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The changing epidemiology of interpersonal firearm violence during the COVID-19 pandemic in Philadelphia, PA

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ABSTRACT

Recent increases in firearm violence in U.S. cities are well-documented, however dynamic changes in the people, places and intensity of this public health threat during the COVID-19 pandemic are relatively unexplored. This descriptive epidemiologic study spanning from January 1, 2015 - March 31, 2021 utilizes the Philadelphia Police Department's registry of shooting victims, a database which includes all individuals shot and/or killed due to interpersonal firearm violence in the city of Philadelphia. We compared victim and event characteristics prior to the pandemic with those following implementation of pandemic containment measures. In this study, containment began on March 16, 2020, when non-essential businesses were ordered to close in Philadelphia. There were 331 (SE = 13.9) individuals shot/quarter pre-containment vs. 545 (SE = 66.4) individuals shot/quarter post-containment (p = 0.031). Post-containment, the proportion of women shot increased by 39% (95% CI: 1.21, 1.59), and the proportion of children shot increased by 17% (95% CI: 1.00, 1.35). Black women and children were more likely to be shot post-containment (RR 1.11, 95% CI: 1.02, 1.20 and RR 1.08, 95% CI: 1.03, 1.14, respectively). The proportion of mass shootings (≥4 individuals shot within 100 m within 1 h) increased by 53% post-containment (95% CI: 1.25, 1.88). Geographic analysis revealed relative increases in all shootings and mass shootings in specific city locations post-containment. The observed changes in firearm injury epidemiology following COVID-19 containment in Philadelphia demonstrate an intensification in firearm violence, which is increasingly impacting people who are likely made more vulnerable by existing social and structural disadvantage. These findings support existing knowledge about structural causes of interpersonal firearm violence and suggest structural solutions are required to address this public health threat.

1. Introduction

Globally, firearm violence has increased during the coronavirus disease 2019 (COVID-19) pandemic (Abdallah et al., 2021; Beard et al., 2021; Donnelly et al., 2021; Navsaria et al., 2020; Qasim et al., 2020; Ramos Perkis et al., 2021; Sutherland et al., 2021). Reports from cities across the United States (U.S.), including New York, Philadelphia, and Chicago, indicate rising rates of firearm injury since March 2020 (Abdallah et al., 2021; Beard et al., 2021; Donnelly et al., 2021; Qasim et al., 2020; Sutherland et al., 2021). Even in cities without an absolute increase in firearm injury incidence during the pandemic, hospitalizations of firearm-injured patients have risen disproportionally when compared to other modes of injury (Matthay et al., 2021a, 2021b; Sherman et al., 2021). Our previous research indicates that the weekly rate of shootings in Philadelphia has nearly doubled since the enactment of the first COVID-19 containment policy on March 16, 2020, an increase that has sustained through November 2020 (Beard et al., 2021).

While the recent increase in firearm injury in U.S. cities is well-

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documented, the dynamic changes in the people, places, and intensity of interpersonal firearm violence during the COVID-19 pandemic remain largely unexplored. Firearm violence in the U.S. is strongly associated with social and structural factors such as concentrated poverty, built and natural resources, infrastructure, and access to firearms (Anglemyer et al., 2014; Beard et al., 2017; Beard and Sims, 2017; Branas et al., 2017; Branas et al., 2018; Choi et al., 2020; Dalve et al., 2021; Friedman et al., 2019; Garvin et al., 2013; Houghton et al., 2021; Jacoby et al., 2018; Knopov et al., 2019; Krieger et al., 2017; Miller et al., 2002a, 2002b, 2002c; Moyer et al., 2019; Tracy et al., 2019; Wong et al., 2020). In the context of these and other upstream determinants, Black men are the most overrepresented among all people who are injured by interpersonal firearm violence in U.S. cities (Beard et al., 2017; Fowler et al., 2015; Houghton et al., 2021; Jacoby et al., 2018). In Philadelphia, historic place-based racial discrimination and resultant racial segregation have led to geographic concentration of firearm violence in certain areas of the city (Beard et al., 2017; Beard and Sims, 2017; Branas et al., 2017; Jacoby et al., 2018). Understanding the epidemiology and geographic characteristics of firearm violence during the pandemic is vital to further understanding and mitigating the intensification of this significant threat to public health. An increase in firearm violence among Black men in existing firearm violence "hot spots" would indicate the need for urgent additional resources aimed at prevention, while demographic and geographic changes in firearm violence during the pandemic could reflect shifting etiologic factors worthy of additional study and alternative interventions.

The aim of this study was to describe the distribution and composition of firearm violence during the COVID-19 pandemic in the city of Philadelphia, Pennsylvania. We also investigated whether there were changes in the incidence of mass shootings, which we have previously found to occur relatively frequently in Philadelphia, at a rate of about once every two to three months prior to the pandemic (Beard et al., 2019a, 2019b). Mass shootings are essential to consider, as they represent a significant burden on the city's hospitals and trauma system and disproportionally affect people living in under-resourced neighborhoods (Beard et al., 2019a, 2019b).

