Title
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Journal
Annals of Internal Medicine, 167(12)

ISSN
1056-8751

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Publication Date
2017-12-19

DOI
10.7326/m17-1792

Peer reviewed

HHS Public Access
Author manuscript
Ann Intern Med. Author manuscript; available in PMC 2018 June 19.

Published in final edited form as:
Ann Intern Med. 2017 December 19; 167(12): 837–844. doi:10.7326/M17-1792.

In-state and interstate associations between gun shows and firearm deaths and injuries: A quasi-experimental study

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Abstract

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

Objective—To determine whether gun shows are associated with short-term increases in locally occurring firearm injuries and whether this association differs by the state in which the gun show occurs.

Design—Quasi-experimental.

Setting—California.

Study Population—Individuals 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 to the two weeks before gun shows occurred, post-show firearm injury rates remained stable in regions near California gun shows but increased from 0.67 (95% CI, 0.55 to 0.80) to 1.14 (95% CI, 0.97 to 1.30) per 100,000 in regions near Nevada shows. After adjustment for seasonality and clustering, California shows were not associated with increases in local firearm injuries (RR, 0.99 [95% CI, 0.97 to 1.02]), but Nevada shows were associated with increases in

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Competing interests
The authors declare no competing interests.

injuries occurring in California (RR, 1.69 [95% CI, 1.16 to 2.45]). The pre-post difference was significantly higher for Nevada shows compared to California shows (Ratio of RRs, 1.70 [95% CI, 1.17 to 2.47]). The Nevada association was driven by significant increases in interpersonal violence firearm injuries (RR, 2.23 [95% CI, 1.01 to 4.89), but corresponded to a small increase in absolute numbers. Non-firearm injuries served as a negative control and were not associated with California or Nevada gun shows. Results were robust to sensitivity analyses.

Limitation—We only examined firearm injuries in California, and gun show occurrence was not randomized.

Conclusion—Gun shows occurring in Nevada, but not California, are 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 firearms regulations.

Introduction

Firearms are a leading cause of morbidity and mortality in the United States (US), accounting for over 36,000 deaths and nearly 85,000 injuries in 2015(1). Ownership of firearms increases the risk of suicide, homicide, and unintentional firearm deaths and injuries in the home (2–8). Greater availability and ownership of firearms also contributes to the higher rate of firearm deaths and injuries (hereafter referred to as "firearm injuries") in the US compared to 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), but many of these transfers do not involve a background check (16), and firearms from gun shows are disproportionately implicated in crimes (17,18). Very little is known about the contribution of gun shows to firearm injuries in the US.

There are more than 4,000 gun shows annually in the US (19). Gun shows, some of which 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 lead to local increases in ownership and use of firearms and affect subsequent rates of firearm injuries. States also differ markedly in firearm regulations, which may modify the association between gun shows and firearm injuries. In particular, interstate activity and flows of firearms from less restrictive to more restrictive states have been documented previously (21), and this pattern, which may limit the effectiveness of firearm regulations in states that have them, may extend to gun shows.

We exploit the natural variation in the timing and location of gun shows to investigate whether gun shows are associated with increases in firearm injury rates, and whether this association varies by the state in which the gun show occurs, using a quasi-experimental, difference-in-differences design. 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 firearm laws in the country and no explicit regulations on gun shows (22). Thus, comparing pre-post differences within California and cross-border differences between California and Nevada gun shows may provide useful information on these different policy environments.

No formal evaluations have assessed the effects of policies regulating gun shows. Observational evidence from five states suggests that gun show activities such as anonymous and undocumented sales occur less frequently in California, where such activities 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 one study has examined the association between gun shows and subsequent firearm injuries (25). Duggan and colleagues examined weekly violent firearm deaths in zip codes in the immediate vicinity of gun shows in California and Texas (25). They found no association and suggested that California's gun show regulations have no effect on violent firearm deaths (25). However, the study was criticized as having low statistical power, incomplete identification of gun shows, and an analytic approach that ignored California's requirement that individuals must wait 10 days between purchasing and obtaining a firearm (26,27).

In this study, we address these gaps while assessing whether firearm injuries increase in nearby California areas immediately following gun shows in California and Nevada. We hypothesize that gun shows lead to increased rates of firearm injuries.

Methods

Overall approach

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

Firearm injuries

We identified fatal and non-fatal firearm injuries in California between 2005 and 2013 using death records from the Office of Vital Statistics and emergency department and inpatient hospitalization records from the Office of Statewide Health Planning and Development (OSHPD). 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 are not available prior to 2005.

Gun show data

We compiled dates and locations of gun shows in California and Nevada between 2005 and 2013 using published gun shows listed in the *Big Show Journal*. This source was the most comprehensive; other magazines (*Gun and Knife* and *Gun List*) and online sources (we considered eleven major websites) did not cover the entire study period or included fewer listings (95% coverage versus 65% coverage in other sources). 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 travel time between each zip code centroid in California and each geocoded gun show location. There is little evidence on how far or how long the effects of gun shows might extend (27). Thus, we selected reasonable timeframes and travel times to balance capturing short-term effects with estimating stable rates, and to include regions that are likely 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 timeframes and travel times in multiple sensitivity analyses. “Before” periods were the 14 days prior to each show; “after” periods were the 14 days after the 10-day waiting period passed from the start of the show (for California shows) or after the start of the show (for Nevada shows, which have no waiting period). Zip code centroids within 60 or 120 minutes driving were considered within traveling distance of California and Nevada shows, respectively. In California, most individuals can access a gun show within 60 minutes driving every few weeks and might not travel farther. For Nevada shows, we hypothesized that some individuals in California would be willing to travel farther to Nevada’s comparatively unregulated environment.

On occasion, zip codes were local to multiple 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 considering this overlap, the zip code would be misclassified as “unexposed” for examination of Show B when it was “exposed” due 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 eliminating the need for overlap exclusions did not alter the findings (results available upon request). Throughout, rates are reported per 100,000 individuals in regions within traveling distance of shows.

