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In-State and Interstate Associations Between Gun Shows and Firearm Deaths and Injuries

A Quasi-experimental Study

Ellicott C. Matthay, MPH; Jessica Galin, MPH; Kara E. Rudolph, PhD, MPH, MHS; Kriszta Farkas, MPH; Garen Wintemute, MD, MPH; and Jennifer Ahern, PhD, MPH

Background: Gun shows are an important source of firearms, but no adequately powered studies have examined whether they are associated with increases in firearm injuries.

Objective: To determine whether gun shows are associated with short-term increases in local firearm injuries and whether this association differs by the state in which the gun show is held.

Design: Quasi-experimental.

Setting: California.

Participants: Persons in California within driving distance of gun shows.

Measurements: Gun shows in California and Nevada between 2005 and 2013 (*n* = 915 shows) and rates of firearm-related deaths, emergency department visits, and inpatient hospitalizations in California.

Results: Compared with the 2 weeks before, postshow firearm injury rates remained stable in regions near California gun shows but increased from 0.67 injuries (95% CI, 0.55 to 0.80 injuries) to 1.14 injuries (CI, 0.97 to 1.30 injuries) per 100 000 persons in regions near Nevada shows. After adjustment for seasonality and clustering, California shows were not associated with increases in local firearm injuries (rate ratio [RR], 0.99 [CI, 0.97 to 1.02]) but Nevada shows were associated with increased injuries in California (RR, 1.69 [CI, 1.16 to 2.45]). The pre–post difference was significantly higher for Nevada shows than California shows (ratio of RRs, 1.70 [CI, 1.17 to 2.47]). The Nevada association was driven by significant increases in firearm injuries from interpersonal violence (RR, 2.23 [CI, 1.01 to 4.89]) but corresponded to a small increase in absolute numbers. Nonfirearm injuries served as a negative control and were not associated with California or Nevada gun shows. Results were robust to sensitivity analyses.

Limitation: Firearm injuries were examined only in California, and gun show occurrence was not randomized.

Conclusion: Gun shows in Nevada, but not California, were associated with local, short-term increases in firearm injuries in California. Differing associations for California versus Nevada gun shows may be due to California's stricter firearm regulations.

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For author affiliations, see end of text.
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Firearms are a leading cause of morbidity and mortality in the United States and accounted for more than 36 000 deaths and nearly 85 000 injuries in 2015 (1). Ownership increases the risk for suicide, homicide, and unintentional firearm death and injury in the home (2–8). Greater availability and ownership of firearms also contributes to the higher rate of firearm deaths and injuries (hereafter called "firearm injuries") in the United States than in other high-income countries (9–12). Gun shows account for 4% to 9% of annual firearm sales (13–15) and 3% of gun owners' most recent gun acquisitions (16). However, many of these transfers do not involve a background check (16) and firearms from gun shows are disproportionately implicated in crimes (17, 18). Little is known about how gun shows contribute to firearm injuries in the United States.

More than 4000 gun shows are held annually in the United States (19). These shows, which can attract thousands of attendees and hundreds of sellers, generate a temporary and diverse source of new and used firearms, ammunition, and related equipment in a competitive market where sales may be subject to less oversight (15, 20). Consequently, gun shows may increase local firearm ownership and use and affect subsequent rates of firearm injury. State regulations also differ markedly, which may modify the association between gun shows and firearm injuries. In particular, interstate activity and the flow of firearms from less to more restrictive states have been documented previously (21), and this pattern, which may limit the effectiveness of regulations in states that have them, may also extend to gun shows.

Using a quasi-experimental, difference-in-differences design, we exploited the natural variation in the timing and location of gun shows to investigate whether they are associated with increased injury rates and whether this association varies by the state in which the gun show is held. California has some of the most restrictive firearm laws in the country, including a comprehensive set of statutes regulating gun shows (22, 23). In contrast, Nevada has some of the least restrictive laws in the country and no explicit regulations on gun shows (22). Thus, comparing pre–post differences in California and cross-border differences between California and Nevada gun shows may provide useful information on these different policy environments.

See also:

Editorial comment 1

Table 1. Characteristics of California and Nevada Gun Shows and Population Exposure to Gun Shows

Characteristic	California	Nevada
Shows, *n*	640	275
Unique show locations, *n*	64	31
Earliest show date	15 January 2005	22 January 2005
Latest show date	7 December 2013	14 December 2013
Shows excluded because of overlap exclusions, *n*	55	114
Final shows in regression analyses, *n*	585	161
Total gun show exposure in final regression analyses, *person-weeks**	2 303 786 333	13 037 052

* Assuming a 2-wk postexposure time frame, as described in the Methods section.

No formal evaluations have assessed the effects of policies regulating gun shows. Observational evidence from 5 states suggests that such activities as anonymous and undocumented sales are less frequent in California, where they are prohibited, than in states where they are legal (24). Previous evidence has also linked firearms purchased at gun shows to crimes (17, 18), but to our knowledge, only 1 study has examined the association between gun shows and subsequent firearm injuries. Duggan and colleagues (25) examined weekly violent firearm deaths in ZIP codes in the immediate vicinity of gun shows in California and Texas. They found no association and suggested that California's gun show regulations have no effect on violent firearm deaths. However, the study was criticized as having low statistical power, incomplete identification of gun shows, and an analytic approach ignoring California's requirement that buyers wait 10 days between purchasing and obtaining a firearm (26, 27).

We addressed these gaps while assessing whether firearm injuries increase in nearby California areas immediately after gun shows in California and Nevada. We hypothesized that gun shows lead to increased rates of firearm injury.

METHODS

Overall Approach

We used a quasi-experimental, difference-in-differences design (28, 29). First, we compared firearm injury rates for the 2 weeks immediately before and after each gun show in California regions within convenient traveling distance of the show. Then, we compared this difference for the California populations exposed to California versus Nevada gun shows. This approach is advantageous because each region's characteristics, other than the occurrence of a show, are unlikely to change appreciably over so short a time. Thus, each region serves as its own control, allowing us to adjust for community-level characteristics that may be associated with firearm injuries.

Firearm Injuries

We identified fatal and nonfatal firearm injuries in California between 2005 and 2013 using death records from the California Department of Public Health Vital Records and emergency department and inpatient hospitalization records from the Office of Statewide Health Planning and Development. External cause-of-injury coding in California's hospital discharge records is mandatory, subject to ongoing quality assurance measures, and considered 100% complete (30). Emergency department records from before 2005 are not available.

Gun Show Data

We compiled dates and locations of gun shows in California and Nevada between 2005 and 2013 using published lists in the *Big Show Journal*. This source was the most comprehensive; other magazines (*Gun and Knife Show Calendar* and *Gun List Magazine*) and online sources (we considered 11 major Web sites) did not cover the entire study period or included fewer listings (95% vs. 65% coverage). We used ABBYY FineReader 12 character recognition software to convert scanned images of show listings to electronic alphanumeric data (31).

Database Construction

Regions considered local to gun shows were determined using the Google Maps Distance Matrix API (32) by measuring the typical driving time between each ZIP code centroid in California and each geocoded gun show location. Little evidence exists on how far or how long the effects of gun shows extend (27). Thus, we selected reasonable time frames and travel distances to balance capturing short-term effects with estimating stable rates and to include regions likely to be affected by gun shows while excluding regions so distant that unrelated firearm injuries might obscure potential relationships. We tested the sensitivity of our results to chosen time frames and travel times in several sensitivity analyses. "Before" periods were the 14 days before each show; "after" periods were the 14 days after the 10-day waiting period from the start of the show for California or after the start of the show for Nevada, which has no waiting period. ZIP code centroids within a 60- or 120-minute drive were considered to be within traveling distance of California and Nevada shows, respectively. In California, most persons can access a gun show within a 60-minute drive every few weeks, but we hypothesized that some persons in California would be willing to travel farther to Nevada's comparatively unregulated environment.

ZIP codes were occasionally local to several gun shows at the same time. This was problematic when the "before" period of a later gun show (show B) overlapped with the "after" period of an earlier show (show A). Without consideration of this overlap, the ZIP code would be misclassified as "unexposed" for examination of show B when it was "exposed" to show A. In these cases, we excluded the overlapping ZIP code from analyses of show B (hereafter "overlap exclusions"). Restricting to ZIP codes far enough from the border to eliminate the need for overlap exclusions did not alter the findings (results available on request). Throughout, rates are reported per 100 000 persons in regions within traveling distance of shows.

Statistical Analysis

We did a difference-in-differences analysis (28, 29) at the gun show–period level using multivariable Poisson mixed-effects regression. The main outcome measure was the rate of firearm injury. The full model specification was as follows:

$$log(Y_{tsk}) = \beta_0 + \beta_1 X_t + \beta_2 X_k + \beta_3 X_t \times X_k + \beta_4 X_m + \rho_{cs} + \rho_c + log(d_{tsk}) + \varepsilon_{tsk}$$

where y_{tks} was the count of firearm injuries at time t in the region surrounding gun show s in state k; β_0, the intercept; X_t, the period (after vs. before); X_k, the state of the show (Nevada vs. California); X_m, month indicators to account for seasonality; ρ_{cs} and ρ_c, random-effects intercepts to account for clustering by gun shows nested within cities; $log(d_{tsk})$, an offset for the number of at-risk persons; and ε_{tsk}, the error term. Statistical testing of the dispersion parameter indicated that a Poisson model was more appropriate than a negative binomial model. Under this specification, exp(β_1) estimates the rate ratio (RR) associated with gun shows in California, exp($\beta_1 + \beta_3$) estimates the RR associated with gun shows in Nevada, and exp(β_3) estimates the difference-in-differences estimate—the ratio of RRs—capturing the increase in firearm injury rates after Nevada shows compared with that after California shows.

P values less than 0.05 were considered statistically significant. Data were processed by using SAS, version 9.3 (SAS Institute), and R, version 3.2.1 (R Foundation), and regression analysis was done using the lme4 package (33) in R, version 3.2.1. This study was approved by the State of California and University of California, Berkeley, Committees for the Protection of Human Subjects.

