Spatial Proximity to Incidents of Community Violence Is Associated with Fewer Suicides in Urban California

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ABSTRACT *Suicide is a leading cause of premature mortality. Aspects of the social environment such as incidents of violence in the community may induce psychological distress and affect suicidality, but these determinants are not well understood. We conducted an ecological study using California vital statistics records, geocoded to address of the decedent, to examine whether proximity to homicide was associated with the occurrence of suicide in urban census tracts. For each urban tract (N = 7194) and each month in 2012, we assessed homicides in the tract or within buffer zones around the tract with a 1-month lag. We estimated two risk difference parameters that capture how suicide risk is related to differences in homicide exposure. Proximity to homicides was negatively associated with suicide occurrence after controlling for demographic factors, seasonality, and other confounders. Estimates suggest that the absence of homicides would be associated with a 4.2 % higher number of tract-months with one or more suicides (95 % confidence interval 2.2–6.0). This relationship was stronger in tracts that were wealthier, older, and less civically engaged. Results were robust to a wide variety of sensitivity tests. Contrary to expectations, we identified a consistent negative association of proximity to homicide with suicide occurrence. It may be that a homicide deters or distracts from suicidality or that aggression or hopelessness may be expressed as inward or outward directed violence in different settings. Further investigation is needed to identify the drivers of this association.*

KEYWORDS *Suicide, Community violence, Social epidemiology, Spatial analysis*

INTRODUCTION

Suicide is a leading cause of premature mortality in the USA and in California.¹ As of 2014, the national suicide rate is 13.4 per 100,000 and has consistently increased over the past decades. Rates are nearly three times higher in certain groups such as middle-aged white men and sexual minorities.^{1,2} Alarming, a 2012 study found that nearly 2 % of all adult Californians—more than half a million—seriously thought about suicide in the previous year.² Furthermore, patterns of suicide rates in California mirror national trends. Better understanding of the factors driving suicide is needed.

Exposure to community violence, meaning witnessing or hearing about incidents of violence in one's own community, is believed to influence a range of health outcomes^{3,4} and may increase the risk of suicide. In particular, exposure to incidents of community violence can lead directly or indirectly to psychological distress, poor

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mental health outcomes such as anxiety and depression, behavioral problems, and substance misuse (see for example⁵), each of which are major risk factors for suicide.^{6,7} Previous research among adolescents has shown that exposure to violence can increase suicidality.^{8–11} However, these studies were generally limited to small samples, utilized self-reported measures of violence exposure and suicide-related outcomes, and assessed suicidal ideation or attempt rather than completed suicides.

The effects of exposure to community violence on suicide risk may also vary by other important characteristics of communities, because the impacts of psychological distress on suicide risk vary depending on other risk factors and predispositions.¹² For example, those already at high risk due to psychiatric disorder⁷ or poor physical health¹³ experience dually increased risk when confronted with distressing life events.¹⁴ Identification of the groups most affected by community violence-induced conditions is important to better inform priority setting and to better understand the relationship between community violence and health.

The relationship between community violence and suicide merits further investigation with population-wide designs and objective measures. In this study, we examine whether spatial proximity to homicide, a measure of exposure to community violence, is associated with the occurrence of suicide across urban neighborhoods in California. We conducted an ecological study using causal inference methods to estimate the associations for how the frequency of suicide might change if community violence could be reduced. We hypothesized that exposure to community violence would be positively associated with suicide, after accounting for potential confounders. We also explored whether these relationships differed by other characteristics associated with suicide risk such as age and access to alcohol. This study extends previous work by utilizing a database that includes the entire population of California, employing objective exposure and outcome assessment, and reporting results as additive parameters that are policy-relevant.

METHODS

Data

We used California Department of Public Health (CDPH) vital statistics records on all deaths occurring in California in 2011 and 2012, the most recent years of data available at the time of study. Death certificate data included information on the cause of death, demographic characteristics, and address of residence of the decedent. Address data was geocoded using ArcMap 10.2.2 with North America Street Map 2009 and linked to the 2010 Census Block Map to identify the latitude, longitude, and census tract of residence. Based on Centers for Disease Control and Prevention-recommended classifications,¹⁵ we used International Classification of Diseases Tenth Revision (ICD-10) codes of Y870, U03, or between X60 and X84 to identify all deaths due to deliberate self-harm and the ICD-10 codes of U01, U02, X85–Y09, Y871, or Y35 to identify all deaths due to homicide. As elaborated below, deaths by homicide in or proximate to a tract served as the measure of exposure to community violence.

Census tracts served as the geographic unit of analysis. We acquired baseline tract-level covariate data from the 2010 Census, the American Community Survey (5-year tract-level estimates for 2008–2012), the CDPH Healthy Communities Data and Indicators Project,¹⁶ and census tract boundary shapefiles from the US Census Bureau.¹⁷ We restricted our analysis to urban census tracts, because patterns and

determinants of suicide and homicide are different in urban versus rural areas^{12,18} and therefore should be examined separately. Census tracts are also significantly larger in rural areas and do not capture communities in the same manner as urban tracts, and therefore, investigation of the relationship between community violence and suicide in rural areas would be better understood with a different study design. Urban tracts were defined as those with greater than 50 % of the population living in a US Census Bureau-defined urban area. The majority of census tracts in California are urban (7194 of 8057 [89.2 %]).