Statistical analysis

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

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

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 time 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 individuals; and ε_{tsk}, the error term. Statistical testing of the dispersion parameter indicated that a Poisson model was more appropriate than negative binomial. Under this specification, exp(β_1) estimates the rate ratio (RR) associated with gun shows in California, exp(β_1 + β_3) estimates the RR associated with gun shows in Nevada, and exp(β_3) estimates the difference-in-differences estimate—the ratio of rate ratios (RRR)

—capturing the increase in firearm injury rates following Nevada shows as compared to the increase following California shows.

P-values of less than 0.05 were considered to indicate statistical significance. Data processing was conducted using SAS 9.3 and R 3.2.1, and regression analysis was conducted using the lme4 package (33) in R 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 conducted subgroup analyses for intentional interpersonal violence, intentional self-harm, unintentional injuries, and injuries of undetermined intent (Appendix Table 1). Because the exposure periods and geographic regions defined for California and Nevada shows were not identical (with versus without waiting period; 60 versus 120 minutes driving), we also stratified the analysis by state. Additionally, we conducted 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 firearm injuries in California 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 non-firearm injuries, as a negative control to assess whether common causes of firearm and non-firearm injuries confounded our findings (34).

Finally, differences in associations between California and Nevada gun shows may be due to differences in the characteristics of the regions exposed to California shows as compared with regions 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 (a) differed between regions exposed to California versus Nevada shows, and (b) may modify the association between gun shows and firearm injuries (35,36). These were: population density, percent veterans, median income, median age, percent White non-Hispanic, hunting licenses per capita, and the overall firearm injury rate 2005–2013. 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 presented in the Appendix.

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

Bias analysis—To assess the potential role of residual confounding due to unmeasured factors, we conducted 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

This research was funded by the NICHD/NIH Office of the Director, the University of California, Berkeley Committee on Research, and the Heising-Simons Foundation. The funding sources had no role in study design, conduct, data collection, data analysis, preparation of the manuscript, or the decision to submit the manuscript for publication.

Results

We identified 640 gun shows in California and 275 gun shows in Nevada between January 1, 2005 and December 31, 2013 (Table 1). Shows occurred on weekends, lasted 2 to 3 days, and were usually held at convention centers or county fairgrounds. Some shows recurred in the same locations at regular intervals, while others occurred irregularly at different times and locations. Overlap restrictions were more common for Nevada shows than California gun shows, because Nevada gun shows were more frequent and in fewer locations than California shows. A map of identified gun show locations is presented in Appendix Figure 2. Characteristics of California and Nevada gun shows and total person-weeks of exposure to gun shows included in this study are presented in Table 1.

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

After adjustment, California shows were not associated with increases in firearm injuries (RR, 0.99; 95% CI, 0.97–1.02), but Nevada shows were associated with significant cross-border increases in firearm injuries in California (RR, 1.69; 95% CI, 1.16–2.45) (Table 3). The difference between states was significant; the occurrence of gun shows in Nevada, compared with California, was associated with a 70% greater increase in firearm injuries (RRR: 1.70; 95% CI: 1.17–2.47). This association corresponds to a rate difference of 0.46 (95% CI, 0.36–0.57) per 100,000, or a 0.3-SD increase relative to the biweekly variability in rates across locations. For Nevada shows, the association was driven by significant increases in firearm injuries from interpersonal violence (RR, 2.23; 95% CI: 1.01–4.89), but corresponded to a small increase in the absolute number of firearm injuries. 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. There were no significant relationships between gun shows and firearm injuries along known trafficking routes or when excluding California's 10-day waiting period (Appendix Table 3).

In sensitivity analyses of varied geographic range and duration of exposure (Appendix Table 2), 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 weeks) time periods, but were not statistically significant for smaller geographic ranges (60 minutes driving), which yielded very few cases, and larger geographic ranges (120 and 180 minutes driving 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 to longer time periods.

Bias analyses and negative control analyses are presented in the Appendix. In brief, for the association between Nevada gun shows and firearm injuries in California to be spurious, there would have to be another factor that matches the precise geographic and temporal pattern of the 275 Nevada gun shows and that is also strongly associated with firearm injuries in California, corresponding to relative risks of at least 1.5 or 2. This factor would also have to be up to 80% more prevalent in the two weeks following Nevada gun shows compared to the two weeks prior. Bias analysis results were similar for the difference-in-differences estimate comparing Nevada to California. Associations between both California and Nevada gun shows and non-firearm injuries were null, or were statistically significant due to the large number of non-firearm unintentional injuries (N = 6,065,633), but not meaningfully different from the null.

Conclusions

We examined the association between California and Nevada gun shows and short-term changes in locally occurring 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 how this association varies by state. Results indicate that firearm injuries in California remained stable following California gun shows but increased by a small but significant amount following Nevada gun shows.

There are several possible explanations for our findings. First, though we did not formally assess the impact or enforcement of firearm policies in California or Nevada, the absence of an increase in firearm injuries following California gun shows may be evidence that California's strict regulatory environment, both gun show-related and otherwise, is mitigating 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). California also enforces restrictions on gun shows (23), including a range of security- and enforcement-related planning and reporting practices, that may deter illegal firearm activity historically seen at gun shows (15,17,18,20). Specialized firearm enforcement agents from the California Department of Justice also conduct surveillance at 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 may motivate individuals to cross into Nevada when seeking a more rapid, 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 California borders, travel to less restrictive states may threaten the effectiveness of laws within California. Indeed, interstate gun trafficking including that between Nevada and California is well-documented and fueled in part by gun shows (18–21,35,36). A third possibility is that Californians near Nevada are affected differently by gun shows than 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 differences in the characteristics of border communities are not a major driver of the observed differences.

