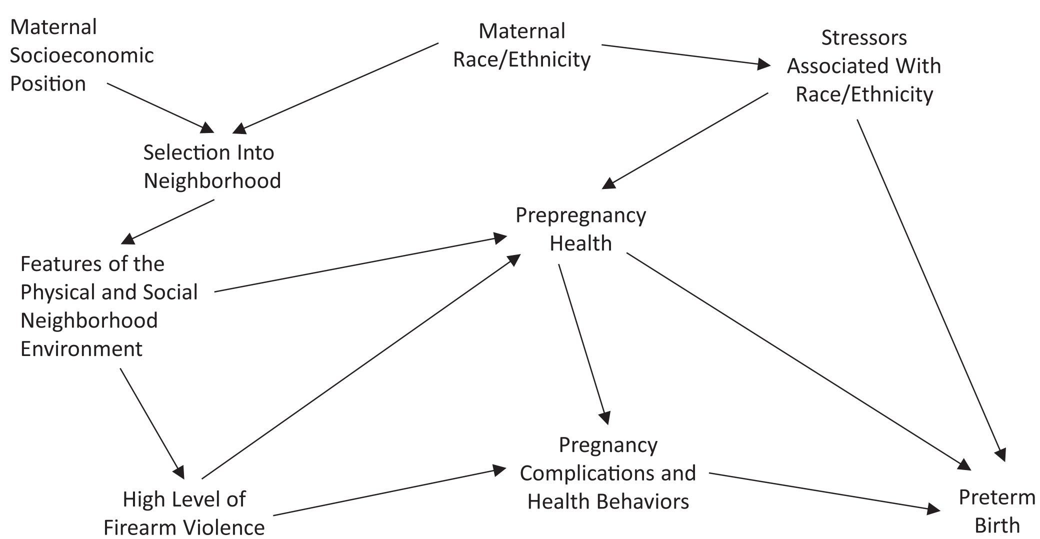

Figure 1. Potential relationships between exposure to firearm violence, pregnancy complications and health behaviors, and preterm birth.

complication or health behavior during pregnancy; Z is prepregnancy BMI, hypertension, and diabetes status; and W is the set of individual covariates. Y_a is the counterfactual outcome if $A = a$, and Y_{a*} is the counterfactual outcome if $A = a^*$. Y_{am} is the counterfactual outcome if $A = a$ and $M = m$. The required confounding assumptions to identify stochastic direct and indirect effects can be written as

$$A \perp Y_{am} \mid W$$
$$A \perp M_a \mid W$$
$$M \perp Y_{am} \mid W, A, Z.$$

The following positivity assumptions are also required:

$$0 < P\Big(M = m|A = a, W, Z\Big) < 1.$$
$$0 < P\Big(A = a|W\Big) < 1.$$

The stochastic direct effect (SDE) is defined as

$$\text{SDE} = E\Big(Y_{a,\widehat{g}_{M|a^*,w}} - Y_{a^*,\widehat{g}_{M|a^*,w}}\Big),$$

Table 1. Demographic and Health Characteristics (%) of Participants According to Birth Record Data Set in a Study of Firearm Violence and Preterm Birth, California, 2007–2011

Demographic or Health Characteristic	Data Set	
	Full Data (n = 1,815,245)	PS-Restricted Data (n = 376,564)
Preterm birth	6.8	7.0
Firearm violence rate[a,b]	22.9	29.0
High level of firearm violence[c]	11.1	23.5
Pregnancy complications		
Early preeclampsia	0.8	0.8
Asthma	3.2	3.2
Gestational diabetes	7.4	7.6
Substance use	1.5	1.8
Any infection	23.0	25.0
Race/ethnicity		
Non-Hispanic		
White	27.0	13.9
Black	5.2	6.0
Alaska Native or American Indian	0.3	0.4
Asian	12.3	7.7
Hawaiian or Pacific Islander	0.4	0.4
Other or ≥2 races	2.0	1.6
Hispanic	52.7	69.9
Educational attainment		
Less than high school	24.8	36.1
Less than college	50.2	53.2
College graduation or more	25.0	10.7
Age, years[b]	28.2	26.9
Type of health insurance		
Private coverage	47.9	32.0
Public coverage	50.0	66.0
Indigent coverage	0.1	0.1
Self-pay or other	2.1	1.9

