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Community-Level Risk Factors for Firearm Assault and Homicide

The Role of Local Firearm Dealers and Alcohol Outlets

Veronica A. Pear,[a,b] Garen J. Wintemute,[a] Nicholas P. Jewell,[c] Magdalena Cerdá,[d] and Jennifer Ahern[b]

Background: Identifying community characteristics associated with firearm assault could facilitate prevention. We investigated the effect of community firearm dealer and alcohol outlet densities on individual risk of firearm assault injury.

Methods: In this density-sampled case–control study of Californians, January 2005–September 2015, cases comprised all residents with a fatal or nonfatal firearm assault injury. For each month, we sampled controls from the state population in a 4:1 ratio with cases. Exposures were monthly densities of county-level pawn and nonpawn firearm dealers and ZIP code-level off-premises alcohol outlets and bars and pubs ("bars/pubs"). We used case–control-weighted G-computation to estimate risk differences (RD) statewide and among younger Black men, comparing observed exposure densities to hypothetical interventions setting these densities to low. We estimated additive interactions between firearm and alcohol retailer density. Secondary analyses examined interventions targeted to high exposure density or outcome burden areas.

Results: There were 67,850 cases and 268,122 controls. Observed (vs. low) densities of pawn firearm dealers and off-premises alcohol outlets were individually associated with elevated monthly risk of firearm assault per 100,000 people ($RD_{\text{pawn dealers}}$: 0.06, 95% CI: 0.05, 0.08; $RD_{\text{off-premises outlets}}$: 0.01, 95% CI: 0.01, 0.03), but nonpawn firearm dealer and bar/pub density were not; models targeting only areas with the highest outcome burden were similar. Among younger Black men, estimates were larger. There was no interaction between firearm and alcohol retailer density.

Conclusions: Our results are consistent with the hypothesis that limiting pawn firearm dealers and off-premises alcohol outlet densities can reduce interpersonal firearm violence.

Keywords: Alcoholic beverages; Case–control study; Firearms; G-computation; Gun violence

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The authors report no conflicts of interest.

The majority of data for this study are available from the State of California upon request for research purposes. We do not have the authority to share the data. Example code for the data analyses are included in the supplemental material.

SDC Supplemental digital content is available through direct URL citations in the HTML and PDF versions of this article (www.epidem.com).

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In the United States (US), firearms cause three of every four homicides.[1] Firearm homicide is the leading cause of death for Black boys and men between the ages of 15 and 34 years. In 2020, firearm assault resulted in over 19,000 preventable deaths and many more nonfatal injuries,[1] leaving those directly and indirectly affected with lasting health, socioemotional, and economic consequences.[2,3]

Access to firearms is a necessary cause of firearm injury and death. While this can be measured in a number of ways, including prevalent firearm ownership and the size of the illicit firearm market, firearm dealer density measures an aspect of firearm access that can be modified through local zoning regulations. Understanding its relationship with firearm violence can therefore inform actionable changes at the local level. Several studies have evaluated community firearm dealer density in relation to firearm homicide by studying Federal Firearms Licenses, with inconsistent findings.[4–11] However, these data lack precision, as businesses with Federal Firearms Licenses may sell firearms infrequently and may open or close any time during the license period.

Alcohol is a major risk factor for firearm violence. An estimated 37% of firearm homicide victims and 34% of firearm homicide perpetrators were under the influence of alcohol at the time of the offense.[12,13] Alcohol use impairs executive functioning and increases impulsive, violent behavior,[14] which increases the chance of assaults or other violent interactions. Like firearms, alcohol must be purchased through a licensed retailer, and access can be modified through rules and regulations on retailer density. A robust body of literature shows that alcohol availability is associated with increased interpersonal violence.[15–17] However, few studies have examined the relationship between alcohol outlet density and firearm assault in particular, and among those that have, the findings are mixed.[9,18–20]

Though a synergistic interaction seems likely—firearms plausibly magnify the risk of violence stemming from alcohol and vice versa—to our knowledge, the joint effect of alcohol and firearm retailer density with firearm assault has not been examined. This study's aims were to evaluate the effects in California on individual-level risk of firearm assault injury from (1) community-level firearm dealer density, (2) community-level alcohol outlet density, and (3) both together (and to quantify their interaction). We examined these effects statewide and among younger Black men, to determine the potential for firearm injury risk reduction in this particularly high-risk population. Secondary analyses explored hypothetical interventions targeted to areas with either the highest exposure density or outcome burden. We sought to improve upon past analyses by using a precise measure of active firearm dealers and a comprehensive measure of (fatal and nonfatal) firearm assault injuries, and by estimating absolute measures of associations that better quantify public health impact than more commonly used relative measures.