A fourth possibility is that the observed association is due to uncontrolled confounders. However, gun shows were not associated with non-firearm injuries, providing evidence that the results are not due to confounding by factors that are common causes of firearm and non-firearm injuries (34). Furthermore, the quantitative bias analysis indicated that for the observed associations to be spurious, there would have to be at least one factor that matches the geographic and temporal pattern of the gun shows, is strongly associated with firearm injuries, is unevenly distributed between California and Nevada, and changes markedly in prevalence in the two weeks following gun shows, compared to the two weeks prior. 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, this study was the first to assess interstate associations and suggests that travel across state lines may be important. Our study avoided several limitations highlighted in previous critiques of the Duggan et al study (26,27), by being well-powered statistically, analyzing data at the show-time 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 non-fatal injuries and unintentional and intent-undetermined firearm injuries, rather than firearm suicides and homicides only. Additionally, we examined geographic areas defined by driving distances and incorporated overlap exclusions for regions simultaneously "exposed" to one show but "unexposed" to another.

This study was subject to several limitations. First, all nonexperimental studies are subject to residual confounding. We minimized the impact of potential confounders by comparing identical regions over short time periods during which factors besides gun shows are unlikely to vary; we also performed negative control and quantitative bias analyses to assess the sensitivity of our results to the presence of an unobserved confounder. Second, the number of firearm injuries in regions exposed to Nevada gun shows is small. However, rates for this region were derived from 13,037,052 person-weeks of exposure (Table 1). Third, cause of death and injury classification on death and discharge records is imperfect. However, studies suggest 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, nonfatal data includes the vast majority of hospital visits for firearm injuries, but does not include military hospitals. Lastly, there is evidence that firearms purchased at gun shows and recovered from crime scenes are rarely found in the immediate region or time period following shows (27). However, these patterns do not necessarily preclude the possibility of a proximate effect, particularly because first use of a gun may predate when a gun is recovered from a crime scene.

In conclusion, gun shows are an important source of firearms and 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 gun shows are associated with cross-border increases in firearm injuries in California. Differences in firearm regulations may explain this pattern, but alternative explanations exist, and the acute increase in the number of firearm injuries attributable to gun shows is small relative to the number of firearm injuries in places exposed to gun shows. Better understanding of the long-term effects of gun shows over larger geographic regions, the effects of gun show policies, and patterns of acquisition and use of firearms would provide important evidence to inform future firearm injury prevention efforts.

Acknowledgments

The authors acknowledge the following funding sources: NICHD/NIH Office of the Director (grant number DP2HD080350), the University of California, Berkeley Committee on Research, and the Heising-Simons Foundation (grant number 2016-219). The analyses, interpretations and conclusions of this paper are attributable to the authors, and not to the California Department of Public Health.

Funding sources:

NICHD/NIH Office of the Director; University of California, Berkeley Committee on Research; Heising-Simons Foundation.

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Appendix

Firearm injury classification codes

We identified fatal and non-fatal firearm injuries in California between 2005 and 2013 using death records from the Office of Vital Statistics and emergency department and inpatient hospitalization records from the Office of Statewide Health Planning and Development (OSHPD) using International Classification of Diseases (ICD) 9th and 10th revision external cause of injury codes (e-codes). To examine variation by firearm injury type, we conducted subgroup analyses for intentional interpersonal violence, intentional self-harm, unintentional injuries, and injuries of undetermined intent. E-codes used in this analysis are presented by subgroup in Appendix Table 1.

Appendix Table 1

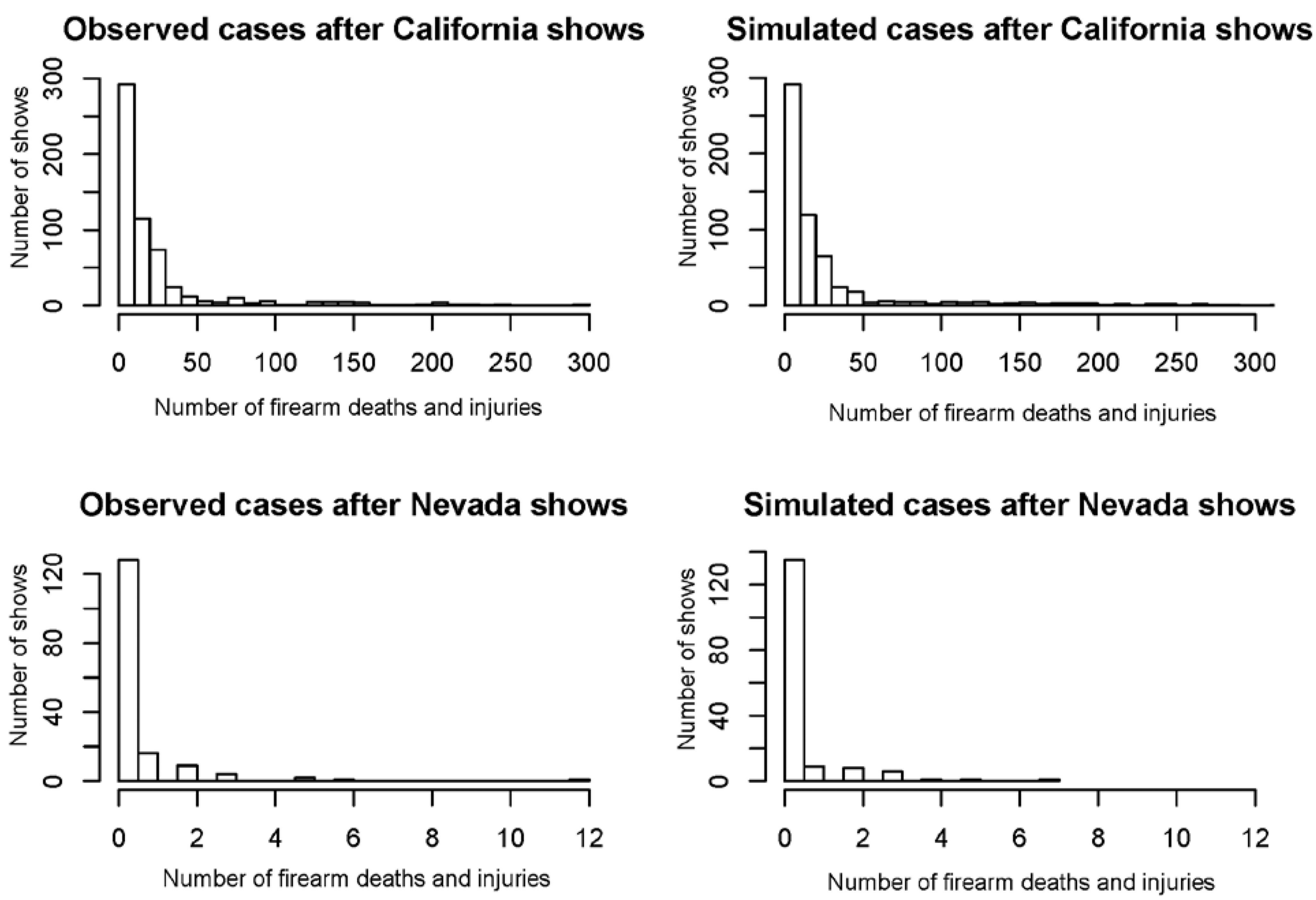
International Classification of Diseases (ICD) 9th and 10th revision external cause of injury codes used to identify and classify firearm deaths and injuries