Subgroup and Secondary Analyses

To examine variation by firearm injury type, we did subgroup analyses for intentional interpersonal violence, intentional self-harm, unintentional injuries, and injuries of undetermined intent (**Appendix Table 1**, available at Annals.org). Because the exposure periods and geographic regions defined for California and Nevada shows were not identical (with vs. without a waiting period; a 60- vs. a 120-minute drive), we also stratified the analysis by state. In addition, we did analyses restricted to specific gun shows and affected regions to examine potential associations along known firearm trafficking routes between Reno and San Francisco and between Las Vegas and Los Angeles. We also tested the association between California gun shows and California firearm injuries ignoring the 10-day waiting period, because activities other than legal firearm purchases (such as ammunition or parts purchases, illegal purchases, and repairs) may affect firearm injuries and do not have a waiting period. We tested the association between gun shows and nonfirearm injuries as a negative control to assess whether common causes of fire-

Table 2. Unadjusted Analyses of the Association Between Firearm Deaths and Injuries in California and Gun Shows in California and Nevada

Firearm Death or Injury Characteristic	2 Weeks Before Gun Shows		2 Weeks After Gun Shows	
	Total Firearm Deaths and Injuries, *n*	**Firearm Death and Injury Rate (95% CI), *events per 100 000 persons****	**Total Firearm Deaths and Injuries, *n***	**Firearm Death and Injury Rate (95% CI), *events per 100 000 persons****
All causes				
California	15 000	1.30 (1.21–1.39)	14 893	1.29 (1.20–1.39)
Nevada	44	0.67 (0.55–0.80)	74	1.14 (0.97–1.30)
Self-directed				
California	1266	0.11 (0.08–0.14)	1275	0.11 (0.08–0.14)
Nevada	15	0.23 (0.16–0.30)	23	0.35 (0.26–0.44)
Interpersonal				
California	9288	0.81 (0.73–0.88)	9277	0.81 (0.73–0.88)
Nevada	9	0.14 (0.08–0.20)	20	0.31 (0.22–0.39)
Unintentional				
California	3887	0.34 (0.29–0.38)	3799	0.33 (0.28–0.38)
Nevada	19	0.29 (0.21–0.37)	29	0.44 (0.34–0.55)
Undetermined				
California	559	0.05 (0.03–0.07)	542	0.05 (0.03–0.06)
Nevada	1	0.02 (0.00–0.03)	2	0.03 (0.00–0.06)

* CIs are based on an assumed Poisson distribution of the rates, as in the main analysis. As noted in the Statistical Analysis section, statistical testing of the dispersion parameter indicated that a Poisson model was more appropriate than a negative binomial model.

Table 3. Adjusted Analyses of the Association Between Firearm Deaths and Injuries in California and Gun Shows in California Versus Nevada

Firearm Death or Injury Characteristic	Association With Gun Shows (After vs. Before)		Ratio of RRs Associated With Nevada vs. California Gun Shows	
	RR (95% CI)	*P* Value	Ratio of RRs (95% CI)	*P* Value
All causes	–	–	1.70 (1.17–2.47)	0.006
California	0.99 (0.97–1.02)	0.55	–	–
Nevada	1.69 (1.16–2.45)	0.006	–	–
Self-directed	–	–	1.51 (0.78–2.90)	0.22
California	1.01 (0.93–1.09)	0.86	–	–
Nevada	1.52 (0.79–2.91)	0.21	–	–
Interpersonal	–	–	2.23 (1.01–4.90)	0.046
California	1.00 (0.97–1.03)	0.94	–	–
Nevada	2.23 (1.01–4.89)	0.046	–	–
Unintentional	–	–	1.57 (0.88–2.81)	0.128
California	0.98 (0.93–1.02)	0.32	–	–
Nevada	1.53 (0.86–2.74)	0.147	–	–
Undetermined*	–	–	–	–
California	–	–	–	–
Nevada	–	–	–	–

RR = rate ratio.
* Not estimated because few events were observed near Nevada shows (see Table 2).

arm and nonfirearm injuries confounded our findings (34).

Finally, differences in associations between California and Nevada gun shows may be due to differing characteristics of regions exposed to California shows versus those exposed to Nevada shows. To address this potential source of variation, we restricted the entire analysis to regions similar to those exposed to Nevada gun shows. We tightly matched on ZIP code characteristics that differed between regions exposed to California versus Nevada shows and may modify the association between gun shows and firearm injuries (35, 36). These were population density, percentage of veterans, median income, median age, percentage of white non-Hispanic persons, hunting licenses per capita, and the overall rate of firearm injury between 2005 and 2013. We tested a range of matching approaches, all of which produced similar matches. Further details on the matching approach and characteristics of this restricted analysis are in the Appendix (available at Annals.org).

Power Calculations

To confirm that our study had sufficient statistical power, we did a power analysis using simulated data that were generated to be similar to the observed data (Appendix Figure 1, available at Annals.org) (37). We applied the main analysis regression approach to each simulated data set and recorded the proportion of simulations with a significant association. This analysis indicated that our study had 87.8% power to detect increases in firearm injuries as large as or larger than those seen for Nevada shows and 84.2% power to detect the difference between California and Nevada gun shows.

Bias Analysis

To assess the potential role of residual confounding due to unmeasured factors, we did a quantitative bias analysis. We estimated the characteristics of an unmeasured confounder that would yield the observed associations between gun shows and firearm injuries, if the true effect were not statistically significant.

Role of the Funding Source

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RESULTS

We identified 640 gun shows in California and 275 in Nevada between 1 January 2005 and 31 December 2013 (Table 1). Shows were held on weekends, usually at convention centers or county fairgrounds, and lasted 2 to 3 days. Some shows returned to the same locations at regular intervals, whereas others were held at irregular times and locations. Overlap exclusions were more common for Nevada shows than for California shows because those in Nevada were more frequent and held in fewer locations. Appendix Figure 2 (available at Annals.org) is a map of gun show locations. Table 1 provides characteristics of California and Nevada gun shows and total person-weeks of exposure to gun shows.

Table 2 presents the number and rate of local firearm injuries before and after California and Nevada gun shows. In the 2 weeks preceding California shows, 15 000 firearm injuries occurred in at-risk regions, but before–after rates remained stable for California shows. For Nevada shows, only 44 firearm injuries occurred during the preshow period (Table 2). However, firearm injury rates increased from 0.67 injuries (95% CI, 0.55 to 0.80 injuries) per 100 000 persons to 1.14 injuries (CI, 0.97 to 1.30 injuries) per 100 000 persons in California regions exposed to Nevada shows.

After adjustment, California shows were not associated with increases in firearm injuries (RR, 0.99 [CI, 0.97 to 1.02]), but Nevada shows were associated with significant cross-border increases in firearm injuries in California (RR, 1.69 [CI, 1.16 to 2.45]) (Table 3). The difference between states was significant: Gun shows in Nevada were associated with a 70% greater increase in firearm injuries than those in California (ratio of RRs, 1.70 [CI, 1.17 to 2.47]). This association corresponds to a rate difference of 0.46 (CI, 0.36 to 0.57) per 100 000 persons, or a 0.3-SD increase relative to the biweekly variability in rates across locations. In terms of cases, the association corresponds to 30 additional injuries in regions exposed to the 161 Nevada shows.

The association with Nevada shows was driven by significant increases in firearm injuries from interpersonal violence (RR, 2.23 [CI, 1.01 to 4.89]). Results for analyses stratified by gun show state (Table 4) or restricted to regions similar to those exposed to Nevada shows (Table 5) were consistent with those from the main analysis. No significant relationships existed between gun shows and firearm injuries along known trafficking routes or when excluding California's 10-day waiting period (Appendix Table 2, available at Annals.org).

In sensitivity analyses of geographic range and duration of exposure (Appendix Table 3, available at Annals.org), associations between California shows and firearm injuries were consistently null. For Nevada gun shows, changes in firearm injuries remained statistically significant for shorter (1-week) and longer (3-week) periods but were not statistically significant for smaller geographic ranges (60-minute drive), which yielded very few cases, or larger geographic ranges (120- and 180-minute drives for California and Nevada guns shows, respectively), which covered large portions of California. Nevada shows were significantly associated with increases in self-directed intentional firearm injuries when longer periods were examined.

The Appendix provides bias and negative control analyses. In brief, for the association between Nevada gun shows and California firearm injuries to be spurious, another factor would have to match the precise geographic and temporal pattern of the 275 Nevada gun shows and also be strongly associated with firearm injuries in California, corresponding to RRs of at least 1.5 or 2. This factor would also have to be up to 80% more prevalent in the 2 weeks after Nevada gun shows than in the 2 weeks before. Bias analysis results were similar for the difference-in-differences estimate comparing Nevada with California. Associations between both California and Nevada gun shows and nonfirearm injuries were null, or were statistically significant because of the large number of nonfirearm unintentional injuries (n = 6 065 633) but not meaningfully different from the null.

Discussion

We examined the association between California and Nevada gun shows and short-term changes in local firearm injuries in California. Using a quasi-experimental, difference-in-differences design, we took advantage of natural variation in the timing and location of gun shows and differences between California and Nevada firearm regulations to compare this association by state. Firearm injuries in California remained stable after California gun shows but increased by a small but significant amount after Nevada shows.