Abbreviation: PS, propensity score.
[a] Number of deaths/injuries per 100,000 person-years.
[b] Values are expressed as mean.
[c] Neighborhoods were classified as having “high firearm violence” if the average rate of firearm violence exceeded the 90th percentile of firearm violence rates (37.97 deaths/injuries per 100,000 person-years).

and the stochastic indirect effect (SIE) is defined as

$$\mathrm{SIE} = E\left(Y_{a,\widehat{g}_{M|a,w}} - Y_{a,\widehat{g}_{M|a^*,w}}\right),$$

where $\widehat{g}_{M|A,W}$ is the observed distribution of the mediator conditional on covariates W and exposure A. By drawing from the distribution of mediator values rather than assigning a mediator value based on what we would expect it to be under different exposure values, we are able to estimate direct and indirect effects without needing to invoke the controversial "cross-world" assumption and can allow for postexposure confounders (56).

The stochastic direct effect estimates the difference in the expected proportion of preterm births in high-firearm-violence neighborhoods versus the comparison neighborhoods, if the distribution of pregnancy complications and health behaviors was the distribution observed in the comparison neighborhoods. The stochastic indirect effect estimates the difference in the expected proportion of preterm births if everyone lived in high-violence neighborhoods and the

Table 2. Demographic and Health Characteristics (%) of Participants (Unadjusted Prevalences) According to Birth Record Data Set and Level of Community Violence in a Study of Firearm Violence and Preterm Birth, California, 2007–2011

Demographic or Health Characteristic	Data Set and Type of Community			
	Full Data		PS-Restricted Data	
	Comparison (n = 1,508,566)	High-Violence[a] (n = 306,679)	Comparison (n = 288,208)	High-Violence (n = 88,356)
Preterm birth	6.6	7.7	6.9	7.4
Firearm violence rate[b,c]	13.0	71.8	23.1	48.5
Pregnancy complications				
Early preeclampsia	0.7	1.0	0.8	0.9
Asthma	3.1	3.7	3.0	3.9
Gestational diabetes	7.4	7.4	7.6	7.5
Substance use	1.4	2.1	1.6	2.3
Any infection	22.3	26.7	24.5	26.3
Race/ethnicity				
Non-Hispanic				
White	30.7	8.5	14.0	13.8
Black	3.8	12.4	5.6	7.4
Alaska Native or American Indian	0.3	0.3	0.4	0.6
Asian	13.5	6.6	7.6	8.2
Hawaiian or Pacific Islander	0.4	0.5	0.4	0.4
Other or ≥2 races	2.1	1.5	1.6	1.7
Hispanic	49.1	70.1	70.5	67.8
Educational attainment				
Less than high school	21.6	40.2	36.8	34.0
Less than college	49.9	51.8	53.0	54.1
College graduation or more	28.5	8.1	10.3	11.9
Age, years[c]	28.6	26.6	26.9	26.9
Type of health insurance				
Private coverage	52.4	25.9	31.8	32.7
Public coverage	45.4	72.2	66.1	65.7
Indigent coverage	0.1	0.0	0.1	0.0
Self-pay or other	2.1	1.9	2.0	1.5

Abbreviation: PS, propensity score.

[a] Neighborhoods were classified as having "high firearm violence" if the average rate of firearm violence exceeded the 90th percentile of firearm violence rates (37.97 deaths/injuries per 100,000 person-years).

[b] Number of deaths/injuries per 100,000 person-years.