Exposure and Outcome Characterization

We characterized the outcome of suicide occurrence as an indicator of whether one or more suicides occurred in each census tract and each month. We characterized exposure to community violence as a set of four indicators of whether one or more homicides occurred during the previous month within each census tract or within buffer zones around the tract. Specifically, the four exposure zones were within the census tract or within 100 m of the tract boundary, between 100 and 500 m, between 500 and 1000 m, and between 1000 and 2000 m from the tract boundary (Fig. 1). The within-tract exposure captures the immediate vicinity of the home, the next two buffer zones capture different areas within overall walking distance, while the fourth captures areas residents may pass through less frequently. Regions were constructed to be mutually exclusive to allow the identification of associations at different distances. We examined homicide exposures with a 1-month lag to ensure that all homicides preceded any suicides. We used binary indicators of the exposure and outcome because the occurrence of more than one suicide or homicide in a given census tract and month was rare, and operationalizing these variables as counts or rates did not change the results (see [Appendix](#)). We restricted to suicides occurring in 2012 with homicide occurrence in prior months drawing on data from 2011.

Covariates

Analyses controlled for a range of tract-level covariates including population demographic factors (percent female, percent aged 18 to 24, percent Hispanic, percent non-Hispanic black, percent non-Hispanic American Indian/Alaskan Native, percent non-Hispanic Asian, and percent born in the USA), household composition factors (percent female-headed households and percent single-person households [a proxy for social isolation]), socioeconomic factors (median household income; percent aged 25 and older with 4-year college degree; percent below poverty level; percent aged 16–14, 25–44, and 45–64 unemployed; and percent receiving public assistance), civic engagement (percent of eligible voters voting in 2012 election), residential environment factors (percent living in different home compared to 1 year ago; change in number of households between 2000 and 2010 censuses; percent within 0.50 mi of a park, beach, open space, or coastline; percent vacant dwellings; and total land area), factors known to precipitate inward and outward directed violence (percent living within 0.25 mi of an alcohol outlet, percent of deaths in 2012 attributable to firearms [a proxy for access to firearms]^{19,20} and latitude of tract centroid [a proxy for hours of daylight]), and month indicators to address seasonality in suicide and homicide incidence.

FIG. 1 Example census tract with homicide exposure buffers.

Statistical Analysis

To quantify the relationship between exposure to incidents of community violence and suicide occurrence, we conducted census tract-month-level logistic regression, controlling for baseline tract-level sociodemographic factors and potential confounders and report odds ratios for tract-month suicide occurrence. Of 86,328 urban census tract-months in 2012, 3744 (4.3 %) were excluded from the final regression model due to incomplete exposure, outcome, or covariate data.

We used the regression approach described above to also estimate two risk difference measures. Both estimate the percent difference in suicide occurrence. The first parameter, the population attributable risk percent (PAR percent), compares observed frequency of suicide to estimated frequency in absence of any homicide and converts this difference to a percent of the observed frequency. The second parameter, the average treatment effect (ATE percent), compares the estimated frequency of suicide if all tract months were exposed to homicide at all distances to the estimated frequency in the absence of any homicides and converts this difference to a percent of the estimated frequency in the absence of any homicides. To estimate these quantities, we used the logistic regression described above to predict the outcome for each census tract month had homicide exposure been ubiquitous or entirely absent. We then averaged the predicted outcomes under different exposure patterns across all census tract-months to get estimates of suicide frequency under different levels of homicide exposure and calculated the differences of interest. Step-by-step illustrations of this method with sample code are available elsewhere.²¹ We report estimates stratified by subgroups of interest for the ATE only, because differences in the PAR percent across subgroups may be attributable to differing

baseline levels of violence exposure rather than differences in the strength of association. Confidence intervals were estimated using the non-parametric bootstrap.²²

To examine the robustness of our results, we conducted an array of sensitivity tests. Broadly, these tests included alterations to the set of control covariates, checks on the forms of the variables included in the models, alterations of the time frames and geographic zones, and alternative approaches to handling spatial and temporal autocorrelation. Observed spatial autocorrelation was negligible, and no further adjustment was necessary. Additional information and results for all sensitivity tests are presented in the [Appendix](#).

Pre-processing of data was conducted using SAS 9.3 and Stata 13.1, construction of spatial exposure measures was conducted using MATLAB R2015b, and regression analysis was conducted using R 3.2.1.

RESULTS

In 2012, 3.8 % of urban tract months in California experienced one or more suicides and 3.1, 4.6, 6.9, and 16.5 % experienced one or more homicides within 100 m, 100–500 m, 500–1000 m, and 1000–2000 m from tract boundaries during the previous month, respectively. This increasing pattern is expected, because the exposure zones are larger and larger areas. Table 1 presents the descriptive characteristics of urban tracts that did and did not have occurrence of suicides and homicides in 2012. Of note, tracts with suicides were quite different from those with homicides. For example, compared to tracts with homicides, tracts with suicides had somewhat older populations with higher education, lower poverty, and fewer minority residents. At the same time, several notable attributes characterized both tracts with homicides and tracts with suicides. Specifically, both tended to have fewer eligible voters voting in the 2012 election, more non-Hispanic American Indian and Asian residents, more individuals living in different housing compared to 1 year earlier, more vacant units, and generally more access to firearms (percent of deaths in 2012 that were firearm-related).