METHODS

Study Design

We conducted a density-sampled population-based case–control study of California residents from January 2005 through September 2015. Cases were all Californians with a firearm assault injury resulting in an in-state emergency department encounter, hospitalization, or death. We selected controls from the general population of California—the population from which cases arose[21,22]—in a 4:1 ratio with cases. As detailed below, we characterized firearm dealer density at the county level and alcohol outlet density at the ZIP code tabulation area (ZCTA) level. We used a case–control-weighted analysis approach to facilitate estimation of a broad range of measures of association, including risk differences and additive interactions. Analyses were adjusted for individual demographics and community socioeconomic characteristics hypothesized to confound the associations of interest, detailed below.

Data and Measures

Exposures

The exposures were community-level firearm and alcohol retailer densities. We used the California Department of Justice Dealer's Record of Sale (DROS) data to capture the monthly number of active pawn and nonpawn firearm dealers from January 2004 to September 2015. DROS data contains statewide records for every legal handgun transfer since 1996 and every long gun transfer since 2014. As long gun transfers were not recorded for the majority of the study period and handguns are more commonly used in firearm homicides and assaults,[23] we excluded long gun transfers from the analytic dataset.

To determine the most appropriate spatial unit of analysis, we geocoded paired DROS dealer and purchaser address data to explore how far people traveled to purchase their firearms. We found that 70% of purchasers and dealers were in the same county, making it the best-performing administrative boundary (see eTable 1; http://links.lww.com/EDE/C66).

Firearm availability was measured with active firearm dealer density measured monthly for each county per 100,000 residents and then transformed into county-specific 12-month moving averages to better approximate a person's past 12-month exposure. Firearm dealers with ≥1 handgun sale in a month were considered "active" in that month. We measured pawn and nonpawn dealer densities separately because pawn shops have been linked to disproportionate sales of crime guns previously and may have a different association with firearm assault victimization than nonpawn dealers.[24–26] We classified dealers as pawn shops if they had "pawn" or "loan" in the business name or email address or had a DROS record for redeeming pawned handguns.

Alcohol outlet density was measured per 100,000 population at the ZCTA level, the smallest geographic area available in our alcohol data, 2004–2015. Studies of alcohol outlet density and violence or injury have found local associations using small geographic units of analysis, including ZIP codes.[27–29] We estimated the 12-month ZCTA density separately for off-premises outlets and bars and pubs (hereafter "bars/pubs"), as they have differing associations with violence.[30] Annual alcohol outlet data were from the California Department of Alcoholic Beverage Control. Additional details are in eMethods; http://links.lww.com/EDE/C66.

Cases

Cases were California residents who experienced a fatal or nonfatal firearm assault injury in California (hereafter "firearm assault") from January 2005 to September 2015, as captured in mortality data from the California Department of Public Health's Comprehensive Death Files and emergency department and inpatient hospital discharge records from the Office of Statewide Health Planning and Development (now the Department of Health Care Access and Information).

Both data sources use the International Statistical Classification of Diseases and Related Health Problems (ICD) to identify injuries: the 10th edition (ICD-10) for mortality data and the 9th edition (ICD-9) for hospital data. Codes used to identify firearm assault are presented in eTable 2; http://links.lww.com/EDE/C66.

Controls

To sample controls from the general population of California, we used American Community Survey[31] data to interpolate the monthly ZCTA-county population by age, sex, and race. In each study month, controls were randomly sampled from the state population (after having removed incident cases for that month) at a ratio of four controls for every case. See eMethods; http://links.lww.com/EDE/C66 for additional details.

Covariates

Covariates were determined a priori based on theory and previous literature. We used a directed acyclic graph to visualize the relationships between variables and to guide confounder selection (eFigure 1; http://links.lww.com/EDE/C66). We included individual age, race–ethnicity, sex; ZCTA percent aged 15–24 years, percent Hispanic, percent non-Hispanic Black, percent male, urbanicity, median household income z-score (hereafter "income"), percent aged 25 years and older with at least a Bachelor's degree (hereafter "education"), the unemployment rate in the civilian workforce over aged 16 years (hereafter "unemployment"), percent of vacant housing units, business establishment density; and county nonfirearm violent crime rate and property crime rate. We controlled for a year to account for secular trends in firearm violence. See eMethods; http://links.lww.com/EDE/C66 for data sources and details.