[c] Values are expressed as mean.

distribution of pregnancy complications and health behaviors was that observed in high-violence neighborhoods versus that observed in the comparison neighborhoods.

Sensitivity analyses. We conducted several sensitivity analyses to assess how robust our findings were to different specifications and assumptions. First, we replicated our analyses using 50 deaths/injuries per 100,000 person-years as the cutoff for defining high-violence neighborhoods. We also assessed whether considering the prepregnancy health variables as baseline confounders, rather than postexposure confounders, influenced the results. We considered the possibility that women who live in high-violence neighborhoods may initiate prenatal care later as a result of stress due to violence exposure. Therefore, we also examined whether living in a high-violence neighborhood was associated with later initiation of prenatal care.

Statistical analyses were completed using R, version 3.5 (57); software code is provided in Web Appendix 3.

RESULTS

There were 2,084,417 mothers eligible to be included in the study who conceived between January 1, 2007, and March 1, 2011, delivered a live singleton, lived in California at the time of delivery, and had information on gestational age included in their birth or hospitalization record. We excluded women who were missing information on maternal race/ethnicity (0.1%), education (3.4%), health insurance type (2.6%), age (0.00005%), and prepregnancy BMI (7.5%). Due to computational limitations, we were unable to perform multiple imputation or other missing-data procedures. Therefore, our analysis included information on 1,815,245 mothers (87.1% of those eligible) (Table 1).

The distribution of firearm violence rates across California was right-skewed (Web Figures 1 and 2). There were 246 (17.1%) ZCTAs that had propensity scores within the area of support (Web Figures 3–6), reflecting the structural confounding. Restricting the population to persons who lived in ZCTAs that fell within this area of support resulted in a sample size of 376,564 (Table 1 and Web Figure 6) with reduced standardized bias in the community covariates between high-violence and comparison communities (Web Table 3). The locations of high-firearm-violence and comparison ZCTAs are shown in Web Figures 7–9. Both the prevalence of preterm birth and the firearm violence rate were higher in the propensity-score–restricted data than in the full data (Table 1).

Table 3. Association Between High Exposure to Firearm Violence[a] and Maternal Health Characteristics in a Study of Firearm Violence and Preterm Birth (Propensity-Score–Restricted Data Set; $n = 376{,}564$), California, 2007–2011

Health Characteristic	Overall Prevalence,[b] %	RD[c]	95% CI
Intermediate variables			
Hypertension	2.1	0.02	−0.18, 0.22
Diabetes	1.2	0.18	0.04, 0.31
Prepregnancy BMI[d]			
<20	9.6	−0.35	−0.97, 0.28
20–30	65.4	−0.59	−1.64, 0.47
>30	25.0	0.91	−0.46, 2.28
Pregnancy complications and health behaviors			
Any infection	25.0	1.34	−0.17, 2.86
Early preeclampsia	0.8	0.03	−0.05, 0.10
Gestational diabetes	7.6	−0.26	−0.89, 0.36
Asthma	3.2	0.76	0.03, 1.48
Substance use	1.8	0.74	0.00, 1.47
Preterm birth			
All	7.0	0.46	0.13, 0.80
Spontaneous	5.1	0.53	0.16, 0.89
Indicated	1.9	−0.07	−0.28, 0.15

Abbreviations: BMI, body mass index; CI, confidence interval; RD, risk difference.

[a] Neighborhoods were classified as having "high firearm violence" if the average rate of firearm violence exceeded the 90th percentile of firearm violence rates (37.97 deaths/injuries per 100,000 person-years).

[b] Prevalences were unadjusted.

[c] Difference in risk between high-violence neighborhoods and comparison neighborhoods. The models adjusted for maternal age, maternal age squared, educational attainment, race/ethnicity, type of health insurance, and the month-year of conception. Stabilized inverse probability of treatment weights were included to account for the community covariates.

[d] Weight (kg)/height (m)^2.