Table 2 presents the unadjusted and adjusted odds ratios and risk difference parameters for the association between exposure to homicide and suicide occurrence. Contrary to expectations, proximity to homicide was *negatively* associated with suicide occurrence in a given tract month, after controlling for confounders. In the absence of any homicides, we estimated that the proportion of tract-months with suicides would be 4.18 % higher (PAR percent 95 % confidence interval [CI] 2.24, 6.00). In addition, we estimated that the proportion of tract-months with suicides would be 48.27 % (ATE percent 95 % CI 30.32, 63.34) higher if no tract-months were exposed to homicide compared to all tract-months exposed. Adjusted models identified statistically significant associations for (a) homicides within the tract or within 100 m of the boundary and (b) homicides between 1000 and 2000 m from the tract boundary but not for homicides between 100 and 500 m or between 500 and 1000 m from the boundary. Results were robust to a wide variety of sensitivity analyses (see [Appendix](#)).

Table 3 presents the estimates of the ATE percent parameter, stratified by census tract subgroups of interest (estimates by covariate quartile for all covariates are presented in the [Appendix](#)). Of note, the magnitude of the association varied substantially across groups, but the negative association between homicide and suicide was persistent. In general, we found stronger associations in census tracts with higher socioeconomic status, more residential stability, and more civic engagement, but variation was notable throughout.

TABLE 1 Bivariate associations between census tract characteristics and suicide or homicide occurrence

Characteristic	Census tract-months with suicides			Census tract-months with homicides in tract or within 100 m of boundary			Qualitative difference
	Yes (%)	No (%)	P value	Yes (%)	No (%)	P value	
Overall	3.8 %	—	—	3.1 %	—	—	
Percent female	50.6	50.6	0.62	50.5	50.6	0.009	
Percent aged 18–24 years	10.1	10.4	<0.001	11.4	10.4	<0.001	Opposite
Percent Hispanic	32.6	37.9	<0.001	49.4	37.3	<0.001	Opposite
Percent non-Hispanic black	5.62	6.31	<0.001	12.1	6.1	<0.001	Opposite
Percent non-Hispanic American Indian or Alaskan Native	0.38	0.32	<0.001	0.35	0.32	<0.001	Same
Percent non-Hispanic Asian	12.5	13.7	<0.001	10.7	13.8	<0.001	Same
Percent born in the USA	75.0	71.5	<0.001	69.3	71.7	<0.001	Opposite
Percent female-headed households	13.4	14.6	<0.001	18.9	14.4	<0.001	Opposite
Percent single-person households	23.8	22.1	<0.001	20.5	22.2	<0.001	Opposite
Median household income	68,092	66,579	0.007	51,288	67,123	<0.001	
Percent aged 25+ with 4-year college degree	32.3	30.3	<0.001	19.1	30.7	<0.001	Opposite
Percent below poverty level	14.1	15.6	<0.001	21.7	15.3	<0.001	Opposite
Percent receiving public assistance	3.75	4.19	<0.001	6.6	4.1	<0.001	Opposite
Percent aged 16–24 unemployed	20.7	21.0	0.40	24.5	20.8	<0.001	
Percent aged 25–44 unemployed	9.74	9.89	0.18	11.99	9.82	<0.001	
Percent aged 45–64 unemployed	9.28	9.31	0.82	11.06	9.25	<0.001	
Percent eligible voters voting in 2012 election	1.64	1.75	<0.001	1.48	1.76	<0.001	Same
Percent in different housing versus 1 year ago	16.7	15.6	<0.001	16.4	15.6	<0.001	Same
Change in number of households 2000–2010	159	105	<0.001	115	107	0.45	
Percent living within 0.50 mi of park	76.4	77.5	0.076	76.8	77.4	0.40	

TABLE 1 *Continued*

Characteristic	Census tract-months with suicides			Census tract-months with homicides in tract or within 100 m of boundary			Qualitative difference
Percent vacant dwellings	6.89	6.33	<0.001	7.16	6.33	<0.001	Same
Land area	3.99	2.25	0.008	2.33	2.32	0.96	Opposite
Percent of population within 0.25 mi of alcohol outlet	50.7	55.8	<0.001	63.6	55.4	<0.001	
Percent firearm-related deaths in 2012	0.98	0.47	<0.001	2.05	0.45	<0.001	Same
Latitude of centroid	35.3	35.3	0.36	35.5	35.3	<0.001	

P values reflect bivariate tests of means using generalized estimating equations for census tract-level clustering

DISCUSSION

Using a large population-based dataset that includes all deaths in California, we identified a consistent negative association of proximity to homicide with suicide occurrence. This study offers numerous strengths over previous studies of the association between exposure to community violence and suicide^{8–11,23–25} by estimating easily interpretable risk difference parameters, employing objective exposure and outcome measures, and utilizing comprehensive statewide data at fine geographic and temporal resolution. A primary limitation of previous studies is that exposure to community violence is highly correlated with other life adversity (poverty, neighborhood deprivation, domestic violence, lack of access to social services) at the individual and community levels, and disentangling these effects is challenging. By drilling down to the month and census tract levels, we compared

TABLE 2 Regression results and risk difference estimates

	Unadjusted		Adjusted	
	OR	95 % CI	OR	95 % CI
Exposure				
Homicide within 100 m	0.89	0.71, 1.11	0.68*	0.54, 0.85
Homicide within 100–500 m	0.88	0.73, 1.06	0.98	0.80, 1.18
Homicide within 500–1000 m	0.77*	0.66, 0.90	0.89	0.76, 1.05
Homicide within 1000–2000 m	0.72*	0.65, 0.80	0.84*	0.75, 0.94
	Estimate	95 % CI	Estimate	95 % CI
PAR percent	–7.07*	–5.32, –8.72	–4.18*	–6.00, –2.24
ATE percent	–54.98*	–67.36, –39.28	–48.37*	–63.34, –30.32