Statistical Analysis

We used case–control-weighted G-computation to estimate risk differences for contrasts of interest representing realistic interventions. While our study question is causal, the parameters estimated are always statistical, with the strength of interpretation considered after weighing the assumptions required for a causal interpretation (in the discussion). G-computation is a parametric substitution estimator: the outcomes are estimated under exposure regimes of interest (which are substituted into the model). Case–control-weighted G-computation corrects for the case–control sampling by reweighting: cases are weighted according to the population prevalence of the outcome, and controls are weighted with (1-prevalence)/(control:case ratio).[32,33] The case–control-weighted G-computation formula is as follows:

$$\Psi\ (P) = \frac{E_W\left\{\left[I\left(Y_{i=1}\right)\times q\left(t\right)\left[E(Y|A_1=1,A_2=1,W_i\right]\right] + \left[I\left(Y_{i=0}\right)\times\frac{\bar{q}(t)}{J(t)}\left[E(Y|A_1=1,A_2=1,W_i)\right]\right]\right\}}{E_W\left[I\left(Y_{i=1}\right)q\left(t\right)+I\left(Y_{i=0}\right)\frac{\bar{q}(t)}{J(t)}\right]}$$

$$-\frac{E_W\left\{\left[I\left(Y_{i=1}\right)\times q\left(t\right)\left[E(Y|A_1=0,A_2=0,W_i\right]\right] + \left[I\left(Y_{i=0}\right)\times\frac{\bar{q}(t)}{J(t)}\left[E(Y|A_1=0,A_2=0,W_i)\right]\right]\right\}}{E_W\left[I\left(Y_{i=1}\right)q\left(t\right)+I\left(Y_{i=0}\right)\frac{\bar{q}(t)}{J(t)}\right]},$$

where Ψ is the risk difference at the true data distribution (P); q_0 and $\bar{q}_0$ are the case and control weights, respectively, at each year-month (t); E(Y | A_1=1, A_2=1, W=w) is the expected value of the outcome (Y) when both exposures (A_1 and A_2) are set to a given value, such as 1, adjusting for confounders (W); and E_w is the expectation over W.

We estimated what we call the conservative population attributable risk (RD_{cPAR}) for two populations: the entire statewide population and the high-risk subgroup of Black boys and men between the ages of 15 and 39 years. The RD_{cPAR} compared firearm assault when firearm and alcohol retailer densities were both kept at their observed values to a scenario in which both were set to low densities. To avoid positivity violations, "low" values were determined by the observed lowest values in each county or ZCTA over the study period (eTable 3; http://links.lww.com/EDE/C66).

Along with these joint interventions, we examined each exposure independently (nonpawn firearm dealer, pawn firearm dealer, off-premises alcohol outlet, and bar/pub outlet) and estimated the corresponding risk ratios (RRs) to provide additional context for understanding the differences of interest. To calculate additive interactions, we subtracted the sum of the individual RDs ("expected") from the joint RD ("observed"). We used bias-corrected and accelerated nonparametric bootstrapped confidence intervals for all case–control-weighted G-computation estimates (n runs = 400).[34]

The parametric model underlying the G-computation estimates was a case–control-weighted logistic regression. We included interactions between firearm and alcohol retailer densities and retained those with $P < 0.20$.[35] To examine nonlinearity, we visualized the bivariate relationships with each continuous variable and the log-odds of the modeled outcome with scatterplots (including smoothed lines of fit). Variables that appeared nonlinear and were significantly associated with the outcome were modeled with restricted cubic splines (nonpawn and pawn firearm dealer densities, off-premises alcohol outlet density, age, percent Black, percent young, percent male, income, and property crime rate). To ensure degrees of freedom were being spent wisely, we chose to not include splines on nonlinear variables that were not significant at alpha = 0.10 when modeled with or without a spline.

Secondary analyses estimated parameters that correspond with capping firearm dealer and/or alcohol outlet density and considered two approaches for targeting such interventions. The first model simulated an intervention targeting only areas with the highest density of the exposures ($RD_{targeted\_exp}$); here, we compared the observed outcome to the outcome under a simulated scenario in which the exposures were set to low density only in counties in the top quartile of firearm dealer density and in ZCTAs in the top quartile of alcohol outlet density. The second model simulated an intervention targeting only areas with the highest burden of the outcome ($RD_{targeted\_out}$); to do this, we compared the observed outcome to the outcome under a simulated scenario in which the exposures were set to low density only in counties and ZCTAs in the top quartile of firearm assault injuries. While each hypothetical intervention is targeted, we estimated the association of that intervention with firearm assault statewide. The top quartile of the exposure or outcome, respectively, was determined with data from the first year of our study, 2005. For consistency across primary and secondary analyses, we implemented and estimated all case–control-weighted G-computation simulated interventions on January 2006–September 2015 data. However, the underlying parametric models made use of all available data and were fit to the full dataset (including 2005).