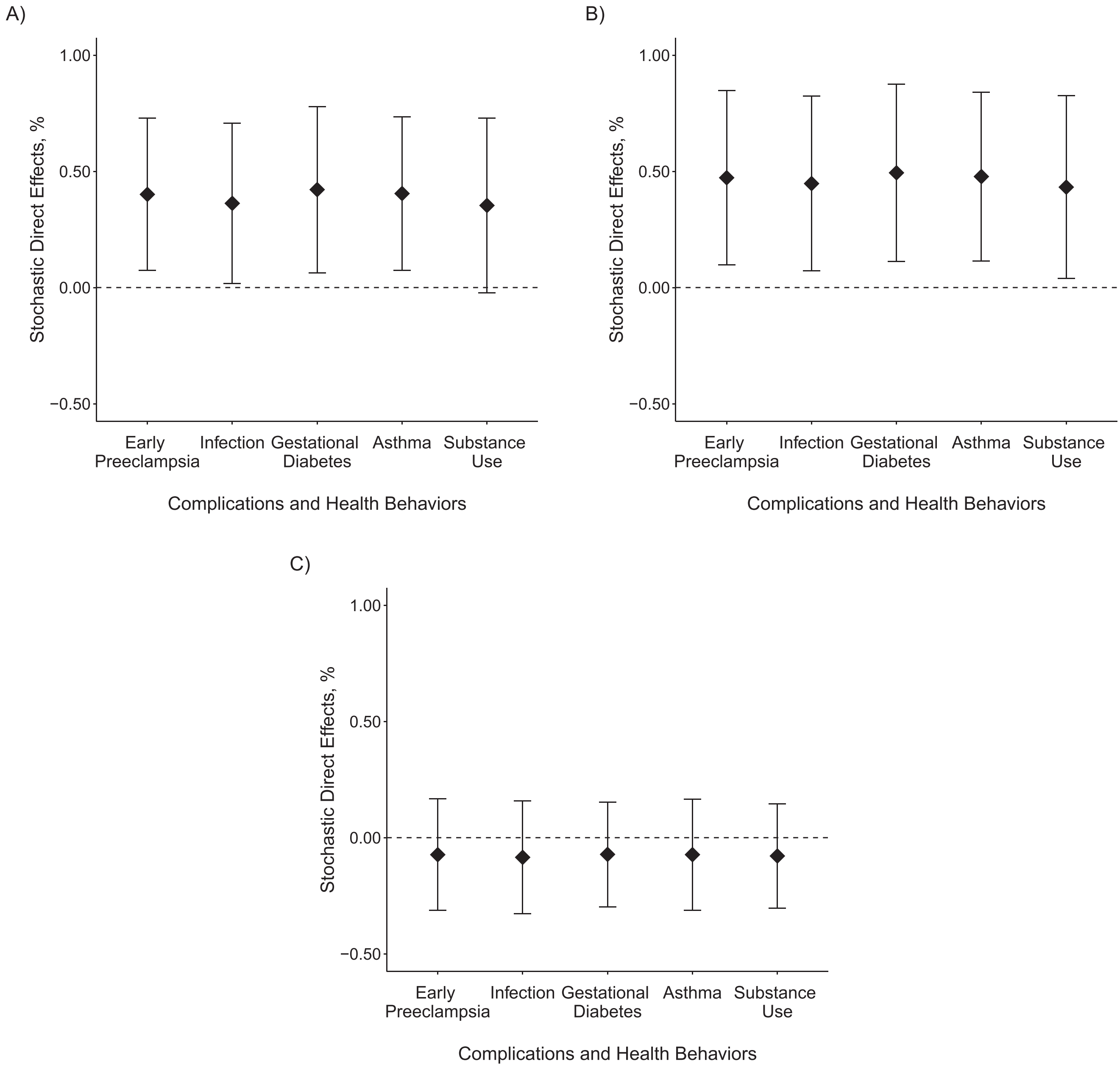

Figure 2. Stochastic direct effects of high firearm violence on risk of preterm birth according to pregnancy complications and health behaviors in propensity-score–restricted data (n = 376,564), California, 2007–2011. A) All preterm births; B) spontaneous preterm births; C) indicated preterm births. The risk difference models adjusted for maternal age, maternal age squared, educational attainment, race/ethnicity, type of health insurance, and month-year of conception. Stabilized inverse probability of treatment weights were included to account for the community covariates. Bars, 95% confidence intervals.