OR odds ratio; CI confidence interval; PAR percent percent difference in suicide occurrence, comparing observed frequency to predicted frequency in absence of any homicide; ATE percent percent difference in suicide occurrence, comparing predicted frequency if all tracts were exposed to homicide to predicted frequency in absence of any homicide in all tracts

**P* < 0.05

TABLE 3 Average treatment effect (ATE) percent estimates by quartile of effect modifiers

	Percent difference in suicide occurrence, comparing predicted frequency if all tracts were exposed to homicide to predicted frequency in absence of any homicide			
	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Tract-level covariate	Estimate (95 % CI)	Estimate (95 % CI)	Estimate (95 % CI)	Estimate (95 % CI)
Percent aged 18–24	–42.35 (–87.17, 41.93)	–69.28 (–87.65, –42.47)	–49.39 (–75.93, –5.82)	–24.85 (–61.07, 35.12)
Percent non-Hispanic black	–21.19 (–75.11, 61.07)	–55.21 (–83.33, –13.60)	–53.70 (–80.37, –14.94)	–53.33 (–74.36, –22.36)
Percent born in the USA	–25.03 (–71.13, 41.72)	–47.88 (–73.66, –9.81)	–47.21 (–79.09, 0.20)	–60.32 (–84.47, –18.45)
Percent single-person households	–60.15 (–81.35, –20.24)	–58.39 (–81.81, –15.40)	–42.93 (–74.34, 2.68)	–30.66 (–68.49, 29.32)
Median household income	–8.01 (–52.12, 51.51)	–52.94 (–76.60, –19.00)	–43.94 (–77.92, 10.35)	–78.87 (–94.96, –46.99)
Percent with 4-year college degree	–4.63 (–46.18, 52.90)	–74.33 (–87.23, –52.17)	–32.05 (–73.43, 35.84)	–57.34 (–90.33, 0.87)
Percent of eligible voters voting in 2012 election	–31.39 (–60.83, 7.88)	–25.24 (–66.78, 30.51)	–77.74 (–93.22, –53.71)	–75.08 (–93.31, –36.29)
Percent in different housing versus 1 year ago	–65.14 (–90.84, –13.55)	–54.51 (–81.44, –12.68)	–44.58 (–73.48, –2.15)	–35.37 (–64.60, 9.77)
Change in number of households 2000–2010	25.55 (–36.17, 129.61)	–81.23 (–93.98, –59.36)	–69.52 (–86.21, –39.19)	–42.12 (–69.54, –3.51)
Percent of population within 0.25 mi of alcohol outlet	–75.88 (–92.59, –45.82)	–49.78 (–78.39, –3.43)	–41.19 (–69.56, 5.37)	–59.06 (–87.60, –8.34)
Overall association	–48.37 %			

This table presents the percent difference in suicide occurrence, comparing the predicted frequency if all tract - months were exposed to homicide at all geographic distances to the predicted frequency in the absence of any homicides

CI confidence interval

communities facing such adversity in months when homicides occurred and in months when homicides did not occur, along with subsequent changes in suicide occurrence. This design allowed us to more closely isolate the health impacts of exposure to community violence. Our estimates are also well supported by the data and do not extrapolate (i.e., do not violate the positivity assumption); while homicides are more common in certain areas, they occur in all places, providing sufficient variation for estimates in this study (see [Appendix](#) for in-depth investigation of potential positivity issues). In addition, we examined exposure to homicide across a range of geographic distances to quantify how far associations between suicide and homicide may extend, and we assessed how observed

associations varied across a wide range of potential effect modifiers to better understand the drivers of the observed associations.

There are several potential explanations for our finding of a negative association between incidents of violence in the community and suicide. First, it is possible that the experienced exposure is not homicide and the stress associated with witnessing or hearing about a homicide *per se*, but rather the response to the sudden death of a community member. This event could be enough of a distraction or a deterrent for people contemplating suicide to prevent some suicidal behavior. Indeed, periods of suicidal thinking and behavior can be transient, which is why some means restriction approaches are effective in preventing suicides rather than inducing substitution.^{26,27} There is also evidence that communities exposed to tragedies experience subsequent increases in social cohesion,^{28,29} which is protective against suicide (see for example^{30,31}). This mechanism may be at play in this study as well.

Second, individuals experiencing anger, frustration, hostility, hopelessness, or depression may express these feelings as self-directed or other-directed violence.^{32–34} Suicidal behavior and interpersonal violence share several common risk factors, and there is evidence that troubled individuals tend to specialize in either inward- or outward-directed violence.^{35–37} This study may be capturing differences in patterns of this expression across communities. In urban neighborhoods where norms surrounding interpersonal violence are less prohibitive, distress may be expressed outward-directed violence, while those living in urban neighborhoods with more restrictive norms may respond to similar feelings with suicidal behavior. Our finding that there are differences in baseline characteristics of tracts that experience more suicides (regardless of homicide incidence) compared with tracts that experience more homicides (regardless of suicide incidence) supports this hypothesis. While our analysis controlled for many of the factors accounting for differences between tracts with suicides and tracts with homicides, covariates were measured at the census tract level and therefore may not adequately address all confounding by these factors.³⁸

Another unexpected finding was that adjusted odds ratios measuring the association between suicide and homicide were statistically significant for homicide exposure only at the inner-most and outer-most exposure ranges (<100 m and 1000–2000 m) but not for the two intermediate exposures (100–500 m and 500–1000 m). This pattern may have emerged for two reasons: first, the association between suicide and homicide was strongest where exposure was most proximal. This explains the first result. Second, the physical size (area) of the zones corresponding to different exposure radii increased as the distance from the tract centroid increased. As a result, homicides in the 1000–2000-m zone were more common than in more proximal zones. This increased frequency may have increased our power to detect an effect at that range.