Death/injury type	ICD-9 (hospital discharge records)	ICD-10 (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

Power calculations

To confirm that our study had sufficient statistical power, we conducted 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 two weeks prior to each gun show (in regions within convenient traveling distance of each show) and simulated the number of firearm deaths and injuries in the two weeks after each gun show. Appendix Figure 1 presents the observed and simulated distributions of firearm deaths and injuries for the two weeks after gun shows. The distributions are very similar, suggesting that the power analysis is based on simulated data that accurately reflects the observed data.

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

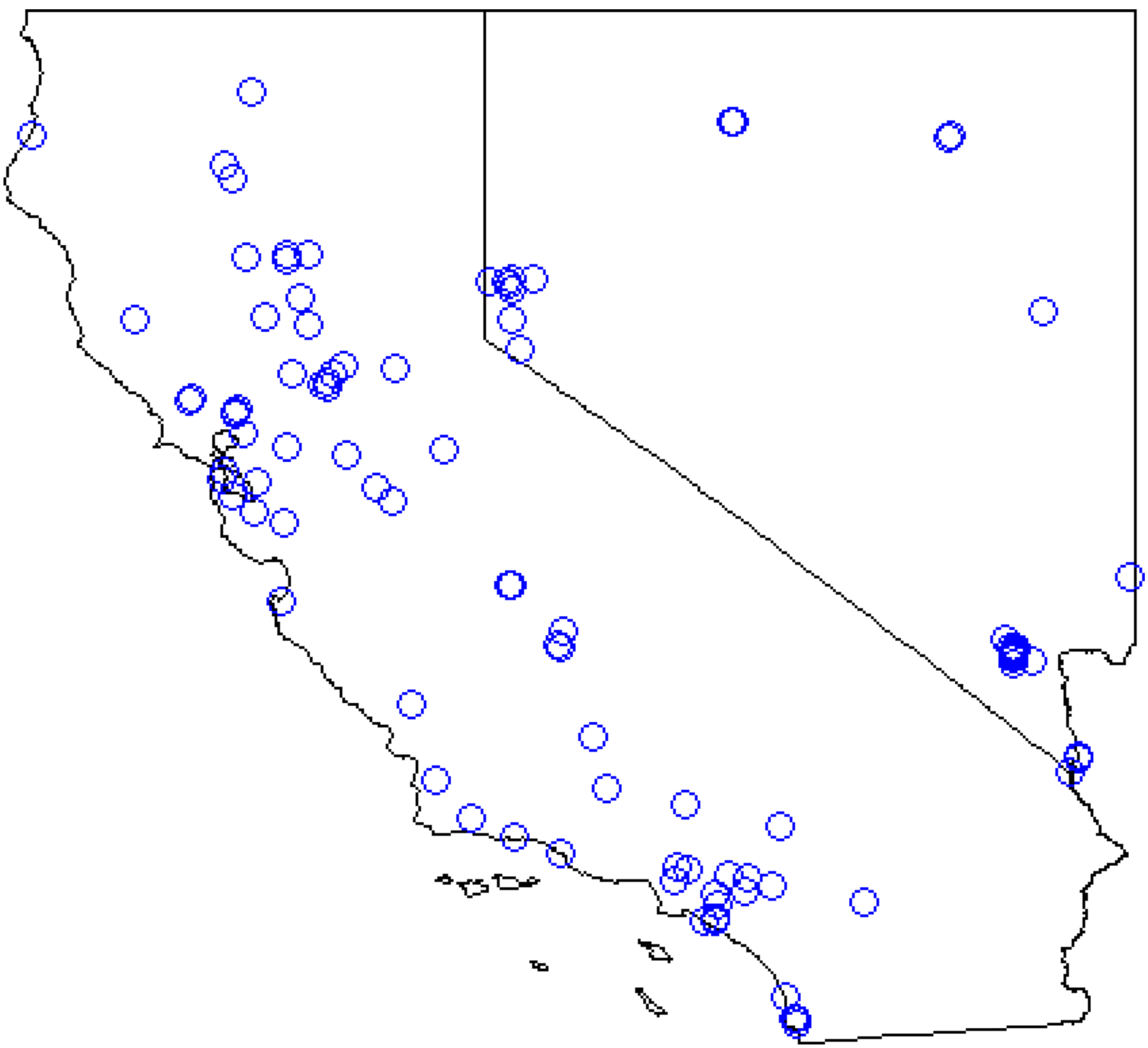


Appendix Figure 1. Comparison of observed and simulated distribution of firearm deaths and injuries during the two weeks following gun shows in nearby regions

Legend: In this figure, 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, during the two weeks following each gun show, in regions within driving distance of each show, by state. For example, this figure shows that in both the observed and simulated data, there were just under 300 gun show regions with no firearm deaths or injuries in the two weeks after the show.