Sensitivity analyses explored whether results differed for fatal and nonfatal firearm assaults. For these analyses, performed separately by case fatality, controls were randomly sampled from all controls used in the primary analyses in a 4:1 ratio with the cases to maintain balance. Case–control-weighted G-computation was then performed to estimate the cPAR for a statewide intervention setting each exposure individually and jointly to low density.

We performed analyses with R 4.0.2 (Vienna, Austria), Stata/MP 13.1 (College Station, Texas), and ArcGIS 10.7 (Redlands, California). This study was approved by the California Health and Human Services Agency's Committee for the Protection for Human Subjects; the University of California, Berkeley's Committee for the Protection for Human Subjects; and the University of California, Davis Institutional Review Board.

RESULTS

From January 2005 to September 2015, there were 69,743 assaultive firearm injuries in California among residents. Records missing ZCTA, age, sex, or race were dropped (n = 1,165; 1.7%). We sampled 274,312 controls for a total sample size of 342,890. Two percent of observations (6,918) were dropped due to missing covariates or extreme values (details in the eMethods; http://links.lww.com/EDE/C66). This yielded a final sample size of 335,972 (67,850 cases and 268,122 controls). Controls closely matched the demographics of the California population (eTable 4; http://links.lww.com/EDE/C66).

Table 1 presents individual- and community-level characteristics of study participants. Cases were more likely than controls to be male (90% vs. 49%), Black (35% vs. 6%), or Hispanic (47% vs. 38%), and between the ages of 10 and 29 years (69% vs. 29%). They lived in areas with lower median household incomes ($45,029 vs. $60,447) and fewer college graduates (15% vs. 26%) than controls. Alcohol outlet density was similar for cases and controls, but active firearm dealer density was lower among cases.

Table 2 displays the unadjusted associations between monthly risk of firearm assault per 100,000 population, weighted to be representative of the state population, by tertile of each exposure. The risk was highest in the lowest tertile of each measure of firearm availability. Conversely, the risk of assault injury increased with higher off-premises alcohol outlets and bar/pub density. The spatial distribution of the exposures and outcome are displayed in eFigure 2; http://links.lww.com/EDE/C66.

Figure 1 and eTable 5; http://links.lww.com/EDE/C66 display the adjusted RDs and RRs, respectively, for firearm assault per 100,000 per month from the primary case–control-weighted G-computation analyses. Considering each exposure individually, we found that the observed (vs. low) density of pawn firearm dealers (RD_{cPAR}: 0.06, 95% confidence interval [CI] = 0.05, 0.08) and off-premises alcohol outlets (RD_{cPAR}: 0.01, 95% CI = 0.01, 0.03) were associated with an increased monthly risk of firearm assault, but densities of nonpawn dealers and bar/pub outlets were not. The RD_{cPAR} for the joint exposure of firearm dealers and alcohol outlets was 0.08 assault injuries per 100,000 (95% CI = 0.06, 0.10), indicating a small increase in risk at observed vs. low levels of firearm dealer and alcohol outlet densities (a statewide difference of about 31 injuries per month, or 368 injuries per year). There was no additive interaction between firearm dealers and alcohol outlet densities (RD_{cPAR}: 0.001, 95% CI = −0.010, 0.007).

Figure 1 also displays results for Black boys and men aged 15–39. We found a similar overall pattern, but the absolute differences were substantially larger in this group than in the overall population (the relative contrasts were very similar; see eTable 5; http://links.lww.com/EDE/C66). Among Black boys and younger men, pawn firearm dealer density and off-premises alcohol outlet density were associated with increased monthly rates of firearm assault (pawn, RD_{cPAR}: 1.67, 95% CI = 1.37, 2.01; off-premises outlets, RD_{cPAR}: 0.33, 95% CI = 0.18, 0.53). Neither nonpawn firearm dealers nor bar/pub outlets were associated with firearm assault. The joint RD_{cPAR} for firearm dealers and alcohol outlets together was 2.15 injuries per 100,000 (95% CI = 1.68, 2.59) in this higher-risk population (equivalent to about nine injuries per month and 106 injuries per year). There was no additive interaction between the exposures (RD_{cPAR}: −0.01, 95% CI = −0.13, 0.14).