Naturally, this study was subject to several limitations. All epidemiological studies are susceptible to residual confounding. We were able to control for a considerable number of potential confounders, and we are not aware of any confounder for which we had no measure, but it is possible that some exist. In addition, we only examined fatal outcomes because the injury outcomes in our database cannot be geocoded, and non-fatal interpersonal violence and suicide attempts might follow different patterns. Cause of death classification on death certificates is also known to be imperfect. Suicides may be miscoded as homicides or unintentional deaths and vice versa. Studies that have examined this issue in greater detail have generally concluded that the degree of misclassification is not substantial enough to alter major trends and patterns.^{39,40}

One final pattern worth noting is that while the tracts where suicides and homicide occurred tended to be quite different, both were characterized by markers of lower civic engagement and higher residential instability. One theory that could be drawn from this information is that areas that are socially turbulent and disconnected are particularly prone to both inward- and outward-directed violence. Further investigation of these associations may be valuable, and regions with these characteristics could be identified and targeted for future prevention efforts.

In sum, we used comprehensive statewide data sources and identified a consistent, negative association between exposure to incidents of homicide in the community and suicide occurrence in urban census tracts in California. Future research should investigate the drivers of the associations, with particular emphasis on discerning whether homicide may serve as a distraction or deterrent for suicide and whether substitution of inward- and outward-directed violence may explain these results. Better understanding of the mechanism behind the relationship would provide important insight that could inform future prevention efforts.

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Authors' Contribution. KEC, JG, and JA made substantial contributions to the conception and design of the study, interpretation of results, and preparation of the manuscript. KEC analyzed the data and drafted the manuscript, and the other authors reviewed it critically for important intellectual content. All authors gave final approval of the version to be published and agree to be responsible for the reported research.

COMPLIANCE WITH ETHICAL STANDARDS

Study Approval. This study was approved by the State of California and University of California, Berkeley Committees for the Protection of Human Subjects. This study was approved by the State of California and University of California, Berkeley Committees for the Protection of Human Subjects.

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APPENDIX

Geocoding

Address data was geocoded using ArcMap 10.2.2 with North America Street Map 2009 and linked to the 2010 Census Block Map to identify the latitude, longitude, and census tract of residence. We used a two-step geocoding process. First, we geocoded addresses to the NA Street Map 2009, keeping matches with a minimum match score of 65, resulting in a match rate of 97.45 %. These decedents were linked to the 2010 Census Block Map using

the longitude and latitude of the street address. Second, for addresses that did not match to the NA Street Map (2.54 %) and for descendants with only zip codes on the death certificate, we directly linked the zip-centroid coordinates to the 2010 Census Block Map.

Checks for Spatial Autocorrelation

Because the geographic unit of analysis was very small, it is possible that the outcomes of neighboring tracts are correlated, violating the assumptions of standard regression models, potentially generating biased point estimates and incorrect inference. To investigate this concern, we calculated the degree of spatial autocorrelation in regression residuals using Moran's I , as recommended by Anselin and colleagues.¹ Moran's I is a measure of spatial autocorrelation which we computed as

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2}$$

where N is the number of spatial units indexed by i and j , X_i and X_j are the residuals, $\bar{X}$ is the mean of the residuals, and w_{ij} are the spatial weights for which we used in the inverse distance between tract centroids. Moran's I ranges between -1 and 1 , where -1 indicates perfect negative autocorrelation and 1 indicates perfect positive autocorrelation. We calculated the Moran's I of the residuals for each month separately, and for 3-month groupings, and found all values to be extremely small (Table 4), and therefore, no adjustment for spatial autocorrelation was necessary. This result is expected, because suicides in a given tract and month are rare and, after controlling for other census tract covariates, appear to occur in space as random blips. Calculation of Moran's I for all months combined was not possible due to computational intensity.

This table displays the estimated spatial autocorrelation, as measured by Moran's I , in the residuals of the study's final logistic regression model, for subsets of observations corresponding to different months of observation, or groups of months. Computation of Moran's I for all census tracts and months simultaneously was not possible due to computational limitations.

Supplemental Results

The bivariate relationships between suicide and exposure to homicides within the census tract and within buffer zones around the census tract are presented in Table 5.

Table 6 presents the estimates of the average treatment effect risk difference parameter, stratified by covariate quartile for all. A subset of these results is presented in the main text in Table 3.

Sensitivity Analyses

To examine the robustness of our results, we conducted an array of sensitivity tests. We tested the varying covariates included in logistic regression models, inclusion of additional interaction terms, entering covariates as quartiled categorical variables or principal components, use of population average models implemented with generalized estimating equations (GEEs) or tract-level random effects to account for tract-level clustering, employing measures of homicide exposure for the

¹Anselin L, Florax RJGM, Rey SJ. *Advances in spatial econometrics: methodology, tools, and applications*. Berlin Heidelberg: Springer-Verlag 2004.