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 pre-exposure and post-exposure periods). In particular, some shows in the Northeast of Nevada were not included in analyses that restricted to Nevada shows within 120 minutes driving of California, but were included in sensitivity analyses extending to larger driving distances.



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

Secondary and sensitivity analyses

There is little evidence on how far or how long the effects of gun shows might extend (27). Thus, we selected reasonable timeframes and travel times to balance capturing short-term effects with estimating stable rates, and to include regions that are likely 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 timeframes and travel times.

Appendix Table 2 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 weeks) time periods, but were not statistically significant for smaller geographic ranges (60 minutes driving), which yielded very few cases, and larger geographic ranges (120 and 180 minutes driving 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 to longer time periods.

Appendix Table 2

Sensitivity analyses for adjusted association between firearm deaths and injuries in California and gun shows in California versus Nevada

Specification[a]	Type of Firearm death/injury	Association with California gun shows (after vs before) (RR [95% CI])	Association with Nevada gun shows (after vs before) (RR [95% CI])	Association with gun shows (Nevada vs California) (RRR [95% CI])
Primary analysis, presented in main text: 2-week exposure period; 60-minute driving distance for California shows; 120-minute driving distance for Nevada shows	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	*b*	*b*	*b*
Shorter time period: 1- week exposure period; 60-minute driving distance for California shows; 120-minute driving distance for Nevada shows	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	*b*	*b*	*b*
Longer time period: 3-week exposure period; 60-minute driving distance for California shows; 120-minute driving distance for Nevada shows	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	*b*	*b*	*b*

Specification[a]	**Type of Firearm death/injury**	**Association with California gun shows (after vs before) (RR [95% CI])**	**Association with Nevada gun shows (after vs before) (RR [95% CI])**	**Association with gun shows (Nevada vs California) (RRR [95% CI])**
Smaller geographic range: 2-week exposure period; 60-minute driving distance for California shows; 60-minute driving distance for Nevada shows	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	*b*	*b*	*b*
Larger geographic range: 2-week exposure period; 120-minute driving distance for California shows; 180-minute driving distance for Nevada shows	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	*b*	*b*	*b*

[a]Specifies the distance between zip code centroids and gun show locations up to which zip codes were considered "exposed", and the duration of the time periods considered before and after each show.

[b]Not estimated, due to the small number of observed events near Nevada shows (see Table 2).

Abbreviations: RR: rate ratio. RRR: ratio of rate ratios. CI: confidence interval.

In additional secondary analyses, we 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 firearm injuries in California 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 3 presents the results of these secondary analyses. There were no significant relationships between gun shows and firearm injuries along known trafficking routes or when excluding California's 10-day waiting period.

Appendix Table 3

Secondary analyses for adjusted association between firearm deaths and injuries along firearm trafficking routes and excluding California's 10-day waiting period

Specification[a]	**Type of firearm death/injury**	**Total firearm deaths and injuries in two weeks preceding gun shows**	**Association with gun shows (after vs before) (RR [95% CI])**
California gun shows; 60-minute driving distance; 2-week exposure period	All causes	15,000	0.99 (0.97, 1.02)
	Self-directed	1,266	1.01 (0.93, 1.09)
	Interpersonal	9,288	1.00 (0.97, 1.03)
	Unintentional	3,887	0.98 (0.94, 1.02)

Specification[a]	Type of firearm death/injury	Total firearm deaths and injuries in two weeks preceding gun shows	Association with gun shows (after vs before) (RR [95% CI])
	Undetermined	559	0.97 (0.86, 1.09)
Analysis restricted to Reno gun shows and firearm deaths and injuries in San Francisco Bay Area zip codes; 2-week exposure period	All causes	8,433	1.02 (0.99, 1.05)
	Self-directed	650	1.04 (0.94, 1.16)
	Interpersonal	5,728	1.02 (0.98, 1.06)
	Unintentional	1,668	1.04 (0.97, 1.11)
	Undetermined	387	0.94 (0.81, 1.08)
Analysis restricted to Las Vegas gun shows and firearm deaths and injuries in Los Angeles Metropolitan Area zip codes; 2-week exposure period	All causes	34,663	0.99 (0.98, 1.01)
	Self-directed	2,619	1.04 (0.98, 1.09)
	Interpersonal	22,026	0.99 (0.97, 1.01)
	Unintentional	8,811	0.99 (0.96, 1.02)
	Undetermined	1,207	0.99 (0.92, 1.08)

[a]Specifies the distance between zip code centroids and gun show locations up to which zip codes were considered "exposed" and the duration of the time periods considered before and after each show. All analyses in this table exclude consideration of California's 10-day waiting period for firearm purchases.

Abbreviations: RR: rate ratio. CI: confidence interval.

Sensitivity analysis restricting to regions similar to those exposed to Nevada gun shows

In interpreting the results of the main analysis, one important consideration is that characteristics of the regions exposed to gun shows may modify the association between gun shows and firearm deaths and injuries. It is possible that 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 the regions exposed to Nevada gun shows. For example, regions exposed to Nevada gun shows tend to be more rural and have lower rates of firearm deaths and injuries (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 (a) differed between regions exposed to California versus Nevada shows, and (b) may modify the association between gun shows and firearm deaths and injuries. These were: population density, percent veterans, median income, median age, percent White non-Hispanic, hunting licenses per capita, and the overall rate of firearm injuries between 2005 and 2013. We used one-to-many greedy Mahalanobis distance matching (a generalization of nearest neighbor matching based on Euclidean distance) with replacement and a caliper of 0.01 standard deviations of the distance measure (43). This means that multiple 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 that is 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 exclusively to locations very similar to this border region.