In secondary analyses examining targeted interventions, we found that the hypothetical intervention targeting the exposure resulted in small estimates with CIs often including the null, but the intervention targeting areas with a high burden of the outcome (denoted with the subscript "targeted out") yielded estimates very similar to those from the statewide cPAR models (Figure 2, eTable 6; http://links.lww.com/EDE/C66). When setting the exposure to low density in areas with the highest burden of the outcome, we found that the observed values of firearm dealer density and off-premises alcohol outlet density were associated with increased monthly risk of assault (nonpawn, $RD_{targeted\_out}$: 0.03, 95% CI = 0.02, 0.04; pawn, $RD_{targeted\_out}$: 0.05, 95% CI = 0.04, 0.07; off-premises outlets, $RD_{targeted\_out}$: 0.01, 95% CI = 0.01, 0.02) but bar/pub density was not. As in the statewide model, the joint association for all

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TABLE 1. Characteristics of Cases and Controls

	Cases[a]	Controls
Total N	67,850	268,122
Individual characteristics		
Sex, n (%)		
Male	60,775 (90)	132,310 (49)
Race–ethnicity, n (%)		
Non-Hispanic white	8,106 (12)	107,336 (40)
Non-Hispanic Black	23,575 (35)	15,890 (5.9)
Hispanic	31,654 (47)	101,251 (38)
Asian American	2,341 (3.5)	36,192 (13)
Native American	170 (0.3)	1,127 (0.4)
Multiracial	2,004 (3.0)	6,326 (2.4)
Age group, n (%)		
0–9	367 (0.5)	35,965 (13)
10–19	17,948 (26)	38,729 (14)
20–29	28,568 (42)	39,978 (15)
30–39	11,618 (17)	37,648 (14)
40–49	5,671 (8.4)	38,104 (14)
50–59	2,571 (3.8)	33,683 (13)
60–69	779 (1.1)	22,370 (8.3)
70–79	227 (0.3)	12,923 (4.8)
80+	101 (0.1)	8,722 (3.3)
ZCTA-Level[b] characteristics		
Alcohol outlet density per 100,000 residents, median (25th, 75th pctl)		
Off-premises	69.23 (55.51, 89.58)	65.84 (50.05, 85.63)
Bar or pub	10.67 (6.03, 18.17)	10.65 (5.50, 17.79)
Business establishment density per 1,000 residents, Median (25th, 75th pctl)	0.21 (0.07, 0.62)	0.34 (0.11, 0.80)
Urbanicity, n (%)		
Urban	64,820 (96)	248,717 (93)
Suburban	2,437 (3.6)	13,615 (5.1)
Rural	593 (0.9)	5,790 (2.2)
Demographics, median (25th, 75th pctl)		
% Male	49.33 (48.53, 50.23)	49.35 (48.57, 50.14)
% Non-Hispanic Black	9.08 (2.94, 19.92)	3.12 (1.43, 6.92)
% Hispanic	53.47 (32.30, 69.92)	32.01 (17.23, 54.65)
% Age 15–24	16.17 (14.42, 17.58)	14.63 (12.42, 16.53)
Median household income	45,029 (37,072, 56,835)	60,447 (47,049, 80,310)
% Bachelor's degree+	14.94 (8.02, 23.91)	25.54 (15.07, 39.95)
% Unemployed	11.82 (9.47, 14.41)	9.37 (7.38, 11.94)
% Vacant housing units	6.94 (5.29, 8.89)	6.13 (4.50, 8.19)
County-Level characteristics		
Active firearm dealer density per 100,000 residents, median (25th, 75th pctl)		
Non-pawn dealer	0.46 (0.39, 0.97)	0.66 (0.41, 1.05)
Pawn dealer	0.54 (0.42, 1.00)	0.75 (0.46, 1.06)
Crime rate per 1,000 residents, median (25th, 75th pctl)		
Property crime	28.92 (25.04, 36.43)	27.45 (23.13, 33.21)
Non-firearm violent crime	3.82 (3.19, 4.17)	3.40 (2.62, 4.14)

[a]2,835 individuals have multiple assaultive firearm injuries.
[b]ZCTA = ZIP Code Tabulation Area.

exposures in the targeted outcome model was 0.08 injuries per 100,000 people per month (95% CI = 0.06, 0.11).

Sensitivity analyses exploring differences in association by case fatality generally found similar patterns of association with larger estimates for nonfatal injuries (eFigure 3; http://links.lww.com/EDE/C66 and eTable 7; http://links.lww.com/EDE/C66).