TABLE 4 Estimated spatial autocorrelation of regression residuals, as measured by Moran's *I*

Time period	Moran's <i>I</i>
January	−0.0000814
February	−0.0001314
March	−0.0001027
April	−0.0001018
May	−0.0001368
June	−0.0001200
July	−0.0000652
August	−0.0000597
September	−0.0002487
October	−0.0000901
November	−0.0000693
December	−0.0000480
January–March	−0.0000152
April–June	−0.0000374
July–September	−0.0000754
October–December	0.0000123

12 months prior to the month of the outcome (rather than the previous month), employing measures of homicide exposure restricted to more proximal buffer zones, collapsing measures of homicide exposure across buffer zones, restricting the dataset to suicide occurrence in a single month to reduce the chances of bias in point estimates or inference due to temporal autocorrelation, inclusion of binary suicide exposure measures in the tract and the same buffer zones with a 1-month lag to capture potential suicide contagion, characterizing the exposures as continuous measures of the number of homicides in each region, characterizing suicide as a rate and employing negative binomial regression, characterizing suicide as a count and employing Poisson regression, restricting the analysis to tracts with greater than 90 % of residents residing in Census Bureau-defined urban areas (rather than greater than 50 %), and implementation of multivariate regression using the SuperLearner ensemble machine learning algorithm rather than logistic regression. SuperLearner makes fewer assumptions about the shape of the relationship between the exposure,

TABLE 5 Distribution of census tract - months with suicides and homicides within the tract and within buffer zones around the tract

One or more homicides in the month prior to possible suicide occurrence			One or more suicides		
			No	Yes	Total
Within 100 m	No	<i>N</i> (%)	80,173 (96.2)	3,137 (3.8)	83,310 (97.0)
	Yes	<i>N</i> (%)	2,514 (96.8)	84 (3.2)	2,598 (3.0)
Between 100 and 500 m	No	<i>N</i> (%)	78,862 (96.2)	3,097 (3.8)	81,959 (95.4)
	Yes	<i>N</i> (%)	3,825 (96.9)	124 (3.1)	3,949 (4.6)
Between 500 and 1000 m	No	<i>N</i> (%)	76,890 (96.2)	3,053 (3.8)	79,943 (93.1)
	Yes	<i>N</i> (%)	5,797 (97.2)	168 (2.8)	5,965 (6.9)
Between 1000 and 2000 m	No	<i>N</i> (%)	68,911 (96.1)	2,824 (3.9)	71,735 (83.5)
	Yes	<i>N</i> (%)	13,776 (97.2)	397 (2.8)	14,183 (16.5)
Total		<i>N</i> (%)	82,687 (96.3)	3,221 (3.7)	85,908 (100)

TABLE 6 Average treatment effect (ATE) percent estimates by quartile of effect modifiers

Tract-level covariate	Percent difference in suicide occurrence, comparing predicted frequency if all tracts were exposed to homicide to predicted frequency in absence of any homicide			
	Quartile 1	Quartile 2	Quartile 3	Quartile 4
	Estimate	Estimate	Estimate	Estimate
	(95 % CI)	(95 % CI)	(95 % CI)	(95 % CI)
Percent non-Hispanic black	-21.19	-55.21	-53.70	-53.33
Percent aged 18–24	-42.35	-69.28	-49.39	-24.85
Median household income	-8.01	-52.94	-43.94	-78.87
Percent with 4-year college degree	-4.63	-74.33	-32.05	-57.34
Percent born in the USA	-25.03	-47.88	-47.21	-60.32
Percent in different housing versus 1 year ago	-65.14	-54.51	-44.58	-35.37
Percent single-person households	-60.15	-58.39	-42.93	-30.66
Change in number of households 2000–2010	25.55	-81.23	-69.52	-42.12
Percent of eligible voters voting in last election	-31.39	-25.24	-77.74	-75.08
Percent aged 16–24 unemployed	-26.69	-47.38	-63.18	-49.16
Percent aged 25–44 unemployed	-60.19	-69.34	-33.53	-35.18
Percent aged 45–64 unemployed	-80.86	-38.08	-28.81	-44.33
Latitude	-55.62	16.50	-56.45	-64.32
Proximity to alcohol outlets	-75.88	-49.78	-41.19	-59.06
Percent Hispanic	-58.18	-70.02	-28.92	-25.60
Percent vacant units	-87.40	-12.05	-46.40	-39.23
Percent female	-47.55	-48.94	-43.21	-47.66
Percent NH AIAN	-0.59	-73.21	-51.92	-40.98
Percent NH Asian	-43.79	-37.91	-62.32	-48.35
Percent below poverty line	-86.62	-38.89	-50.58	-20.83
Percent female-headed HH	-22.89	-40.22	-69.19	-33.54
Land area	2.91	-56.37	-55.45	-55.52
Percent on public assistance	-68.83	-53.98	-56.44	-17.75
Proximity to parks ^a	-45.98		-52.01	
Percent firearm deaths 2012 ^a	-43.14		-56.32	
Overall association	-48.37			

This table presents the percent difference in suicide occurrence, comparing the predicted frequency if all tract - months were exposed to homicide at all geographic distances to the predicted frequency in the absence of any homicides

CI confidence interval, HH household, NH non-Hispanic, AIAN American Indian and Alaskan Native

^aInsufficient variation in covariate to assess effects by quartiles; variation assessed by halves

outcome, and covariates (i.e., allows for non-linearity), thereby reducing the chances that the measured association is an artifact of a misspecified model.² We also tested the

²Laan VD, J M, Polley EC, *et al.* Super Learner. *Stat Appl Genet Mol Biol* 2007;6.<http://www.degruyter.com/view/j/sagmb.2007.6.1/sagmb.2007.6.1.1309/sagmb.2007.6.1.1309.xml> (accessed 9 April 2015).

van der Laan MJ, Rose S. *Targeted Learning: causal Inference for observational and experimental data*. New York, NY: Springer New York 2011. <http://link.springer.com/10.1007/978-1-4419-9782-1> (accessed 29 June 2015).