Of the 1769 zip codes in California, 490 remained after restriction, 192 of which were matched more than once due to replacement. Appendix Table 4 presents the distribution of the potentially modifying characteristics before and after restriction, and compared to zip codes exposed to Nevada gun shows. After restriction, the zip codes that remained were very similar to those exposed to Nevada gun shows. Compared to 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.

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	Metric	All California zip codes	Zip codes exposed to California shows	Zip codes exposed to Nevada gun shows	California zip codes similar to those exposed to Nevada gun shows
Population density	Minimum	1	1	1	1
	25th percentile	43	372	7	18
	Median	2,501	3,907	89	145
	75th percentile	6,893	8,132	1,460	1,804
	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	9,219	9,219	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

Characteristic	Metric	All California zip codes	Zip codes exposed to California shows	Zip codes exposed to Nevada gun shows	California zip codes similar to those exposed to Nevada gun shows
Median age	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	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 capita	Minimum	0	0	172	172
	25th percentile	508	413	2,198	2,845
	Median	1,597	1,118	5,232	5,254
	75th percentile	5,296	3,759	9,675	9,031
	Maximum	1,340,930	1,340,930	389,725	389,725
Overall rate of firearm deaths and injuries, 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

Negative control analysis

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

Appendix Table 5

Negative control analysis for adjusted association between non-firearm injury deaths and hospital visits in California and gun shows in California versus Nevada

Type of non-firearm injury death or hospital visit	Association with California gun shows (after vs before) (RR [95% CI])	Association with Nevada gun shows (after vs before) (RR [95% CI])	Association with gun shows (Nevada vs California) (RRR [95% CI])
All injuries	1.01 (1.00, 1.01) [b]	0.99 (0.97, 1.00)	0.98 (0.96, 1.00) [b]
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) [b]	0.98 (0.97, 1.00)	0.98 (0.96, 1.00) [b]
Undetermined	[a]	[a]	[a]

Abbreviations: RR: rate ratio. RRR: ratio of rate ratios. CI: confidence interval.

[a]Not estimated, due to the small number of observed events near Nevada shows (see Table 2).

[b]Confidence interval excludes 1.

Quantitative bias analysis for an unobserved confounder

To assess the potential role of residual confounding due to unmeasured factors, we conducted a quantitative bias analysis for two of the measured associations in this study: first, the association between gun shows in Nevada and firearm deaths and injuries in California, and second, the association between state of gun show occurrence and increases in firearm deaths and injuries following gun 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 for the rate ratio (RR) (44) and applied it to the estimated rate ratio of the association between Nevada gun shows and firearm deaths and injuries in California ($\beta_1 + \beta_3$) in the main regression analysis).

We defined the following random variables: Let A be a binary indicator representing exposure to Nevada gun shows (i.e. the time period is in the two weeks after Nevada gun shows versus the two weeks prior), Y be the rate of firearm deaths and injuries per 100,000 population in California, X be the measured covariates controlled in the main analysis, and U be an unmeasured confounder. Following VanderWeele and Arah's analysis, we made three assumptions: first, that the association between U and Y does not vary between strata of A; second, 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:

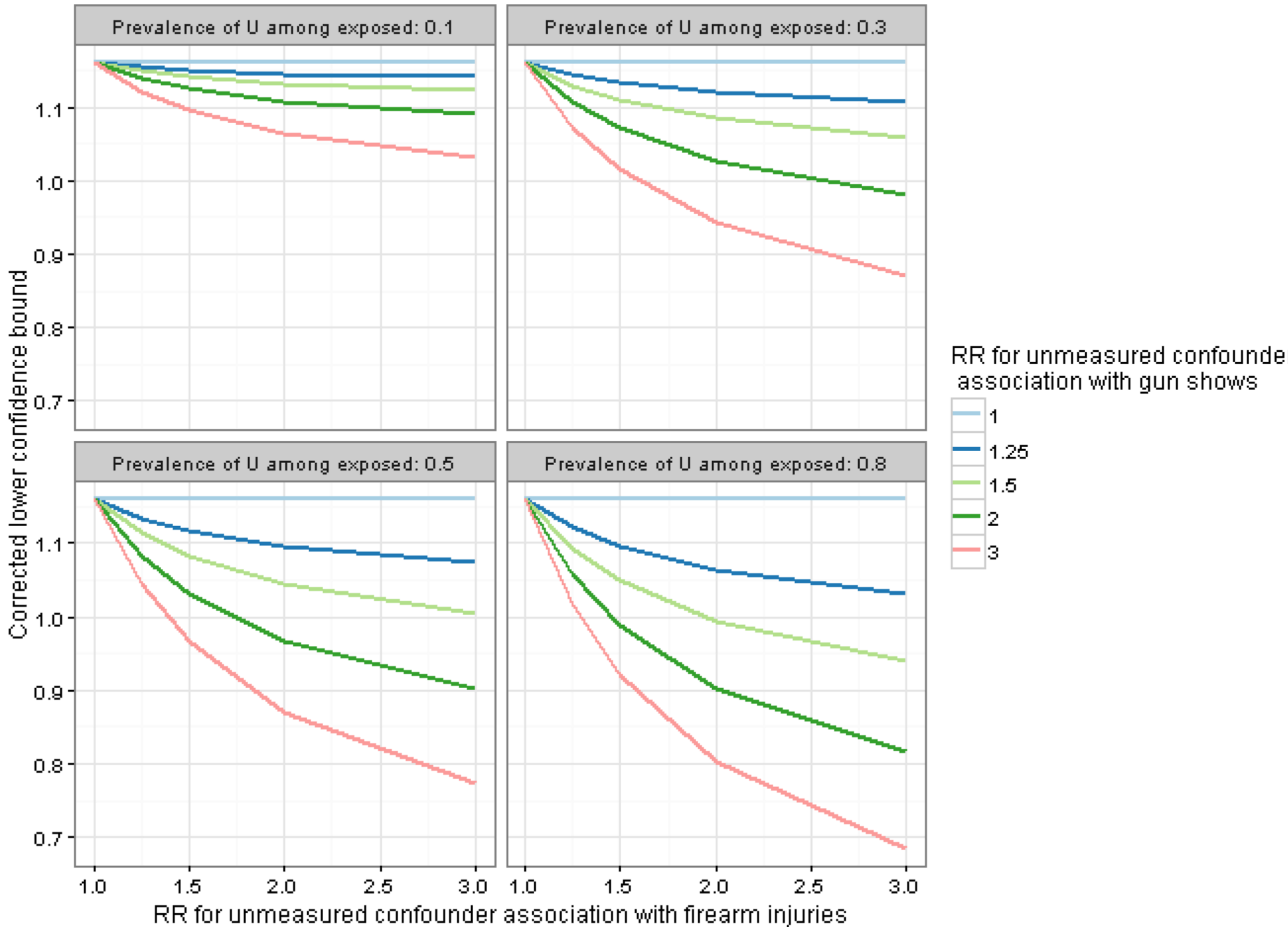
$$d^{RR}_{+a}(x) = \frac{1 + (\gamma - 1)P(U = 1|a = 1, x)}{1 + (\gamma - 1)P(U = 1|a = 0, x)}$$