DISCUSSION

This study adds to the limited literature on the relationship between community firearm and alcohol availability and firearm assault by using improved data—accurate measures of active firearm dealers and both fatal and nonfatal firearm assaults—and by using rigorous methods to estimate absolute scale measures that are most relevant for public health. While we have improved upon past research and enhanced the quality of the evidence available to decisionmakers, our study does not meet the criteria for causal interpretation (as is explained in the limitations section); findings are therefore discussed as associations. We found that community-level firearm and alcohol retailer densities

TABLE 2. Risk of Firearm Assault per 100,000 Residents per Month by Tertile of Firearm Dealer and Alcohol Outlet Density

	Tertile	Homicides/Assaults[a]
Active firearm dealer density per 100,000 residents		
Non-pawn dealers	Low	2.39
	Medium	1.07
	High	1.16
Pawn dealers	Low	2.48
	Medium	1.00
	High	1.17
Alcohol outlet density per 100,000 residents		
Off-premises outlets	Low	1.15
	Medium	1.67
	High	1.72
Bar/pub outlets	Low	1.39
	Medium	1.53
	High	1.59

[a]Estimates are weighted to be representative of the population.

were associated with an increased risk of firearm assault after adjusting for confounders. We estimate that observed firearm dealer and alcohol outlet densities are associated with ~368 more firearm assault injuries annually, 106 of which are among younger Black men, than would be expected under low density conditions. While the joint associations were larger than the independent associations, we did not find evidence of additive interaction between the exposures.

Associations were substantially stronger among Black boys and men aged 15–39 years than among the overall population, suggesting community-level interventions may be an important part of a comprehensive strategy to reduce firearm assault in those at highest risk. Targeted models reducing exposure densities only in areas with the greatest burden of firearm assault yielded associations that were nearly equivalent to those from statewide intervention models. By quantifying associations for modifiable community-level risk factors, we hope to build the evidence base to support local solutions (e.g., zoning interventions) to policymakers and public health practitioners working to prevent firearm violence.

Our first study's aim was to evaluate the effect of community-level firearm dealer density on individual risk of firearm assault injury. We found that the density of pawn firearm dealers and, to a lesser extent, nonpawn firearm dealers were associated with slightly increased risk. Our conclusions are consistent with previous work finding community firearm availability (mostly measured with Federal Firearms License density) to be associated with increased rates of firearm homicide and firearm intimate partner homicide.[4,5,8,36,37] The stronger association between pawn dealers and nonpawn dealers is also supported by previous studies.[38,39]

There are several mechanisms through which firearm dealers may increase the risk of firearm assault. Dealers act as point sources from which firearms flow into a community. Only a minority (11% in one study of inmates[40]) of persons who commit firearm crimes purchase their firearm directly from a dealer. Nonetheless, the higher the prevalence of