Several factors could explain our findings. First, although we did not formally assess the effect or enforcement of firearm policies in either state, the absence of an increase in firearm injuries after California gun shows may be evidence that California's strict regulatory environment, both gun show–related and otherwise, mitigates potential risk from gun shows through deterrence. Among other restrictions, California requires that all private transfers be documented by a licensed dealer and include a background check (22). It also enforces restrictions on gun shows (23), including a range of security- and enforcement-related planning and reporting practices, that may deter the illegal firearm activity historically seen at gun shows (15, 17, 18, 20). Specialized firearm enforcement agents from the California Department of Justice also do surveillance at

Table 4. Adjusted Analyses of the Association Between Firearm Deaths and Injuries in California and Gun Shows in California and Nevada, by State

Firearm Death or Injury Characteristic	Association With Gun Shows (After vs. Before) RR (95% CI)	*P* Value
All causes		
California	0.99 (0.97–1.02)	0.53
Nevada	1.68 (1.16–2.44)	0.006
Self-directed		
California	1.01 (0.93–1.09)	0.85
Nevada	1.53 (0.80–2.94)	0.198
Interpersonal		
California	1.00 (0.97–1.03)	0.93
Nevada	2.22 (1.00–4.94)	0.050
Unintentional		
California	0.98 (0.94–1.02)	0.30
Nevada	1.53 (0.86–2.73)	0.150
Undetermined		
California	0.97 (0.86–1.09)	0.62
Nevada*	–	–

RR = rate ratio.
* Not estimated because few events were observed near Nevada shows (see Table 2).

Table 5. Adjusted Analyses of the Association Between Firearm Deaths and Injuries in California and Gun Shows in California Versus Nevada, Restricted to Regions Similar to Those Exposed to Nevada Gun Shows

Type of Firearm Death or Injury	RR of Association With California Gun Shows (After vs. Before) (95% CI)	RR of Association With Nevada Gun Shows (After vs. Before) (95% CI)	Ratio of RRs of Association With Gun Shows (Nevada vs. California) (95% CI)
All causes	0.97 (0.91–1.04)	1.68 (1.18–2.40)	1.73 (1.21–2.48)
Self-directed	1.04 (0.88–1.23)	1.54 (0.80–2.94)	1.47 (0.75–2.88)
Interpersonal	0.98 (0.88–1.08)	2.22 (1.01–4.88)	2.28 (1.03–5.03)
Unintentional	0.91 (0.82–1.03)	1.53 (0.86–2.72)	1.67 (0.92–3.01)
Undetermined*	–	–	–

RR = rate ratio.
* Not estimated because few events were observed near Nevada shows (see Table 2).

California gun shows. In contrast, Nevada does not require background checks or documentation for private transfers and places no regulations on gun shows. Thus, California's measures may prevent illegal activities that could lead to increases in interpersonal firearm injuries.

A second possibility is that California's regulations and 10-day waiting period motivate buyers to cross into Nevada when seeking a faster, less-regulated source of firearms. This mechanism, which suggests displacement rather than deterrence, would imply that even if California's regulations are mitigating risk from gun shows within its borders, travel to less-restrictive states may threaten the effectiveness of California's laws. Indeed, interstate gun trafficking, including that between Nevada and California, is well-documented and fueled in part by gun shows (18–21, 38, 39).

A third possibility is that gun shows affect Californians near Nevada differently from Californians in the rest of the state. However, analyses restricted to regions similar to those along the California–Nevada border produced results consistent with the main analysis, suggesting that the characteristics of border communities are not major drivers of the observed differences.

Gun show occurrence was not randomized. Thus, a fourth possibility is that the observed association is due to uncontrolled confounders. However, gun shows were not associated with nonfirearm injuries, providing evidence that the results are not due to confounding by common causes of firearm and nonfirearm injuries (34). Furthermore, the quantitative bias analysis indicated that for the observed associations to be spurious, at least 1 factor would have to match the geographic and temporal pattern of the gun shows, be strongly associated with firearm injuries, be unevenly distributed between California and Nevada, and change markedly in prevalence in the 2 weeks after gun shows compared with the 2 weeks before. Identifying a factor that fits these criteria is challenging, which strengthens confidence in our results. Similar bias analyses have been used to bolster evidence of the association between firearm ownership and suicide (40).

Our null findings for California gun shows are consistent with those of Duggan and colleagues (25). However, our study was the first to our knowledge to assess interstate associations and suggests that travel across state lines may be important. Our study avoided several limitations highlighted in previous critiques of Duggan and colleagues' study (26, 27) by being well-powered statistically, analyzing data from the show-period level rather than the ZIP code–week level, and accounting for California's 10-day waiting period. Our approach was also strengthened by inclusion of nonfatal injuries and unintentional and intent-undetermined firearm injuries, rather than only firearm suicides and homicides. In addition, we examined geographic areas defined by driving distances and incorporated overlap exclusions for regions simultaneously exposed to 1 show and unexposed to another.

This study had limitations. First, all nonexperimental studies are subject to residual confounding. We minimized the effect of potential confounders by comparing identical regions over brief periods, during which factors other than gun shows are unlikely to vary; we also did negative control and quantitative bias analyses to assess the sensitivity of our results to an unobserved confounder. Second, few firearm injuries occurred in regions exposed to Nevada gun shows; however, rates for this region were derived from 13 037 052 person-weeks of exposure (Table 1). Third, cause-of-death and cause-of-injury classification on death and discharge records is imperfect, although studies suggest that the degree of misclassification is not substantial enough to alter major trends and patterns (41, 42). Fourth, we did not examine associations with firearm injuries in Nevada populations. Future research on the effects of gun shows in Nevada and other states would be valuable. Fifth, data on nonfatal injuries include most hospital visits for firearm injuries but do not include military hospitals. Lastly, evidence suggests that firearms purchased at gun shows and recovered from crime scenes are rarely found in the immediate region or period after shows (27). However, these patterns do not preclude the possibility of a proximate effect, particularly because first use of a gun may predate its recovery from a crime scene.

In conclusion, gun shows are an important source of firearms and may offer an opportunity for regulatory intervention. Results from this study suggest that California gun shows are not associated with short-term increases in firearm injuries but that Nevada shows are associated with cross-border increases in firearm injuries in California. Differences in regulations may explain this pattern, but alternative explanations exist, and the short-term increase in firearm injuries attributable to gun shows is small relative to the number of firearm injuries in places exposed to gun shows. Better understanding the long-term effects of gun shows over larger geographic regions, the effects of gun show policies, and the patterns of acquisition and use of firearms would provide important evidence to inform future efforts to prevent firearm injuries.

From University of California, Berkeley, School of Public Health, Berkeley, California; and University of California, Davis, Sacramento, California.

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Requests for Single Reprints: Ellicott C. Matthay, MPH, 50 University Hall, University of California, Berkeley, Berkeley, CA 94704; e-mail, ematthay@berkeley.edu.

Current author addresses and author contributions are available at Annals.org.

References

1. **Centers for Disease Control and Prevention; National Center for Injury Prevention and Control.** Web-based Injury Statistics Query and Reporting System (WISQARS). 2005. Accessed at www.cdc.gov/injury/wisqars on 22 January 2016.
2. **Kellermann AL, Rivara FP, Rushforth NB, Banton JG, Reay DT, Francisco JT, et al.** Gun ownership as a risk factor for homicide in the home. N Engl J Med. 1993;329:1084-91. [PMID: 8371731]
3. **Kellermann AL, Rivara FP, Somes G, Reay DT, Francisco J, Banton JG, et al.** Suicide in the home in relation to gun ownership. N Engl J Med. 1992;327:467-72. [PMID: 1308093]
4. **Kellermann AL, Somes G, Rivara FP, Lee RK, Banton JG.** Injuries and deaths due to firearms in the home. J Trauma. 1998;45:263-7. [PMID: 9715182]
5. **Dahlberg LL, Ikeda RM, Kresnow MJ.** Guns in the home and risk of a violent death in the home: findings from a national study. Am J Epidemiol. 2004;160:929-36. [PMID: 15522849]
6. **Wiebe DJ.** Homicide and suicide risks associated with firearms in the home: a national case-control study. Ann Emerg Med. 2003;41:771-82. [PMID: 12764330]
7. **Miller M, Azrael D, Hemenway D.** Firearm availability and unintentional firearm deaths, suicide, and homicide among 5-14 year olds. J Trauma. 2002;52:267-74. [PMID: 11834986]
8. **Azrael D, Hemenway D.** 'In the safety of your own home': results from a national survey on gun use at home. Soc Sci Med. 2000;50:285-91. [PMID: 10619696]
9. **Grinshteyn E, Hemenway D.** Violent death rates: the US compared with other high-income OECD countries, 2010. Am J Med. 2016;129:266-73. [PMID: 26551975] doi:10.1016/j.amjmed.2015.10.025
10. **Hemenway D, Miller M.** Firearm availability and homicide rates across 26 high-income countries. J Trauma. 2000;49:985-8. [PMID: 11130511]
11. **Hemenway D, Shinoda-Tagawa T, Miller M.** Firearm availability and female homicide victimization rates among 25 populous high-income countries. J Am Med Womens Assoc (1972). 2002;57:100-4. [PMID: 11991417]
12. **Killias M.** International correlations between gun ownership and rates of homicide and suicide. CMAJ. 1993;148:1721-5. [PMID: 8485675]
13. **Cook PJ, Ludwig J.** Guns in America: Results of a Comprehensive National Survey on Firearms Ownership and Use. Washington, DC: Police Foundation; 1996.
14. **Hepburn L, Miller M, Azrael D, Hemenway D.** The US gun stock: results from the 2004 national firearms survey. Inj Prev. 2007;13:15-9. [PMID: 17296683]
15. **Wintemute GJ.** Inside Gun Shows: What Goes On When Everybody Thinks Nobody's Watching. Sacramento, CA: Violence Prevention Research Program; 2009.
16. **Miller M, Hepburn L, Azrael D.** Firearm acquisition without background checks: results of a national survey. Ann Intern Med. 2017;166:233-9. [PMID: 28055050] doi:10.7326/M16-1590
17. **Braga AA, Kennedy DM.** Gun control in America: gun shows and the illegal diversion of firearms. Georgetown Public Policy Review. 2000;6:7-24.
18. **U.S. Department of the Treasury; Bureau of Alcohol, Tobacco and Firearms.** Following the Gun: Enforcing Federal Laws Against Firearms Traffickers. Washington, DC: US Gov Pr Office; 2000.
19. Gun Shows: Brady Checks and Crime Gun Traces. Washington, DC: Bureau of Alcohol, Tobacco and Firearms; 1999.
20. **Cook PJ, Braga AA.** Comprehensive firearms tracing: strategic and investigative uses of new data on firearms markets. Ariz Law Rev. 2001;43:277-309.
21. **Knight B.** State gun policy and cross-state externalities: evidence from crime gun tracing. Am Econ J Econ Policy. 2013;5:200-29.
22. **Fleegler EW, Lee LK, Monuteaux MC, Hemenway D, Mannix R.** Firearm legislation and firearm-related fatalities in the United States. JAMA Intern Med. 2013;173:732-40. [PMID: 23467753] doi:10.1001/jamainternmed.2013.1286
23. A.B. 295, 1999 State Assemb., Reg. Sess. (Cal. 1999). Accessed at http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=199920000AB295 on 13 December 2016.
24. **Wintemute GJ.** Gun shows across a multistate American gun market: observational evidence of the effects of regulatory policies. Inj Prev. 2007;13:150-5. [PMID: 17567968]