In propensity-score–restricted data, the firearm violence rate was approximately 2 times higher in the high-violence neighborhoods than in the lower-violence neighborhoods, and the prevalence of preterm birth was about 0.5 percentage points higher among women who lived in a high-violence neighborhood (7.4% vs. 6.9%) (Table 2). The prevalence of early preeclampsia was 0.1 percentage point higher in high-violence neighborhoods, and prevalences of asthma and substance use were 0.9 and 0.7 percentage points higher, respectively. The prevalence of infection was 1.8 percentage points higher among women living in high-violence neighborhoods.

The adjusted first-stage effects showed that the largest associations of pregnancy complications or health behaviors with high neighborhood violence were observed for infection, asthma, and substance use (Table 3). Furthermore, living in a neighborhood with high firearm violence was associated with increased risk of diabetes and a higher pre-pregnancy BMI, although the estimate for higher prepregnancy BMI was imprecise. The adjusted total effects showed that women living in high-violence neighborhoods had a higher prevalence of preterm birth (risk difference = 0.46, 95% confidence interval (CI): 0.13, 0.80); the association was driven by spontaneous preterm birth (Table 3).

The mediation results showed a direct effect of high firearm violence on risk of preterm birth (Figure 2, panel A), with stronger associations for spontaneous preterm deliveries than for indicated preterm deliveries (Figure 2, panels B and C). The largest stochastic indirect effects were observed for infection (stochastic indirect effect = 0.04, 95% CI: 0.00, 0.08) and substance use (stochastic indirect effect = 0.04, 95% CI: 0.01, 0.06) (Figure 3, panel A). While the magnitudes of the indirect effects were small, the proportion of the total effect mediated was not trivial. For example, substance use and infection both mediated almost 10% of the association between high firearm violence and preterm birth.