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 [95% confidence interval: 1.16 – 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. Each graph represents a different 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 measures 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, 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. 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. In order for the association between Nevada gun shows and firearm deaths and injuries in California to be spurious, there would have to be another factor that matches the geographic and temporal pattern of the 275 Nevada gun shows and that is also quite strongly associated with firearm deaths and injuries in California. This factor would also have to be notably more prevalent after Nevada gun shows versus before, corresponding to relative risks of at least 1.5 or 2 for a confounder that is up to 80% more prevalent in the two weeks following Nevada gun shows compared to the two weeks prior. 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 artefact of Nevada gun shows; for example, if individuals at higher risk of firearm deaths and injuries come to California areas near Nevada shows when Nevada shows are occurring, or happenings at Nevada gun shows prompt individuals 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.



Appendix Figure 3.

Bias analysis results for association between Nevada gun shows and California firearm deaths and injuries

Association between state of gun show occurrence and increases in firearm deaths and injuries following gun shows

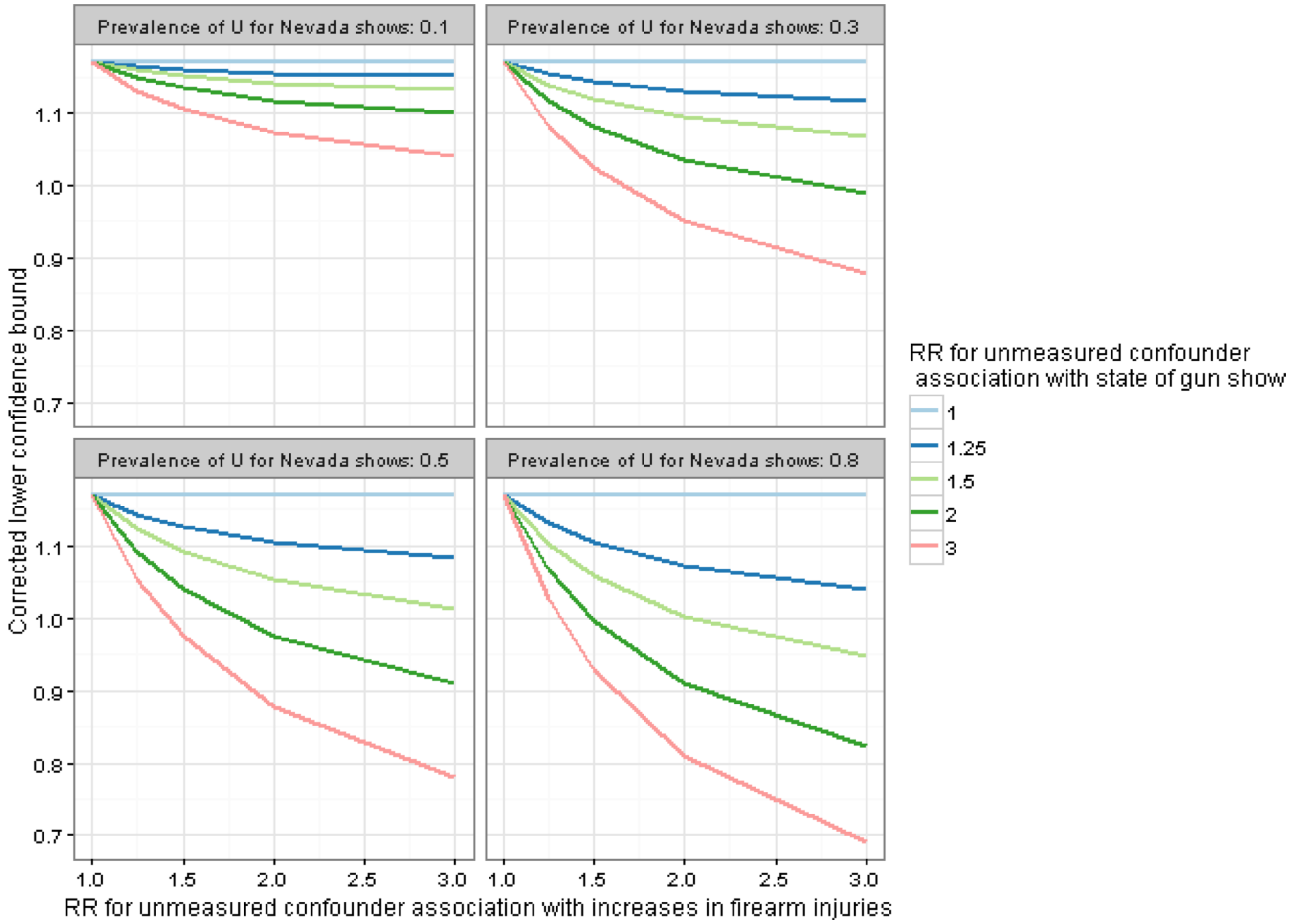
We also estimated the characteristics of an unmeasured confounder that would yield the observed association between the state in which the gun show occurred and increases in firearm deaths and injuries following gun shows, if the true effect were not statistically significant. Again, we used the bias equation presented by VanderWeele and Arah (44), but in this case, we applied it to the ratio of RRs (RRR) for the association between the state in which the gun show occurs (Nevada versus California) and increases in firearm deaths and injuries following 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 occurred (Nevada versus California), Y be the change in rate of firearm deaths and injuries per 100,000 population in the two weeks prior to gun shows compared to the two 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 three assumptions as above, and the bias in the conditional causal RR is defined as above.