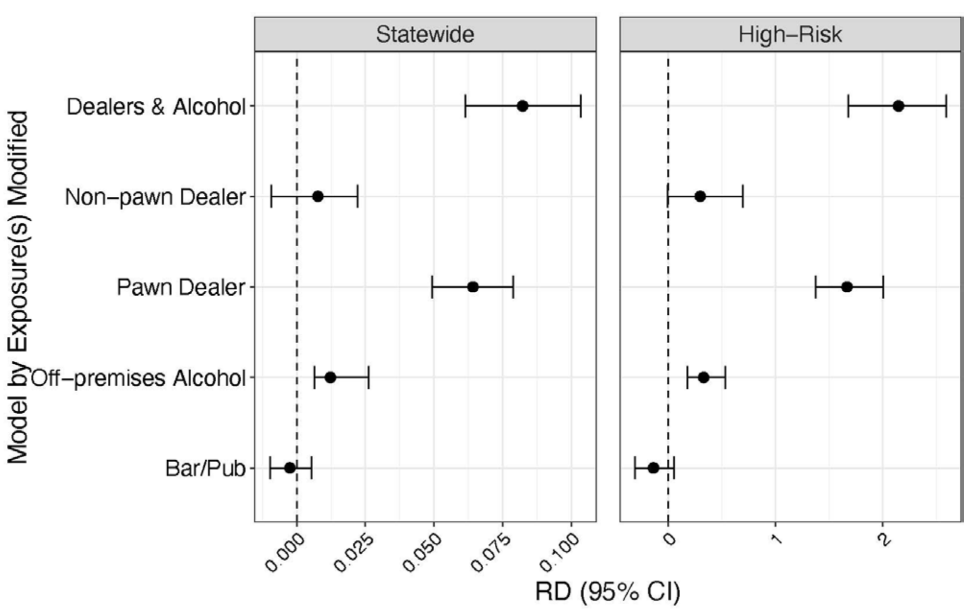

FIGURE 1. Adjusted risk differences for firearm homicide/assault per 100,000 residents per month for statewide interventions, by population[a,b,c]. A, Risk differences (RDs) and 95% confidence intervals (CIs) estimate the adjusted conservative population attributable risk (cPAR). B, The high-risk estimates are for Black boys and men aged 15–39. C, "Dealers & Alcohol" includes nonpawn and pawn dealers and off-premises outlets and bars/pubs. Nonpawn and pawn dealer density were measured per 100,000 population at the county level. Off-premises outlets and bars/pubs were measured per 100,000 population at the ZCTA level.

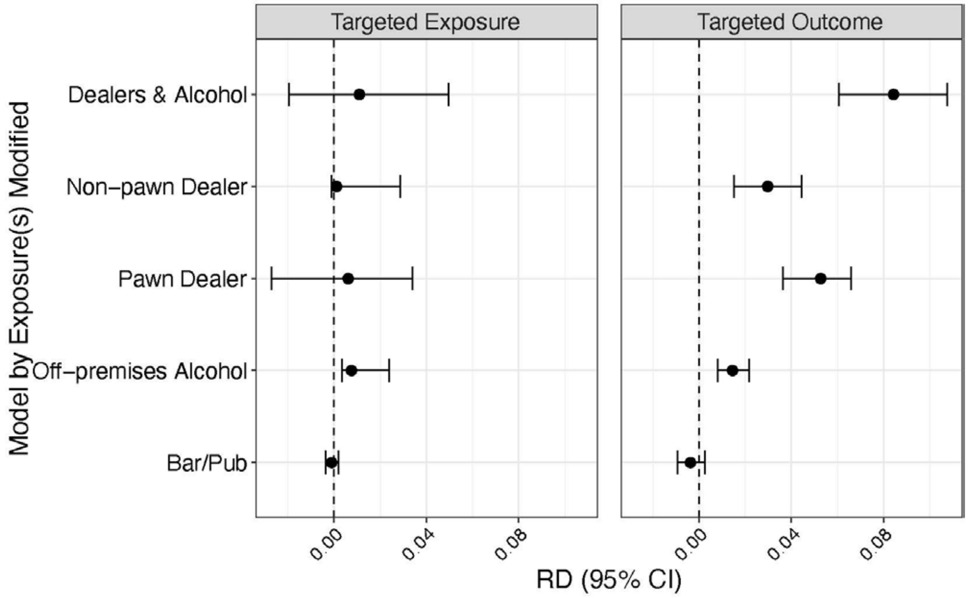

FIGURE 2. Adjusted risk differences for firearm homicide/assault per 100,000 residents per month for targeted interventions[a,b.] A, Risk differences (RDs) and 95% confidence intervals (CIs) reflect adjusted marginal statewide associations under two hypothetical interventions. Targeted exposure models intervened only in areas with the highest density of the exposures. Targeted outcome models intervened in only areas with the highest burden of the outcome. B, "Dealers & Alcohol" includes nonpawn and pawn dealers and off-premises outlets and bars/pubs. Nonpawn and pawn dealer density were measured per 100,000 population at the county level. Off-premises outlets and bars/pubs were measured per 100,000 population at the ZCTA level.

firearm ownership is in a community, the easier it is for a firearm to change hands between friends or family members (the primary source of firearms used in assaults).[41,42] Dealers also supply firearms (knowingly or unknowingly) to traffickers and to straw purchasers, who then transfer the weapons to the illicit market.[39,43,44] Many firearms stay local to the original dealer; about a third of crime guns traced by the Bureau of Alcohol, Tobacco, Firearms, and Explosives originated from a dealership in the community where the crime occurred,[45] and 45% were recovered within 25 miles of the original dealer.[46]

Our second aim was to evaluate the effect of community-level alcohol outlet density on individual risk for firearm assault. We found modest positive associations between off-premises alcohol outlet density, but not bar/pub density, and assault. Previous studies of single cities in the US also found off-premises outlets, but not on-premises outlets, to be associated with firearm assault.[16,18] However, firearm crime was not associated with alcohol outlet density in a study of counties in New York,[19] and a study of gunshot wounds in Chicago found that the association with alcohol outlet proximity was heterogeneous across the city.[47] Geographic and methodologic differences preclude comparing results directly.