TABLE 7 Results of sensitivity analyses

Model specification	Population attributable risk percent	Average treatment effect percent
Final reported model	−4.18 (95 % confidence interval −6.00, −2.24)	−48.37 (95 % confidence interval −63.34, −30.32)
Model: tract-month-level logistic regression		
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: percent of female; percent of aged 18 to 24; percent of Hispanic; percent of black; percent of American Indian/Alaskan Native; percent of Asian; percent of born in the USA; percent of single-mother households; percent of single-person households; median household income; percent of aged 25 and older with 4-year college degree; percent of below poverty level; percent of aged 16–14, 25–44, and 45–64 unemployed; percent of receiving public assistance; percent of eligible voters voting in 2012 election; percent of living in different home compared to 1 year ago; change in number of households between 2000 and 2010 censuses; percent of within 0.50 mi of a park, beach, open space, or coastline; percent of vacant dwellings; total land area; percent of living within 0.25 mi of an alcohol outlet; percent of deaths in 2012 attributable to firearms; latitude of tract centroid; and month dummies		
Model: tract-month-level logistic regression	−4.42	−36.60
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: percent of female, percent of aged 18 to 24, percent of Hispanic, percent of black, median household income, and month dummies		
Model: tract-month-level logistic regression	−4.21	−48.6
Outcome: occurrence of one or more suicides in tract month (binary)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
<p>Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)</p> <p>Covariates: percent of female; percent of aged 18 to 24; percent of Hispanic; percent of black; percent of born in the USA; percent of single-mother households; percent of single-person households; median household income; percent of below poverty level; percent of aged 16 and older unemployed; percent of eligible voters voting in 2012 election; percent of living in different home compared to 1 year ago; percent of within 0.50 mi mile of a park, beach, open space, or coastline; percent of vacant dwellings; total land area; percent of living within 0.25 mi of an alcohol outlet; percent of deaths in 2012 attributable to firearms; latitude of tract centroid; and month dummies</p> <p>Model: tract-month-level logistic regression</p>	–4.04	–48.3
<p>Outcome: occurrence of one or more suicides in tract month (binary)</p> <p>Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)</p> <p>Covariates: same as in final model but parameterized as quartiled categorical variables</p> <p>Model: tract-month-level logistic regression</p>	–4.68	–42.60
<p>Outcome: occurrence of one or more suicides in tract month (binary)</p> <p>Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)</p> <p>Covariates: same as in final model but parameterized as top 5 principal components accounting for largest proportion of variance</p> <p>Model: tract-month-level logistic regression</p>	–7.09	–62.00
<p>Outcome: occurrence of one or more suicides in tract month (binary)</p>		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model but parameterized as top 10 principal components accounting for largest proportion of variance Model: tract-month-level logistic regression	–4.97	–52.70
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model but parameterized as top 15 principal components accounting for largest proportion of variance Model: tract-month-level logistic regression	–4.66	–51.20
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model but parameterized as top 20 principal components accounting for largest proportion of variance Model: tract-month-level logistic regression	–4.18	–48.4
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model, plus tract-level random effect Model: tract-month-level regression for binary outcome with generalized estimating equations (GEEs) for clustered standard errors	–4.18	–48.4

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–8.00	–20.3
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary during the 12 months prior (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–1.93	39.80
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500 and 500–1000 m from boundary with 1-month lag (three binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–1.27	–32.60
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500 m from boundary with 1-month lag (two binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–1.15	–30.40
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary with 1-month lag (one binary indicator)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Covariates: same as in final model Model: tract-month-level logistic regression	−4.38	−17.40
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 2000 m of boundary with 1-month lag (one binary indicator)		
Covariates: same as in final model Model: tract-month-level logistic regression	−2.14	−16.60
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 1000 m of boundary with 1-month lag (one binary indicator)		
Covariates: same as in final model Model: tract-month-level logistic regression	−1.37	−18.20
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 500 m of boundary with 1-month lag (one binary indicator)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for January 2012 only</i>	−8.03	−59.50
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for February 2012 only</i>	0.97	−24.70
Outcome: occurrence of one or more suicides in tract month (binary)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for March 2012 only</i>	–6.06	–51.10
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for April 2012 only</i>	–3.64	–44.70
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for May 2012 only</i>	–6.09	–77.90
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for June 2012 only</i>	–2.56	–57.90
Outcome: occurrence of one or more suicides in tract month (binary)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for July 2012 only</i>	2.45	–55.60
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for August 2012 only</i>	–6.06	–66.50
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for September 2012 only</i>	–4.74	–39.70
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for October 2012 only</i>	–6.00	–61.10
Outcome: occurrence of one or more suicides in tract month (binary)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for November 2012 only</i>	–5.96	–50.30
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression, <i>data for December 2012 only</i>	–5.18	–60.00
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–4.23	–48.70
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model, plus suicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators) Model: tract-month-level semi-parametric regression for binary outcome, <i>estimated using SuperLearner</i>	–3.90	–45.90

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level logistic regression	–4.25	–44.20
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: <i>number of homicides</i> within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four <i>continuous</i> variables)		
Covariates: same as in final model Model: tract-month-level logistic regression	–4.22	–44.70
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: <i>number of homicides</i> within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four <i>categorical</i> variables)		
Covariates: same as in final model Model: tract-month-level negative binomial regression	–4.03	–46.90
Outcome: <i>suicide rate</i> in tract month (continuous)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model Model: tract-month-level Poisson regression	–4.13	–46.80
Outcome: <i>number of suicides</i> in tract month (continuous)		