We estimated the corrected lower confidence bound for the RRR estimate of the association between the state of the gun show and increases in firearm deaths and injuries following shows (observed: 1.70 [95% confidence interval: 1.17 – 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. Each graph represents a different 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 following gun shows, the color of each line measures 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, the association between the state of the gun show and increases in firearm death and injuries following gun shows would still be statistically significant, with a corrected lower confidence bound above 1. 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 following gun 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. In order for the association between state and increases in firearm deaths and injuries following shows to be spurious, there would have to be another factor that matches the geographic and temporal pattern of the 915 gun shows in both states. This factor would also have to be quite 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 relative risks of at least 1.5 to 2 for a confounder that is up to 80% more prevalent for Nevada shows compared to 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).



Appendix Figure 4.

Bias analysis results for association between state of gun show occurrence and increases in firearm deaths and injuries following gun shows

References

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Table 1

Characteristics of California and Nevada gun shows and population exposure to gun shows

Characteristic	California	Nevada
Number of shows	640	275
Number of unique show locations	64	31
Earliest show date	1/15/2005	1/22/2005
Latest show date	12/7/2013	12/14/2013
Number of shows excluded due to overlap restrictions	55	114
Final number of shows in regression analyses	585	161
Total person-weeks of gun show exposure in final regression analyses[a]	2,303,786,333	13,037,052

[a]Assuming a 2-week post-exposure time frame, as described in methods section.

Table 2

Unadjusted association between gun shows in California and Nevada and firearm deaths and injuries in California

Type of firearm death/injury	State of gun show	Two weeks preceding gun shows		Two weeks following gun shows	
		Total firearm deaths and injuries	Firearm death and injury rate per 100,000 (95% CI)	Total firearm deaths and injuries	Firearm death and injury rate per 100,000 (95% CI)
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	1,266	0.11 (0.08, 0.14)	1,275	0.11 (0.08, 0.14)
	Nevada	15	0.23 (0.16, 0.30)	23	0.35 (0.26, 0.44)
Interpersonal	California	9,288	0.81 (0.73, 0.88)	9,277	0.81 (0.73, 0.88)
	Nevada	9	0.14 (0.08,0.20)	20	0.31 (0.22, 0.39)
Unintentional	California	3,887	0.34 (0.29, 0.38)	3,799	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)

Abbreviations: CI: confidence interval.

Confidence intervals are based on an assumed Poisson distribution for the 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 negative binomial.

Table 3

Adjusted analyses of association between firearm deaths and injuries in California and gun shows in California versus Nevada

Type of firearm death/injury	State of gun show	Association with gun shows (after vs before)		Ratio of RRs associated with Nevada versus California gun shows	
		RR (95% CI)	**P value**	**RRR (95% CI)**	**P value**
All causes	California	0.99 (0.97, 1.02)	0.546	1.70 (1.17, 2.47)	0.006
	Nevada	1.69 (1.16, 2.45)	0.006		
Self-directed	California	1.01 (0.93, 1.09)	0.862	1.51 (0.78, 2.90)	0.219
	Nevada	1.52 (0.79, 2.91)	0.208		
Interpersonal	California	1.00 (0.97, 1.03)	0.942	2.23 (1.01, 4.90)	0.046
	Nevada	2.23 (1.01, 4.89)	0.046		
Unintentional	California	0.98 (0.93, 1.02)	0.317	1.57 (0.88, 2.81)	0.128
	Nevada	1.53 (0.86, 2.74)	0.147		
Undetermined	California	*a*	*a*	*a*	*a*
	Nevada	*a*	*a*		

Abbreviations: RR: rate ratio. RRR: ratio of rate ratios. CI: confidence interval.

[a] Not estimated, due to the small number of observed events near Nevada shows (see Table 2).

Table 4

Adjusted analyses of association between firearm deaths and injuries in California and gun shows in California and Nevada stratified by state

Type of firearm death/injury	State of gun show	Association with gun shows (after vs before)	
		RR (95% CI)	P value
All causes	California	0.99 (0.97, 1.02)	0.533
	Nevada	1.68 (1.16, 2.44)	0.006
Self-directed	California	1.01 (0.93, 1.09)	0.846
	Nevada	1.53 (0.80, 2.94)	0.198
Interpersonal	California	1.00 (0.97, 1.03)	0.934
	Nevada	2.22 (1.00, 4.94)	0.050
Unintentional	California	0.98 (0.94, 1.02)	0.304
	Nevada	1.53 (0.86, 2.73)	0.150
Undetermined	California	0.97 (0.86, 1.09)	0.623
	Nevada	*a*	*a*

Abbreviations: RR: rate ratio. CI: confidence interval.

[a]Not estimated, due to the small number of observed events near Nevada shows (see Table 2).

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Table 5

Adjusted analyses of 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/injury	Association with California gun shows (after vs before) (RR [95% CI])	Association with Nevada gun shows (after vs before) (RR [95% CI])	Association with gun shows (Nevada vs California) (RRR [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	*a*	*a*	*a*

Abbreviations: RR: rate ratio. RRR: ratio of rate ratios. CI: confidence interval.

[a] Not estimated, due to the small number of observed events near Nevada shows (see Table 2).