25. **Duggan M, Hjalmarsson R, Jacob BA.** The short-term and localized effect of gun shows: evidence from California and Texas. Rev Econ Stat. 2011;93:786-99.
26. **Hemenway D.** How to find nothing. J Public Health Policy. 2009; 30:260-8. [PMID: 19806067] doi:10.1057/jphp.2009.26
27. **Wintemute GJ, Hemenway D, Webster D, Pierce G, Braga AA.** Gun shows and gun violence: fatally flawed study yields misleading results. Am J Public Health. 2010;100:1856-60. [PMID: 20724672] doi:10.2105/AJPH.2010.191916
28. **Angrist JD, Pischke JS.** Mostly Harmless Econometrics: An Empiricist's Companion. Princeton, NJ: Princeton Univ Pr; 2009.
29. **Dimick JB, Ryan AM.** Methods for evaluating changes in health care policy: the difference-in-differences approach. JAMA. 2014; 312:2401-2. [PMID: 25490331] doi:10.1001/jama.2014.16153
30. **Centers for Disease Control and Prevention.** Strategies to improve external cause-of-injury coding in state-based hospital discharge and emergency department data systems: recommendations of the CDC Workgroup for Improvement of External Cause-of-Injury Coding. MMWR Morb Mortal Wkly Rep. 2008;57:1-16.
31. ABBYY FineReader. 2016. Accessed at www.abbyy.com/en-us/finereader on 9 November 2016.
32. Developer's guide: Google Maps Distance Matrix API. 2016. Accessed at https://developers.google.com/maps/documentation/distance-matrix/intro on 3 September 2016.
33. **Bates D, Maechler M, Bolker B, Walker S, Christensen RHB, Singmann H, et al.** lme4: Linear Mixed-Effects Models using 'Eigen' and S4. 2016. Accessed at https://cran.r-project.org/web/packages/lme4/index.html on 14 December 2016.
34. **Lipsitch M, Tchetgen Tchetgen E, Cohen T.** Negative controls: a tool for detecting confounding and bias in observational studies. Epidemiology. 2010;21:383-8. [PMID: 20335814] doi:10.1097/EDE.0b013e3181d61eeb
35. **Morin R.** The demographics and politics of gun-owning households. Washington, DC: Pew Research Center; 2014. Accessed at www.pewresearch.org/fact-tank/2014/07/15/the-demographics-and-politics-of-gun-owning-households on 10 July 2017.
36. **Parker K, Horowitz JM, Igielnik R, Oliphant B, Brown A.** America's complex relationship with guns. Washington, DC: Pew Research Center; 2017.
37. **Arnold BF, Hogan DR, Colford JM Jr, Hubbard AE.** Simulation methods to estimate design power: an overview for applied research. BMC Med Res Methodol. 2011;11:94. [PMID: 21689447] doi:10.1186/1471-2288-11-94
38. **Wintemute GJ, Romero MP, Wright MA, Grassel KM.** The life cycle of crime guns: a description based on guns recovered from young people in California. Ann Emerg Med. 2004;43:733-42. [PMID: 15159705]
39. **Braga AA, Wintemute GJ, Pierce GL, Cook PJ, Ridgeway G.** Interpreting the empirical evidence on illegal gun market dynamics. J Urban Health. 2012;89:779-93. [PMID: 22669643] doi:10.1007/s11524-012-9681-y
40. **Miller M, Swanson SA, Azrael D.** Are we missing something pertinent? A bias analysis of unmeasured confounding in the firearm-suicide literature. Epidemiol Rev. 2016;38:62-9. [PMID: 26769723] doi:10.1093/epirev/mxv011
41. **Caveney AF, Smith MA, Morgenstern LB, Lisabeth LD.** Use of death certificates to study ethnic-specific mortality. Public Health Rep. 2006;121:275-81. [PMID: 16640150]
42. **Mohler B, Earls F.** Trends in adolescent suicide: misclassification bias? Am J Public Health. 2001;91:150-3. [PMID: 11189813]

Current Author Addresses: Ms. Matthay, Ms. Galin, Drs. Rudolph and Ahern, and Ms. Farkas: 50 University Hall, University of California, Berkeley, Berkeley, CA 94704.
Dr. Wintemute: Violence Prevention Research Program, UC Davis Medical Center, 2315 Stockton Boulevard, Sacramento, CA 95817.

Author Contributions: Conception and design: E.C. Matthay, J. Galin, K.E. Rudolph, G. Wintemute, J. Ahern.
Analysis and interpretation of the data: E.C. Matthay, J. Galin, K.E. Rudolph, G. Wintemute, J. Ahern.
Drafting of the article: E.C. Matthay, J. Galin, J. Ahern.
Critical revision of the article for important intellectual content: E.C. Matthay, K.E. Rudolph, K. Farkas, G. Wintemute, J. Ahern.
Final approval of the article: E.C. Matthay, J. Galin, K.E. Rudolph, K. Farkas, G. Wintemute, J. Ahern.
Provision of study materials or patients: G. Wintemute.
Statistical expertise: E.C. Matthay, K.E. Rudolph.
Obtaining of funding: G. Wintemute, J. Ahern.
Administrative, technical, or logistic support: E.C. Matthay, J. Galin.
Collection and assembly of data: E.C. Matthay, J. Galin, K. Farkas, G. Wintemute, J. Ahern.

Appendix: In-State and Interstate Associations Between Gun Shows and Firearm Deaths and Injuries: Supplemental Information, Methods, and Results

Firearm Injury Classification Codes

We identified fatal and nonfatal firearm injuries in California between 2005 and 2013 using International Classification of Diseases, 9th and 10th Revisions, external cause-of-injury codes contained in death records from the California Department of Public Health Vital Records and in emergency department and inpatient hospitalization records from the Office of Statewide Health Planning and Development. To examine variation by firearm injury type, we did subgroup analyses for intentional interpersonal violence, intentional self-harm, unintentional injuries, and injuries of undetermined intent. International Classification of Diseases codes used in this analysis are presented by subgroup in Appendix Table 1.

Power Calculations

To confirm that our study had sufficient statistical power, we did a power analysis using simulated data that were generated to be similar to the observed data. We used the observed number of firearm deaths and injuries for the 2 weeks before each gun show (in regions within convenient traveling distance of each show) and simulated the number of firearm deaths and injuries in the 2 weeks after each show. Appendix Figure 1 presents the observed and simulated distributions of firearm deaths and injuries for the 2 weeks after gun shows. The distributions are very similar, suggesting that the power analysis is based on simulated data that accurately reflect the observed data.

We applied the main analysis regression approach to each simulated data set and recorded the proportion of simulations with a significant association. This analysis indicated that our study had 87.8% power to detect increases in firearm deaths and injuries as large as or larger than those seen for Nevada shows and 84.2% power to detect the difference between California and Nevada gun shows.

Gun Show Locations

Appendix Figure 2 presents the locations of all gun shows identified in California and Nevada between 2005 and 2013. Locations included in each analysis depend on the analysis specification (geographic range [driving distance] and duration of preexposure and postexposure periods). In particular, some shows in northeastern Nevada were not included in analyses restricted to Nevada shows within a 120-minute drive of California but were included in sensitivity analyses extending to longer driving distances.

Secondary and Sensitivity Analyses

Little evidence exists on how far or how long the effects of gun shows extend (27). Thus, we selected reasonable time frames and travel times to balance capturing short-term effects with estimating stable rates and to include regions likely to be affected by gun shows while excluding regions so distant that unrelated firearm injuries might obscure potential relationships. We then tested the sensitivity of our results to chosen time frames and travel times.

Appendix Table 3 presents the results of these sensitivity analyses. Associations between California shows and firearm deaths and injuries were consistently null. For Nevada gun shows, changes in firearm injuries remained statistically significant for shorter (1-week) and longer (3-week) periods but were not statistically significant for smaller geographic ranges (60-minute drive), which yielded very few cases, and larger geographic ranges (120- and 180-minute drives for California and Nevada guns shows, respectively), which covered large portions of California. Nevada shows were significantly associated with increases in self-directed intentional firearm injuries when examining longer periods.

We restricted additional secondary analyses to specific gun shows and affected regions to examine potential associations along known firearm trafficking routes between Reno and San Francisco and between Las Vegas and Los Angeles. We also tested the association between California gun shows and California firearm injuries ignoring the 10-day waiting period, because activities other than legal firearm purchases, such as ammunition or parts purchases, illegal purchases, and repairs, may affect firearm injuries and do not have a waiting period.

Appendix Table 2 presents the results of these secondary analyses. No significant relationships existed between gun shows and firearm injuries along known trafficking routes or when California's 10-day waiting period was excluded.