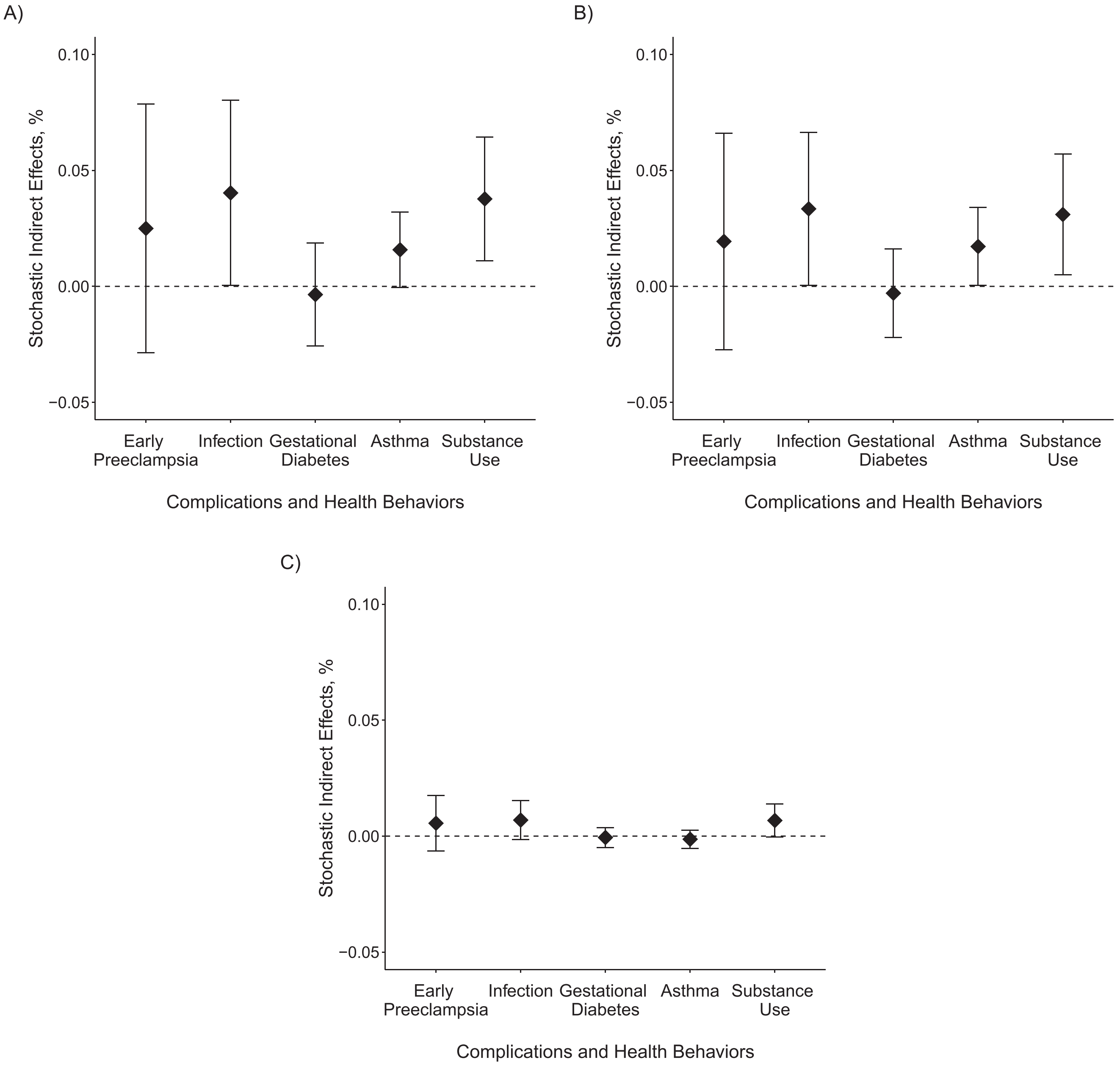

Figure 3. Stochastic indirect effects of high firearm violence on risk of preterm birth according to pregnancy complications and health behaviors in propensity-score–restricted data (n = 376,564), California, 2007–2011. A) All preterm births; B) spontaneous preterm births; C) indicated preterm births. The risk difference models adjusted for maternal age, maternal age squared, educational attainment, race/ethnicity, type of health insurance, and month-year of conception. Stabilized inverse probability of treatment weights were included to account for the community covariates. Bars, 95% confidence intervals.

The results of the sensitivity analyses using an alternate cutoff for high violence were very similar to those presented here (see Web Appendix 4, Web Table 4, Web Figure 10, and Web Figure 11). To assess whether receipt of prenatal care might have resulted in differential misclassification of complications, we examined whether mothers living in high-firearm-violence communities were less likely to receive early prenatal care. We found that living in a neighborhood with high firearm violence was associated with a small *increased* likelihood of receiving prenatal care during the first 3 months of pregnancy, although the confidence intervals were wide and crossed the null (risk difference = 2.1, 95% CI: −1.3, 5.5).

DISCUSSION

In this study, we estimated the relationship between living in a neighborhood with high firearm violence and risk of preterm birth and assessed whether pregnancy complications or health behaviors during pregnancy mediated this relationship. Firearm violence may be one mechanism by which histories of economic and racial segregation affect maternal health in the present (12). Our findings suggest that firearm violence increases risk of spontaneous preterm birth, with the strongest mediation associations being seen for infection and substance use. We also found associations of firearm violence with preexisting diabetes, prepregnancy BMI, asthma, infection, and substance use during pregnancy. These results suggest that living in a neighborhood with high firearm violence affects maternal health before and during pregnancy, with implications for infant health.