TABLE 7 *Continued*

Model specification	Population attributable risk percent	Average treatment effect percent
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model		
Model: tract-month-level logistic regression, data restricted to tracts with >90 % of population living in US Census Bureau-defined urban areas ($N = 79,884$)	–4.43	–49.40
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model		
Model: tract-month-level logistic regression	–4.26	–49.40
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as in final model, plus tract population		
Model: tract-month-level logistic regression	–2.78	–27.50
Outcome: occurrence of one or more suicides in tract month (binary)		
Exposure: homicide occurrence within the tract or within 100 m of boundary and 100–500, 500–1000, and 1000–2000 m from boundary with 1-month lag (four binary indicators)		
Covariates: same as final model, except without percent of deaths in 2012 attributable to firearms		

Population attributable risk (PAR) percent percent difference in suicide occurrence, comparing observed frequency to predicted frequency in absence of any homicide; *average treatment effect (ATE) percent* percent difference in suicide occurrence, comparing predicted frequency if all tracts were exposed to homicide to predicted frequency in absence of any homicide

degree of spatial autocorrelation in regression residuals by calculating the Moran's I , with spatial weights constructed as the inverse distance between tract centroids, as recommended by Anselin and colleagues. Observed spatial autocorrelation was negligible, and no further adjustment was necessary. Table 7 presents the population attributable risk (PAR) percent and average treatment effect (ATE) percent estimates for all sensitivity analyses. Confidence intervals are not presented due to intensity of computational requirements.

Positivity

One possible explanation for our findings is that predictions made to estimate risk difference parameters extrapolate beyond what the data can support. This issue is known as positivity and would be a problem if there were census tracts where homicides never occurred or always occurred, and we were predicting what would happen if the opposite were true.

Positivity is one of the assumptions required for causal interpretation of the results. This means that individuals in all confounder subgroups have to be observed under each of the different exposure conditions for which estimates are made. When this is the case, an analysis is described as having good support. This assumption is necessary because we use what we know about people who do experience a particular exposure to predict what would happen for other similar people who instead got different exposures; to do this well and without extrapolation, we need people of all confounder subgroups to experience all exposures for which we are estimating. In our study, this means assuming, for example, that when we predict outcomes for individuals living in tracts with frequent homicides if they were instead exposed to no homicides, that there are people with no exposure to homicide who have similar characteristics to those exposed to frequent homicide. This should be assessed empirically in the data before estimates are made.

A simple way to assess the level of support is to examine the distribution of each confounder across levels of the exposure. The tables below show the distribution of several tract-level baseline characteristics, by homicide exposure categories. For example, in the first table, census tracts in all median household income categories are observed at all levels of homicide exposure. Census tracts in all median household income subgroups have been observed under the different exposure conditions, thus allowing us to estimate outcomes for census tracts of a given median income at one level of exposure, had they instead been exposed to another level with good support.

For the positivity assumption to hold, this pattern must be true, not only for the univariate distribution of each covariate but also for the multivariate distribution of all of the covariates. In a simple example, census tracts in combinations of median household income, age distribution, and race/ethnicity levels would need to be observed in all exposure conditions for which estimates are made, if those were the three confounders. One of the most common ways to assess positivity in the multivariate distribution of covariates is to calculate and compare the probability of experiencing a particular exposure level, also known as the propensity score.^{3,4} When individuals in different exposure groups have similar propensity scores, it suggests that the two groups have similar covariate distributions.

³Ahern J, Hubbard A, Galea S. Estimating the effects of potential public health interventions on population disease burden: a step-by-step illustration of causal inference methods. *Am J Epidemiol* 2009;169:1140-1147.

⁴Petersen ML, Porter KE, Gruber S, Wang Y, van der Laan MJ. Diagnosing and responding to violations in the positivity assumption. *Stat Methods Med Res* 2012;21(1):31-54.

Homicide Exposure Distribution by Confounders

Median household income	Any homicide in tract or within 100 m		Any homicide between 100 and 500 m from tract boundary		Any homicide between 500 and 1000 m from tract boundary		Any homicide between 1000 and 2000 m from tract boundary	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
Quartile 1	19,534	1,106	18,805	1,835	17,972	2,668	14,781	5,859
Quartile 2	19,902	762	19,627	1,037	19,119	1,545	17,010	3,654
Quartile 3	20,198	430	19,990	638	19,606	1,022	17,989	2,639
Quartile 4	20,398	242	20,278	362	20,020	620	18,895	1,745

m meters

Population aged 18–24 years	Any homicide in tract or within 100 m		Any homicide between 100 and 500 m from tract boundary		Any homicide between 500 and 1000 m from tract boundary		Any homicide between 1000 and 2000 m from tract boundary	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
Quartile 1	20,515	233	20,323	425	20,082	666	18,679	2,069
Quartile 2	20,136	516	19,915	737	19,512	1,140	17,871	2,781
Quartile 3	19,782	786	19,381	1,187	18,793	1,775	16,615	3,953
Quartile 4	19,599	1,005	19,081	1,523	18,330	2,274	15,510	5,094

m meters

Percent of non-Hispanic black	Any homicide in tract or within 100 m		Any homicide between 100 and 500 m from tract boundary		Any homicide between 500 and 1000 m from tract boundary		Any homicide between 1000 and 2000 m from tract boundary	
	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)
Quartile 1	20,313	375	20,099	589	19,850	838	18,560	2,128
Quartile 2	20,275	377	20,070	582	19,751	901	18,331	2,321
Quartile 3	20,032	584	19,785	831	19,317	1,299	17,373	3,243
Quartile 4	19,400	1,204	18,735	1,869	17,790	2,814	14,401	6,203

m meters

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