Sensitivity Analysis Restricted to Regions Similar to Those Exposed to Nevada Gun Shows

One important consideration in interpreting the results of the main analysis is that characteristics of the regions exposed to gun shows may modify the association between shows and firearm deaths and injuries. The observed differences in associations between California and Nevada gun shows and firearm deaths and injuries may be due to differences in the characteristics of the regions exposed to California gun shows versus those exposed to Nevada gun shows. For example, regions exposed to Nevada gun shows tend to be more rural and have lower rates of firearm death and injury (Table 2 and Appendix Table 4).

To address this potential source of variation, we restricted the entire analysis to regions similar to those exposed to Nevada gun shows. We identified these regions by tightly matching on ZIP code characteristics that differed between regions exposed to California versus Nevada shows and may modify the association between gun shows and firearm deaths and injuries. These were population density, percentage of veterans, median income, median age, percentage of white non-Hispanic persons, hunting licenses per capita, and the overall rate of firearm injury between 2005 and 2013. We used 1-to-many greedy Mahalanobis distance matching (a generalization of nearest-neighbor matching based on Euclidean distance) with replacement and a caliper of 0.01 SDs of the distance measure (43). This means that several ZIP codes exposed to California shows could be matched to each ZIP code exposed to a Nevada show. We discarded ZIP codes with characteristics with values outside the range of those observed for ZIP codes exposed to Nevada gun shows. Other matching approaches, such as optimal or nearest-neighbor matching based on the propensity score, produced nearly identical matches. Although restricting to the California region along the California–Nevada border exposed to both California and Nevada gun shows was not possible because the populations were too sparse to estimate stable rates of firearm deaths and injuries, this approach provides a close approximation by restricting locations to those very similar to this border region.

Of the 1769 ZIP codes in California, 490 remained after restriction and 192 of those were matched more than once because of replacement. Appendix Table 4 presents the distribution of the potentially modifying characteristics before and after restriction and compared with ZIP codes exposed to Nevada gun shows. After restriction, the remaining ZIP codes were very similar to those exposed to Nevada gun shows. Compared with all California ZIP codes, the restricted set is less densely populated; includes more veterans and non-Hispanic whites; and has higher median income, median age, and hunting licenses per capita.

Table 5 presents the results of the restricted analysis. Results are nearly identical to those of the main analysis, suggesting that modification by these factors is not a driver of the observed differences in associations between California and Nevada gun shows and firearm deaths and injuries.

Negative Control Analysis

We tested the association between gun shows and nonfirearm injuries as a negative control to assess whether common causes of firearm and nonfirearm injuries confounded our findings (34). Using the same data sources and analytic approach as in the main analysis, we found that neither California nor Nevada gun shows were meaningfully associated with short-term increases in nonfirearm injuries (Appendix Table 5). Although several of the tested associations were statistically significant, this finding was driven by the large number of nonfirearm unintentional injuries (n = 6 065 633), and the RRs were effectively null. These results provide further evidence that the results are not due to confounding by common causes of firearm and nonfirearm injuries.

Quantitative Bias Analysis for an Unobserved Confounder

To assess the potential role of residual confounding due to unmeasured factors, we did a quantitative bias analysis for 2 of the measured associations: that between gun shows in Nevada and firearm deaths and injuries in California and that between state of gun show and increases in firearm deaths and injuries after shows.

Association Between Gun Shows in Nevada and Firearm Deaths and Injuries in California

We estimated the characteristics of an unmeasured confounder that would yield the observed association between gun shows in Nevada and firearm deaths and injuries in California, if the true effect were not statistically significant. To do this, we used the bias equation presented by VanderWeele and Arah (44) for the RR and applied it to the estimated RR of the association between Nevada gun shows and firearm deaths and injuries in California (exp[$\beta_1 + \beta_3$] in the main regression analysis).

We defined the following random variables: Let A be a binary indicator representing exposure to Nevada gun shows (that is, the period is the 2 weeks after Nevada gun shows versus the 2 weeks before), let Y be the rate of firearm deaths and injuries per 100 000 population in California, let X be the measured covariates controlled in the main analysis, and let U be an unmeasured confounder. Following VanderWeele and Arah's analysis, we made 3 assumptions: first, that the association between U and Y does not vary between strata of A; second, that the association between U and A does not vary between strata of X; and third, that U is binary. Under these conditions, the bias in the conditional causal RR is defined as the ratio between the observed RR and the true conditional causal RR and is computed as:

$$d_{+a}^{RR}(x) = \frac{1 + (\gamma - 1)P(U = 1|a = 1,x)}{1 + (\gamma - 1)P(U = 1|a = 0,x)}$$

where γ is the association between U and Y, defined as $\gamma = E(Y|a,x,u = 1)/E(Y|a,x,u = 0)$. The association between U and A is defined as $\delta = P(U = 1|a = 1,x)/P(U = 1|a = 0,x)$.

We estimated the corrected lower confidence bound of the RR for the association between Nevada gun shows and the rate of firearm deaths and injuries in California (observed RR, 1.69 [CI, 1.16 to 2.45]) across a range of bias scenarios. We tested values of γ (the relative association of U with Y) ranging from 1 to 3, values of δ (the relative association of U with A) ranging from 1 to 3, and prevalence of U among the exposed ($P(U = 1|a = 1,x)$) ranging between 0.1 and 0.8. This analysis tells us how prevalent U must be and how strong the U–A and U–Y relationships would have to be for an uncontrolled confounder to explain the association observed in our study.

Appendix Figure 3 presents the results of this analysis. Across all of the scenarios we considered, an unmeasured confounder would need to be associated with both gun shows and firearm deaths and injuries with RRs of at least 1.5 or 2 to yield the observed association, if the true effect were not statistically significant.

This analysis informs our interpretation of the results. For the association between Nevada gun shows and firearm deaths and injuries in California to be spurious, another factor would have to match the geographic and temporal pattern of the 275 Nevada gun shows and be strongly associated with firearm deaths and injuries in California. This factor would have to be notably more prevalent after Nevada gun shows than before, corresponding to RRs of at least 1.5 or 2 for a confounder that is up to 80% more prevalent in the 2 weeks after Nevada gun shows than in the 2 weeks before. Identifying a factor that fits these criteria is challenging. Similar bias analyses have been used to strengthen evidence of the association between firearm ownership and suicide (40). One possibility is that this factor is a marker or artifact of Nevada gun shows; for example, if persons at higher risk for firearm deaths and injuries come to California areas near Nevada shows when Nevada shows are occurring, or happenings at Nevada gun shows prompt persons in nearby California to use their firearms in ways they otherwise might not, then we might see the observed association. There may be other explanations as well.

Association Between State of Gun Show and Increases in Firearm Deaths and Injuries After Gun Shows

We also estimated the characteristics of an unmeasured confounder that would yield the observed association between the state in which the gun show was held and increases in firearm deaths and injuries after gun shows, if the true effect were not statistically significant. Again, we used the bias equation presented by VanderWeele and Arah (44), but in this case, we applied it to the ratio of RRs for the association between the state in which the gun show was held (Nevada vs. California) and increases in firearm deaths and injuries after gun shows ($\exp[\beta_3]$ in the main regression analysis).

For this application, we defined the following random variables: Let A be a binary indicator representing the state in which the gun show was held (Nevada vs. California), Y be the change in rate of firearm deaths and injuries per 100 000 population in the 2 weeks before gun shows compared with the 2 weeks after, X be the measured covariates controlled in the main analysis, and U be an unmeasured confounder. Following VanderWeele and Arah's analysis, we made the same 3 assumptions as above, and the bias in the conditional causal RR is defined as above.

We estimated the corrected lower confidence bound for the ratio of RRs estimate of the association between the state of the gun show and increases in firearm deaths and injuries after shows (observed, 1.70 [CI, 1.17 to 2.47]) across a range of bias scenarios. Again, we tested values of γ (the relative association of U with Y) ranging from 1 to 3, values of δ (the relative association of U with A) ranging from 1 to 3, and prevalence of U for Nevada gun shows ($P(U = 1|a = 1,x)$) ranging between 0.1 and 0.8. This analysis tells us how prevalent U must be for Nevada gun shows and how strong the U–A and U–Y relationships would have to be for an uncontrolled confounder to explain the association observed in our study.

Appendix Figure 4 presents the results of this analysis. Across all of the scenarios we considered, an unmeasured confounder would need to be associated with both the state of the gun shows and increases in firearm deaths and injuries after shows with RRs of at least 1.5 or 2 to yield the observed association, if the true effect were not statistically significant.

This analysis informs our interpretation of the results. For the association between state and increases in firearm deaths and injuries after shows to be spurious, another factor would have to match the geographic and temporal pattern of the 915 gun shows in both states. This factor would also have to be strongly associated with both the state of the gun show and changes in firearm deaths and injuries immediately before and after the shows, corresponding to RRs of at least 1.5 to 2 for a confounder that is up to 80% more prevalent for Nevada shows than California shows. Identifying a factor that fits these criteria is challenging. Similar bias analyses have been used to strengthen evidence of the association between firearm ownership and suicide (40).