Routine activities theory suggests that violent crimes occur when a "likely offender" crosses paths with a "suitable target" when no bystander is present and able to intervene.[48] This theory helps to make sense of the null finding with bars/pubs, as these outlets have bartenders and bouncers who can serve as "guardians" to prevent violence at the outlet. Conversely, off-premises alcohol consumption is less monitored, resulting in more opportunities for violence to occur.

Our third aim was to evaluate the joint effect of community-level firearm and alcohol retailer densities on the individual-level risk of firearm assault. We hypothesized that the effect of firearm dealers on assault would be stronger in areas with greater alcohol availability, as firearm safety is undermined by inebriation. However, we found no interactions; the joint associations were equivalent to the sum of the individual associations. Nevertheless, the larger joint associations illustrate the benefit of targeting both firearm dealers and (off-premises) alcohol outlets simultaneously.

While our associations were modest, they are comparable to other policies that affect firearm access. We estimated a 7% reduction in risk of firearm assault among younger Black men under a hypothetical intervention setting firearm dealer and alcohol outlet density to low. In comparison, background checks for mental illness and restraining orders have been associated with ~7%–12% reductions in the rate of homicide[49] and domestic violence restraining orders have been associated with ~7%–19% reductions in the rate of intimate partner homicide.[50–53]

Across all absolute measures of association, the RDs were larger for the higher-risk group than the statewide population, while the relative measures were very similar. This makes sense, as the baseline rate of firearm assault in younger Black men is much higher than in the overall population. These findings demonstrate the importance of evaluating absolute differences when trying to gauge public health impact and potential to reduce racial/ethnic disparities: similar RRs translated to considerable differences in RDs between the statewide and high-risk populations, with estimates for the latter being 25–50 times larger than the former.

Limitations

Our study faced several limitations which, taken together, suggest that our findings should be interpreted as quantifying associations, not causal effects. Results may not generalize to states outside of California, which has a unique firearm policy environment. Additionally, there may be some measurement errors in our exposure and outcome data. We were unable to capture dealers who sold long guns exclusively; however, dealers who sold handguns were of primary interest. We could not directly measure the proportion of community members who owned or had access to a firearm or the flow of illegal firearms into communities, but by focusing on dealers, which are the principal source of new firearms in their communities, we were targeting upstream drivers that are modifiable by local interventions and policy.

We only captured firearm injuries that were fatal or warranted going to the hospital, but the great majority of firearm assault injuries appear in hospitalization and emergency department data.[54] Another concern is the accuracy of ICD coding: it is likely that some proportion of firearm injuries coded as unintentional were truly assaults, resulting in a systematic undercount of nonfatal firearm assault injuries. A study using data from three hospitals estimated that 28% of nonfatal assaults were miscoded as unintentional injuries[55] (which themselves constitute about 24% of nonfatal firearm injuries in California[56]). This misclassification would likely not differ with respect to the exposure, however, so it would lead to bias towards the null.

We were also limited by uncontrolled confounding, as we did not have individual-level measures of, for example, socioeconomic status. Finally, like other spatial analyses, our findings are subject to the modifiable areal unit problem; it is possible our results would be different had we used different geographic units in analyses (e.g., cities).[57] However, we empirically determined the county to be the best administrative unit to measure firearm dealer density, and ZCTA is appropriate for measuring alcohol outlet density[27–29] (and was the smallest unit of analysis available to us).

Finally, it is possible that firearm dealers opened in response to increased violence, which introduces potential reverse causation. This association would only appear over a longer period, given the many bureaucratic and financial requirements of opening a business. While not correcting for this potential issue, our analyses limit its impact by lagging the exposure relative to the outcome.

Conclusions

Firearm violence is a complex problem, best addressed by multiple interventions targeting different social-ecological levels.[58,59] Community-level interventions can be particularly important in such cases; they can shift the burden away from individuals, address systemic problems, and respond to local conditions. Firearm dealers and alcohol outlets are both modifiable exposures, as they are subject to rules and regulations such as zoning laws. Our findings suggest that community-level interventions limiting the density of both pawn firearm dealers and off-premises outlets simultaneously may be associated with larger reductions in firearm assault, particularly among those at highest risk, than interventions on either exposure alone. Importantly, such interventions had nearly equal associations with firearm assault in statewide and targeted intervention models limited to areas with the highest burden of the outcome. Additional research with better control of individual-level confounding would help strengthen the evidence base for these exposures.

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