Our results are consistent with most previous research linking community violence with worse health (2, 11, 13, 24, 26–31, 58–68). A few prior studies have investigated mediation associations related to violence and gestational outcomes, although most studies assessed violence as the mediator rather than the exposure (48, 69). In addition, as discussed above, the methods utilized in prior studies relied on several strong assumptions (70, 71). Given our attention to the issue of structural confounding and our use of a mediation method that addressed the limitations of past approaches, our findings strengthen the evidence relating violence exposure to maternal and infant health.

Our analysis improved on previous studies but nevertheless had several limitations. To achieve more reliable estimates, we averaged firearm violence levels over the 2007–2011 study period. Because of limited data availability, we were not able to achieve strict temporality with the exposure, as the mediators and outcomes also occurred during this time. However, prior evidence suggests that exposure to firearm violence increases risk of the health conditions considered in this study (1, 27, 29, 31, 64, 65, 67, 68, 72, 73), and we think the direction of causation is more likely to be from community violence to health than the reverse. However, to ensure that the consideration of prepregnancy health conditions as postexposure confounders did not meaningfully impact the findings, we reran the analyses adjusting for them as baseline confounders, and the results were very similar. We dichotomized neighborhood-level firearm violence in order to facilitate estimation of the propensity scores, but a choice of cutoff had to be made among many options. In order to assess whether this choice influenced our results, we replicated the analysis using 50 deaths/injuries per 100,000 person-years as the firearm violence rate cutoff and found no meaningful differences in the findings.

Furthermore, because this study used administrative data, there may have been several potential sources of measurement error. In particular, firearm violence injuries and deaths were geocoded to the ZCTA in which the victim lived at the time of hospitalization or death, rather than the place where the shooting occurred. This may have mischaracterized the extent of exposure if people tend to be victims of gun violence in neighborhoods other than those in which they reside. Women's residences during pregnancy were assumed to be those listed on the birth certificate at delivery, which may have resulted in some exposure misclassification if women moved between high- and low-violence neighborhoods during pregnancy. Due to the nature of the linked birth and hospitalization records used in this analysis, we only had maternal address information at the ZCTA level. Therefore, as in any analysis that characterizes a neighborhood unit, our findings may have been sensitive to the choice of geographic unit, known as the modifiable area unit problem (74). ZCTAs have well-described limitations with respect to their use in health research (75); however, the ZCTA was the smallest unit for which data were available, and larger units would not have captured local dynamics in firearm violence.

Pregnancy complications and health behaviors were identified on the basis of diagnoses from the maternal hospitalization, emergency department, and ambulatory surgery records linked to the birth record, which are recorded with some measurement error (75). Complications identified only from routine prenatal appointments that were not recorded at the time of delivery were not captured, and therefore we expect that this analysis captured only the most severe instances of complications and behaviors. A more complete discussion of the potential for misclassification of these variables is presented in Web Appendix 5. To assess whether there was differential misclassification of complications by timing of prenatal care, we examined whether living in a high-violence neighborhood was associated with later initiation of prenatal care; we found this to be unlikely. Finally, while we identified spontaneous preterm birth by means of a commonly used algorithm (5), another approach has recently been developed that may be more valid; however, not all of the variables needed for this alternative approach are available in the California data (76).

There is evidence to suggest that strong social support may buffer the impact of community violence exposure (31, 77). Interventions designed to foster social groups and support in the prenatal-care setting have had success in improving birth outcomes (78–80) and maternal health behaviors during pregnancy (81). Doula care during pregnancy has also been shown to improve both maternal and infant health outcomes (82, 83). To the extent that the association between firearm violence and preterm birth in our study is due to internalized stress or maladaptive coping behaviors, interventions designed to support women exposed to violence may be especially helpful in improving birth outcomes and maternal health.

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