Web-Only References

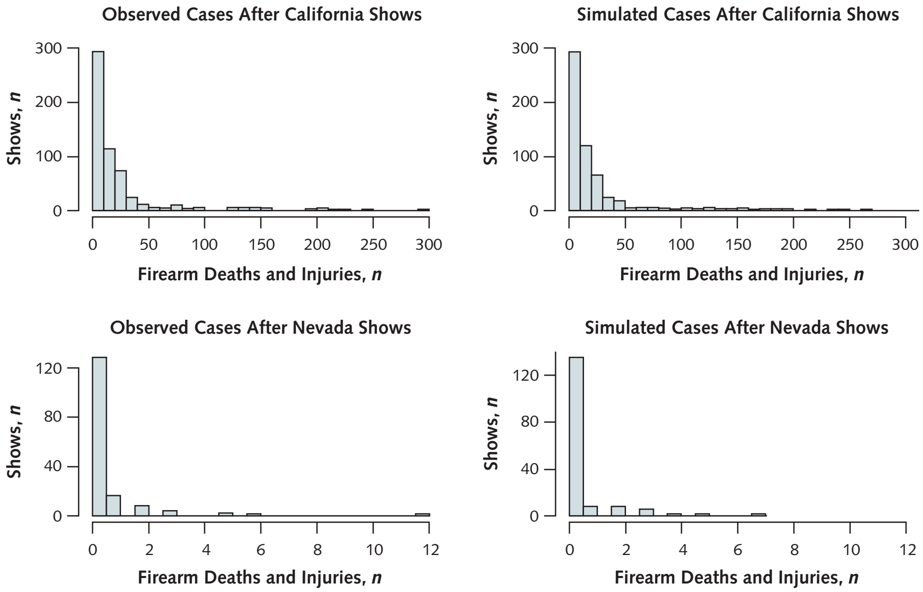
43. Ho D, Imai K, King G, Stuart EA. MatchIt: nonparametric preprocessing for parametric causal inference. J Stat Softw. 2011;42:1-28. doi:10.18637/jss.v042.i08
44. VanderWeele TJ, Arah OA. Bias formulas for sensitivity analysis of unmeasured confounding for general outcomes, treatments, and confounders. Epidemiology. 2011;22:42-52. [PMID: 21052008] doi:10.1097/EDE.0b013e3181f74493

Appendix Table 1. ICD-9 and ICD-10 External Cause-of-Injury Codes Used to Identify and Classify Firearm Deaths and Injuries

Death or Injury Type	ICD-9 Codes (Hospital Discharge Records)	ICD-10 Codes (Mortality Records)
Intentional interpersonal violence	E9650–E9654, E970	U01.4, X93–X95, Y35.0
Intentional self-harm	E9550–E9554	X72–X73
Unintentional injuries	E922	W32–W34
Injuries of undetermined intent	E9850–E9854	Y22–Y24

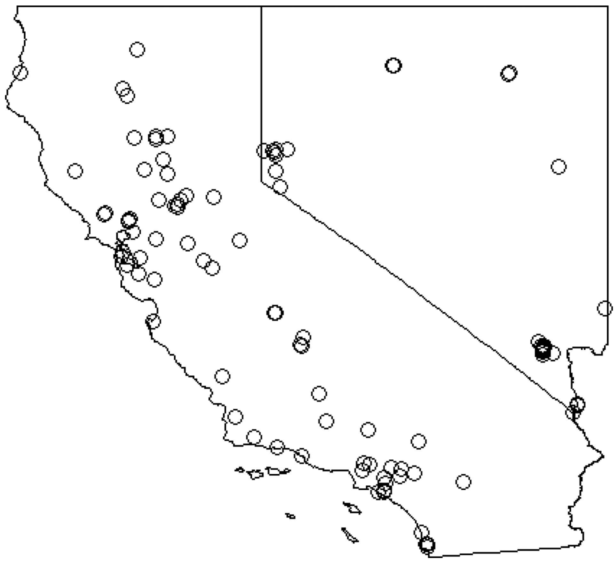
ICD-9 = International Classification of Diseases, Ninth Revision; ICD-10 = International Classification of Diseases, 10th Revision.

Appendix Figure 1. Comparison of observed and simulated distribution of firearm deaths and injuries during the 2 weeks after gun shows in nearby regions.



The unit of analysis is the gun show. The figure presents the distribution of the observed and simulated number of firearm deaths and injuries, per gun show, ≤2 wk after each gun show, in regions within driving distance of each show, by state. For example, in both the observed and simulated data, just fewer than 300 gun show regions had no firearm deaths or injuries ≤2 wk after the show.

Appendix Figure 2. Locations of gun shows in California and Nevada.



Appendix Table 2. Secondary Analyses for the Adjusted Association Between Firearm Deaths and Injuries Along Firearm Trafficking Routes and Excluding California's 10-Day Waiting Period

Type of Firearm Death or Injury*	Total Firearm Deaths and Injuries in 2 Weeks Before Gun Shows, *n*	RR of Association With Gun Shows (After vs. Before) (95% CI)
California gun shows and California deaths and injuries†		
All causes	15 000	0.99 (0.97–1.02)
Self-directed	1266	1.01 (0.93–1.09)
Interpersonal	9288	1.00 (0.97–1.03)
Unintentional	3887	0.98 (0.94–1.02)
Undetermined	559	0.97 (0.86–1.09)
Reno gun shows and San Francisco deaths and injuries‡		
All causes	8433	1.02 (0.99–1.05)
Self-directed	650	1.04 (0.94–1.16)
Interpersonal	5728	1.02 (0.98–1.06)
Unintentional	1668	1.04 (0.97–1.11)
Undetermined	387	0.94 (0.81–1.08)
Las Vegas gun shows and Los Angeles deaths and injuries§		
All causes	34 663	0.99 (0.98–1.01)
Self-directed	2619	1.04 (0.98–1.09)
Interpersonal	22 026	0.99 (0.97–1.01)
Unintentional	8811	0.99 (0.96–1.02)
Undetermined	1207	0.99 (0.92–1.08)

RR = rate ratio.
* By specification, that is, distance between ZIP code centroids and gun show locations up to which ZIP codes were considered “exposed” and the periods considered before and after each show. The analyses in this table exclude consideration of California's 10-d waiting period for firearm purchases.
† 60-min driving distance and 2-wk exposure period.
‡ San Francisco Bay area ZIP codes and 2-wk exposure period.
§ Los Angeles metropolitan area ZIP codes and 2-wk exposure period.

Appendix Table 3. Sensitivity Analyses for the Adjusted Association Between Firearm Deaths and Injuries in California and Gun Shows in California Versus Nevada

Type of Firearm Death or Injury*	RR of Association With California Gun Shows (After vs. Before) (95% CI)	RR of Association With Nevada Gun Shows (After vs. Before) (95% CI)	Ratio of RRs of Association With Gun Shows (Nevada vs. California) (95% CI)
Primary analysis, presented in main text†			
All causes	0.99 (0.97–1.02)	1.69 (1.16–2.45)	1.70 (1.17–2.47)
Self-directed	1.01 (0.93–1.09)	1.52 (0.79–2.91)	1.51 (0.78–2.90)
Interpersonal	1.00 (0.97–1.03)	2.23 (1.01–4.89)	2.23 (1.01–4.90)
Unintentional	0.98 (0.93–1.02)	1.53 (0.86–2.74)	1.57 (0.88–2.81)
Undetermined‡	–	–	–
Shorter period§			
All causes	1.00 (0.97–1.03)	1.77 (1.17–2.66)	1.76 (1.17–2.66)
Self-directed	0.99 (0.90–1.09)	2.01 (0.90–4.46)	2.03 (0.91–4.55)
Interpersonal	1.00 (0.97–1.04)	2.62 (1.22–5.62)	2.61 (1.22–5.61)
Unintentional	1.01 (0.95–1.06)	1.12 (0.59–2.11)	1.11 (0.59–2.10)
Undetermined‡	–	–	–
Longer period‖			
All causes	0.98 (0.95–1.00)	2.45 (1.56–3.83)	2.51 (1.60–3.93)
Self-directed	1.00 (0.93–1.09)	2.46 (1.13–5.34)	2.45 (1.13–5.34)
Interpersonal	0.99 (0.95–1.02)	6.62 (1.97–22.21)	6.72 (2.00–22.55)
Unintentional	0.94 (0.90–0.99)	1.72 (0.89–3.31)	1.82 (0.94–3.52)
Undetermined‡	–	–	–
Smaller geographic range¶			
All causes	0.99 (0.97–1.02)	1.54 (0.72–3.30)	1.56 (0.73–3.32)
Self-directed	1.01 (0.93–1.09)	1.30 (0.35–4.85)	1.29 (0.35–4.83)
Interpersonal	1.00 (0.97–1.03)	1.00 (0.14–7.07)	1.00 (0.14–7.07)
Unintentional	0.98 (0.93–1.02)	1.99 (0.68–5.83)	2.04 (0.70–5.98)
Undetermined‡	–	–	–
Larger geographic range**			
All causes	1.00 (0.97–1.03)	1.08 (0.85–1.36)	1.08 (0.85–1.37)
Self-directed	1.01 (0.92–1.11)	0.66 (0.37–1.20)	0.66 (0.36–1.20)
Interpersonal	0.99 (0.95–1.04)	1.14 (0.77–1.71)	1.15 (0.77–1.72)
Unintentional	1.01 (0.95–1.07)	1.24 (0.87–1.77)	1.23 (0.86–1.76)
Undetermined‡	–	–	–

RR = rate ratio.
* By specification, that is, distance between ZIP code centroids and gun show locations up to which ZIP codes were considered "exposed" and the time periods considered before and after each show.
† 2-wk exposure period, 60-min driving distance for California shows, and 120-min driving distance for Nevada shows.
‡ Not estimated because few events were observed near Nevada shows (see Table 2).
§ 1-wk exposure period, 60-min driving distance for California shows, and 120-min driving distance for Nevada shows.
‖ 3-wk exposure period, 60-min driving distance for California shows, and 120-min driving distance for Nevada shows.
¶ 2-wk exposure period, 60-min driving distance for California shows, and 60-min driving distance for Nevada shows.
** 2-wk exposure period, 120-min driving distance for California shows, and 180-min driving distance for Nevada shows.

Appendix Table 4. Distribution of Characteristics of Regions Exposed to Gun Shows Before and After Restriction to Regions Similar to Those Exposed to Nevada Gun Shows

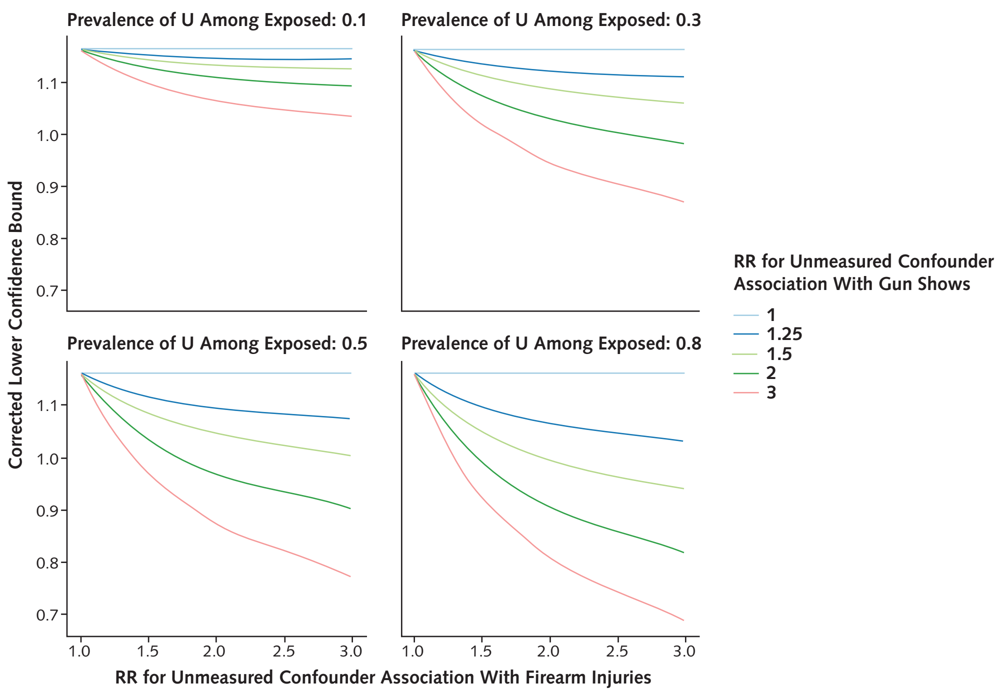
Characteristic	All California ZIP Codes	ZIP Codes Exposed to California Shows	ZIP Codes Exposed to Nevada Shows	California ZIP Codes Similar to Those Exposed to Nevada Shows
Population density, *persons per square mile*				
Minimum	1	1	1	1
25th percentile	43	372	7	18
Median	2501	3907	89	145
75th percentile	6893	8132	1460	1804
Maximum	113 893	113 893	10 457	10 457
Veterans, %				
Minimum	0	0	0	0
25th percentile	5	5	8	9
Median	8	8	12	12
75th percentile	12	11	17	15
Maximum	100	100	100	100
Median income, *$*				
Minimum	9219	9219	12 120	12 120
25th percentile	42 544	45 094	42 804	43 770
Median	57 202	60 901	55 383	54 221
75th percentile	76 727	80 308	69 065	65 811
Maximum	240 833	240 833	127 637	127 637
Median age, *y*				
Minimum	8	8	20	20
25th percentile	32	32	36	36
Median	38	37	42	42
75th percentile	45	43	49	48
Maximum	88	88	70	70
White, non-Hispanic persons, %				
Minimum	0	0	0	0
25th percentile	32	29	66	60
Median	58	53	81	76
75th percentile	78	73	91	85
Maximum	100	100	100	100
Hunting licenses per 10 000 persons, *n*				
Minimum	0	0	172	172
25th percentile	508	413	2198	2845
Median	1597	1118	5232	5254
75th percentile	5296	3759	9675	9031
Maximum	1 340 930	1 340 930	389 725	389 725
Overall rate of firearm death and injury per 100 000 persons, 2005–2013				
Minimum	0.0	0.0	0.0	0.0
25th percentile	0.9	1.0	0.8	1.3
Median	1.9	1.8	1.6	2.2
75th percentile	3.7	3.5	3.1	3.2
Maximum	1230.6	1230.6	54.6	54.6

Appendix Table 5. Negative Control Analysis for the Adjusted Association Between Nonfirearm Injury Deaths and Hospital Visits in California and Gun Shows in California Versus Nevada

Type of Nonfirearm Injury Death or Hospital Visit	RR of Association With California Gun Shows (After vs. Before) (95% CI)	RR of Association With Nevada Gun Shows (After vs. Before) (95% CI)	Ratio of RRs of Association With Gun Shows (Nevada vs. California) (95% CI)
All injuries	1.01 (1.00–1.01)*	0.99 (0.97–1.00)	0.98 (0.96–1.00)*
Self-directed	1.00 (0.99–1.01)	1.04 (0.90–1.20)	1.04 (0.90–1.20)
Interpersonal	1.00 (0.99–1.01)	1.01 (0.92–1.11)	1.01 (0.92–1.11)
Unintentional	1.01 (1.01–1.01)	0.98 (0.97–1.00)	0.98 (0.96–1.00)*
Undetermined†	–	–	–

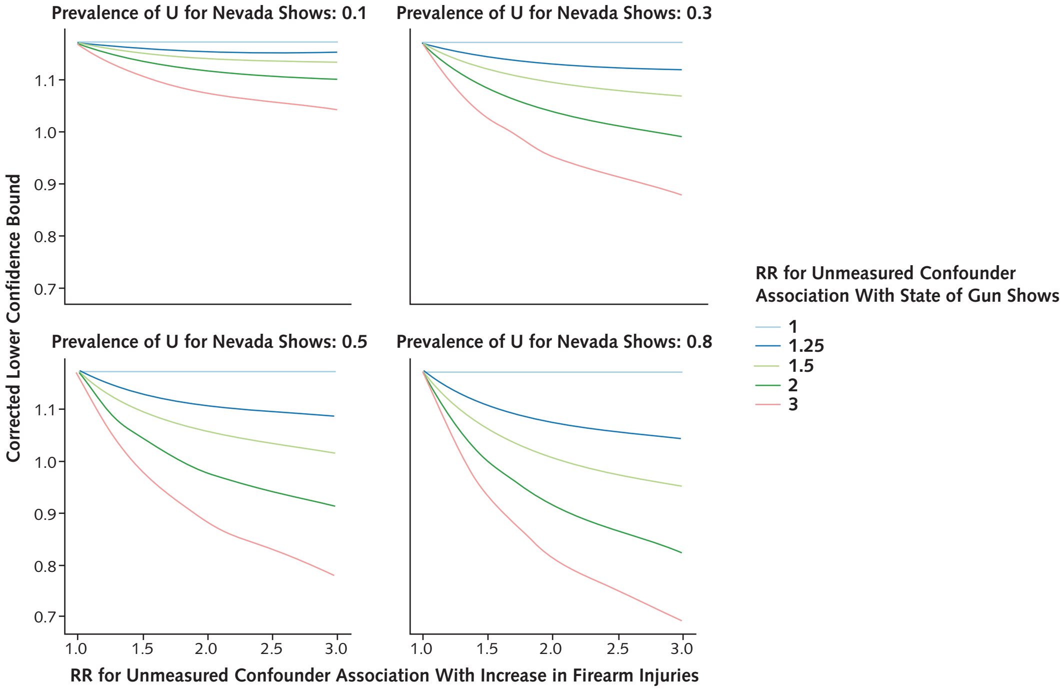
RR = rate ratio.
* CI excludes 1.
† Not estimated because few events were observed near Nevada shows (see Table 2).

Appendix Figure 3. Bias analysis results for the association between Nevada gun shows and California firearm deaths and injuries.



Each graph represents a scenario for the prevalence of U among the exposed ($P(U = 1|a = 1,x)$, which ranges from 0.1 to 0.8). In each plot, the *x*-axis measures the association between the unmeasured confounder and firearm deaths and injuries in California, the color of each line indicates the association between the unmeasured confounder and exposure to Nevada gun shows, and the *y*-axis displays the corrected lower confidence bound for the given bias scenario. For example, when the prevalence of U is 0.1, the RR for the U–gun shows association is 3, and the RR for the U–firearm deaths and injuries association is 3, then the association between Nevada gun shows and California firearm deaths and injuries would still be statistically significant, with a corrected lower confidence bound above 1. RR = rate ratio.

Appendix Figure 4. Bias analysis results for the association between state of gun show and increases in firearm deaths and injuries after gun shows.



Each graph represents a scenario for the prevalence of U for Nevada gun shows ($P(U = 1|a = 1,x)$, which ranges from 0.1 to 0.8). In each plot, the *x*-axis measures the association between the unmeasured confounder and increases in firearm deaths and injuries after gun shows, the color of each line indicates the association between the unmeasured confounder and the state of the gun show, and the *y*-axis displays the corrected lower confidence bound for the given bias scenario. For example, when the prevalence of U is 0.1 for Nevada gun shows, the RR for the U–A association is 3, and the RR for the U–Y association is 3, then the association between the state of the gun show and increases in firearm death and injuries after gun shows would still be statistically significant, with a corrected lower confidence bound above 1. RR = rate ratio.

Annals of Internal Medicine

Firearm Injury After Gun Shows: Evidence to Gauge the Potential Impact of Regulatory Interventions

The recent mass shooting in Las Vegas, Nevada, was a painful reminder that injuries and deaths resulting from access to guns continue to bedevil many parts of U.S. society, including communities; the health care industry; and the families of those injured, killed, or threatened by firearms. Although the problem created by more than 300 million guns in the United States will ultimately need a political solution, science and scientific publications have important roles in assessing and promoting awareness about interventions that may reduce the 36 000 fatal and 85 000 nonfatal firearm injuries each year (1).

The lack of meaningful action by Congress has left states to chip away in myriad ways at reducing access to guns by those likely to use them for harm against themselves or others. Several studies have shown an inverse association between the stringency of state legislation to restrict firearm access and the rate of firearm injuries and deaths (2). However, our knowledge about the effect of policies regulating gun shows on firearm morbidity and mortality is severely limited.

Matthay and colleagues (3) examined the association between gun shows occurring separately in California and Nevada and short-term changes in the rates of fatal and nonfatal firearm injuries in California regions exposed to those shows. Gun shows account for only a small proportion of private-party firearm transfers; nevertheless, they can be a source of guns used in crime (4). Gun shows allow both licensed dealers and unlicensed persons to sell firearms to attendees. Whereas purchases from federally licensed dealers require a background check of the potential buyer before a sale is made, several states do not require these checks in private-party sales, as was the case in Nevada during Matthay and colleagues' study period. In California, on the other hand, firearm transfers at shows must be processed through a licensed dealer (5). Thus, the concern was raised that California residents can simply drive over the state line and purchase guns at a Nevada show without any background check or waiting period.

Matthay and colleagues compared the rates of firearm injuries in the 2 weeks after and before gun shows among California residents within convenient driving distance of shows in Nevada versus California. Their analysis accounted for California's 10-day waiting period between purchasing and obtaining a gun. Comparing California regions exposed to Nevada shows with those exposed to California shows, the ratios of after–before rate ratios were 1.70 (95% CI, 1.17 to 2.47) for all-intent firearm injuries and 2.23 (CI, 1.01 to 4.90) for interpersonal firearm injuries. This ratio was mainly driven by changes in firearm injuries after Nevada shows. Whereas firearm injuries of any intent did not change meaningfully among California regions exposed to California gun shows, the rate of interpersonal firearm injuries increased significantly among California regions exposed to Nevada shows. However, as the authors note, the difference in absolute rates of firearm injuries was small: an overall increase from 0.67 to 1.14 injuries per 100 000 California residents exposed to Nevada shows.

The authors should be commended for using various strategies, including negative control analysis and quantitative bias analysis, to gauge their findings' sensitivity to assumptions and robustness to potential confounding. These approaches are important, especially considering the differences between California regions exposed to California versus Nevada shows. Table 2 of the article shows notable differences between the absolute rates of firearm injuries before shows in those 2 types of region: In regions exposed to California shows, the rate of interpersonal firearm injuries was greater than that of each other type of firearm injury, whereas in regions exposed to Nevada shows, the rate of unintentional firearm injuries was highest. As such, unmeasured differences might exist between those 2 California regions that can influence short-term changes in the rates of firearm injuries after gun shows. A limitation of the study, as acknowledged by authors, is that firearm injuries were not examined among Nevada residents themselves. If unregulated gun shows increase firearm injuries in the short term, one may expect to see such an association among Nevada residents exposed to shows in that state.

The data in Matthay and colleagues' study may suggest some association between gun shows and self-directed and unintentional firearm injuries, but the estimates (that is, about 50% to 60% relative increase) were not statistically significant. It is often forgotten that about two thirds of firearm deaths in the United States are suicides. A prior study by Wintemute and colleagues showed that purchasers of a handgun had a 57-fold and 7-fold increased risk for firearm suicide in the first week and first year, respectively, after purchase (6). Evidence indicates that the means available to commit self-harm matter and that restricting the most lethal means (that is, firearms) can prevent the loss of lives due to suicide (7). Also, future research should examine whether gun shows affect unintentional firearm injuries, and if so, what plausible explanations might exist.

The study by Matthay and colleagues has many implications for gun policy in the United States. Laws regulating access to guns matter and do make a difference, especially collectively (2); however, their impact on an individual basis is a somewhat small chip in the granite wall of firearm injuries and deaths. The state-by-state nature of these laws, due to the lack of federal

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legislation, results in barriers to gun access that can be easily breached by a car trip. It does not reduce the importance of the laws but does reduce their impact.

Unfortunately, the amount of research on firearms is disproportionately low compared with the burden they impose on health care and society as a whole. In 1996, Congress inserted language into the Centers for Disease Control and Prevention appropriation bills that essentially prevented it from conducting and funding firearm-related research (8, 9); this lack of funding continues to this day. Nevertheless, the public health burden of firearm-related injuries and death demands that research on interventions to reduce this toll be continued, funded by local and state governments, foundations, and philanthropy.

Ali Rowhani-Rahbar, MD, MPH, PhD
University of Washington
Seattle, Washington

Frederick P. Rivara, MD, MPH
University of Washington and Seattle Children's Research Institute
Seattle, Washington

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Requests for Single Reprints: Frederick P. Rivara, MD, MPH, University of Washington, Box 359960, 325 Ninth Avenue, Seattle, WA 98104; e-mail, fpr@uw.edu.

Current author addresses are available at Annals.org.

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References

1. **Centers for Disease Control and Prevention; National Center for Injury Prevention and Control.** Web-based Injury Statistics Query and Reporting System (WISQARS). Accessed at www.cdc.gov/injury/wisqars on 3 October 2017.
2. **Santaella-Tenorio J, Cerdá M, Villaveces A, Galea S.** What do we know about the association between firearm legislation and firearm-related injuries? Epidemiol Rev. 2016;38:140-57. [PMID: 26905895] doi:10.1093/epirev/mxv012
3. **Matthay EC, Galin J, Rudolph KE, Farkas K, Wintemute GJ, Ahern J.** In-state and interstate associations between gun shows and firearm deaths and injuries. A quasi-experimental study. Ann Intern Med. 2017. [Epub ahead of print]. doi:10.7326/M17-1792
4. **Wintemute G.** Background Checks for Firearm Transfers. Violence Prevention Research Program, University of California, Davis; 2013. Accessed at www.ucdmc.ucdavis.edu/vprp/CBC%20White%20Paper%20Final%20Report%20022013.pdf on 3 October 2017.
5. **Law Center to Prevent Gun Violence.** Gun Shows in California. 2016. Accessed at http://smartgunlaws.org/gun-shows-in-california on 3 October 2017.
6. **Wintemute GJ, Parham CA, Beaumont JJ, Wright M, Drake C.** Mortality among recent purchasers of handguns. N Engl J Med. 1999;341:1583-9. [PMID: 10564689]
7. **Barber CW, Miller MJ.** Reducing a suicidal person's access to lethal means of suicide: a research agenda. Am J Prev Med. 2014;47:S264-72. [PMID: 25145749] doi:10.1016/j.amepre.2014.05.028
8. **Kellermann AL, Rivara FP.** Silencing the science on gun research. JAMA. 2013;309:549-50. [PMID: 23262635] doi:10.1001/jama.2012.208207
9. Department of Health and Human Services Appropriations Act, Pub. L. No.104-208, 110 Stat. 1996. Accessed at www.congress.gov/104/plaws/publ208/PLAW-104publ208.pdf on 11 October 2017.

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Current Author Addresses: Dr. Rowhani-Rahbar: University of Washington Department of Epidemiology, Box 357236, Seattle, WA 98195.
Dr. Rivara: University of Washington, Box 359960, 325 Ninth Avenue, Seattle, WA 98104.

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Study: Gun deaths, injuries in California spike following Nevada gun shows

By Brett Israel | Media Relations
brett.israel@berkeley.edu, (510) 643-7741

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Berkeley — When gun shows are held in Nevada, gun-related deaths and injuries spike across the state line in California for at least the next two weeks. A new study by researchers at the University of California, Berkeley, examined gun deaths and injuries in California before and after gun shows in California and Nevada, and their results show a nearly 70 percent increase in deaths and injuries from firearms in California communities within convenient driving distance of Nevada gun shows. No spike in gun deaths or injuries was found following gun shows in California.

More than 4,000 gun shows are held annually in the U.S., and gun shows account for 4 to 9 percent of annual firearm sales. Some gun shows draw thousands of attendees and hundreds of sellers, whose transactions may not be subject to vigorous oversight. Some of these transactions are between private parties and do not involve a background check. Research has shown that firearms from gun shows are disproportionately implicated in crimes. California has some of the strongest firearm laws in the country, including a comprehensive set of statutes regulating gun shows. Nevada has some of the least restrictive firearm laws in the country and no explicit regulations on gun shows.

"Our study suggests that California's strict regulations — on firearms, generally, and on gun shows, specifically — may be effective in preventing short-term increases in firearm deaths and injuries following gun shows," said the study's lead author, Ellicott Matthay, a Ph.D. student in UC Berkeley's School of Public Health.

The study was funded in part by the National Institutes of Health (NIH), through a NIH Director's New Innovator Award to Jennifer Ahern, associate professor of public health at Berkeley and the study's senior author. Additional funding was provided by the Heising-Simons Foundation. Garen Wintemute, of the Violence Prevention Research Program in the Department of Emergency Medicine at UC Davis, collaborated on the study. It will be published online on October 24 in the journal *Annals of Internal Medicine*.

The study identified 275 gun shows in Nevada (mostly in Reno and Las Vegas) and 640 gun shows in California between 2005 and 2013. No publicly available database of gun shows exists for either state, so the researchers combed through trade publications to identify the dates and locations of gun shows.

Gun shows in Nevada were associated with increases in firearm deaths and injuries in California communities within convenient driving distance. California gun shows, in contrast, were not associated with local, short-term increases in firearm deaths and injuries. Non-firearm injuries served as a negative control and were not associated with California or Nevada gun shows.

Compared to the two weeks before the gun shows occurred, post-show firearm injury rates remained stable in regions near California gun shows. But post-show firearm injury rates increased from 0.67 per 100,000 people to 1.14 per 100,000 in regions near Nevada shows. This 70 percent increase translates to 30 more firearms deaths or injuries in California near the state line after 161 Nevada gun shows.

“The area of California that borders Nevada is sparsely populated, and over the study period there were relatively few Nevada gun shows. However, there are thousands of gun shows in the United States each year, most of them in relatively unregulated states. If we extended this study nationwide, it is possible that the number of deaths and injuries associated with gun shows would be far greater,” Ahern said.

Unlike firearm purchases through federally licensed dealers, private transfers of a gun from one person to another do not require background checks in many states. Gun shows make private transfers easier by drawing large crowds together for the purpose of buying and selling guns. During the study period, California required background checks on all transfers, including private transfers, but Nevada did not. (Nevada voters approved a private gun sale background check requirement in November 2016, but it has not been implemented.)

“The study suggests that travel to less-restrictive states may threaten the effectiveness of firearm laws within California. When a less-restrictive is next to a state that is more restrictive, there may be spillover effects,” Matthay said. “More research is needed to know for certain.”