2. Methods

2.1. Data and variables

Philadelphia has a population of 1.6 million and a poverty rate of 24.3% (U.S. Census Bureau, 2019). In this study, we used data from the Philadelphia Police Department's (PPD) registry of shooting victims from January 1, 2015 to March 31, 2021 (OpenDataPhilly, 2021). This registry is updated daily and includes all individuals shot and/or killed with a firearm as a result of interpersonal violence in the city of Philadelphia. PPD data capture approximately twice the number of firearm-injured individuals compared to hospital-based registries in the same city and have been used in multiple evaluations of firearm injury epidemiology (Beard et al., 2021; Beard et al., 2017; Beard et al., 2019a, 2019b; Jacoby et al., 2018; Kaufman et al., 2019; Moyer et al., 2019). Available fields in the PPD data describe the time and date when the shooting occurred, the block level location (e.g. 3400 Block North Broad St) with geographic coordinates of the shooting event, and whether the shooting occurred inside or outside. The dataset also includes demographic characteristics of the individuals shot (sex, age, race, and ethnicity [Latino, non-Latino]) and whether the shooting was fatal or non-fatal. Information about the shooter and about individuals with self-inflicted firearm injuries is not included in this dataset.

Using previously described methods, we identified whether individuals were shot as part of a "mass shooting" (Beard et al., 2019a, 2019b). Data for all firearm-injured individuals were ordered sequentially based on the date and time of the shooting. Each person shot was grouped with any other individuals shot within 1 h and within 100 m (approximately 1 city block). Groups containing $\geq$4 firearm-injured individuals were defined as "mass shootings," using criteria from previous studies and Gun Violence Archive (Beard et al., 2019a; Gun Violence Archive, 2022).

The main exposure of interest was the enactment of Philadelphia's first COVID-19 containment policy, which we defined as coinciding with the closure of non-essential businesses on March 16, 2020 (Beard et al., 2021; City of Philadelphia Board of Health, 2020).

2.2. Statistical analysis

We examined the population distribution of firearm violence in four steps. The first three steps assess the relative change in firearm violence epidemiology before and during the pandemic and describe the magnitude of the observed change. The final step examines relative changes in places impacted by firearm violence pre- and post-containment.

First, we compared event and demographic characteristics of individuals shot in all shootings and non-mass shootings (those in which three or fewer individuals were shot) during the pre-containment period (January 1, 2015 to March 15, 2020) to the post-containment period (March 16, 2020 to March 31, 2021). We calculated the rate ratio and 95% confidence interval within categories (e.g. comparing the proportion of individuals shot who were women across the two periods). Examining the characteristics of non-mass shootings allowed us to determine if mass shootings could account for the demographic changes across time periods.

Next, we calculated and compared quarterly counts of all individuals shot, women shot, men shot, children shot, and mass shootings in the pre- vs. post-containment periods. We chose quarterly counts instead of monthly or weekly counts given the relatively rare occurrence of mass shootings. We constructed line plots of the absolute counts of shootings within categories (all individuals shot, women, children, and mass shootings), aggregated by quarter during the study period. Guided by the findings of the first two stages, we then conducted further subgroup analyses for women and children (aged <18 years) to better understand changes in demographic and shooting event characteristics in these groups pre- vs. post-containment.

Fourth, kernel density estimation assessed the geographic distribution of all shootings and mass shootings across Philadelphia. Kernel densities were constructed using an adaptive bandwidth, raster cell size of 128 $\times$ 128 ft, and uniform weights for each shooting. Spatial data were projected using the Albers Equal Area coordinate system. Separate raster layers described the kernel densities pre- and post-containment for both shooting types. We then calculated the rate ratio of pre-containment vs. post-containment period shooting incidence by dividing the raster cell values (completed using the `risk()` tool in the `sparr` package in R).

Statistical analysis was performed with R version 4.0.4. A p-value <0.05 for 2-sided tests was considered statistically significant. The Temple University Institutional Review Board determined that this analysis of publicly available data was not human subjects research and did not require approval.

3. Results

Table 1 presents descriptive statistics for individuals shot, and event characteristics for all shootings and non-mass shootings in the pre- vs. post-containment periods. When assessing all shootings during the pre-containment period, individuals shot were predominately young (mean age = 28.6; SE = 0.1), Black (82.4%), men (91.8%). 8.2% of firearm-injured individuals were women and 7.8% were children. Of the 6896 individuals shot in the pre-containment period, 1393 (20.2%) died. Among the 2456 individuals shot post-containment, the proportion of women shot increased by 39% (95% CI: 1.21, 1.59; $p < 0.001$) while the proportion of children shot increased by 17% (95% CI: 1.00, 1.35; $p = 0.046$). In the post-containment period, shootings were less likely to be

Table 1
Characteristics of individuals shot in all shootings and non-mass shootings before and after COVID-19 containment policy enactment in Philadelphia, PA.

Variable	All shootings				Non-mass shootings[a]			
	Pre-Containment January 1, 2015 - March 15, 2020 (n = 6896)	Post-Containment March 16, 2020 - March 31, 2021 (n = 2456)	RR (95% CI)	P-Value[c]	Pre-Containment January 1, 2015 - March 15, 2020 (n = 6650)	Post-Containment March 16, 2020 - March 31, 2021 (n = 2322)	RR (95% CI)	P-Value[c]
Age in years, mean (SE)	28.6 (0.1)	28.7 (0.2)	(–-)	(–-)	28.7 (0.1)	28.7 (0.2)	(–-)	(–-)
Women, n (%)	564 (8.2)	279 (11.4)	1.39 (1.21, 1.59)	**<0.001**	522 (7.8)	246 (10.6)	1.35 (1.17, 1.56)	**<0.001**
Children (< 18 years), n (%)	535 (7.8)	222 (9.0)	1.17 (1.00, 1.35)	**0.046**	480 (7.2)	198 (8.5)	1.18 (1.01, 1.38)	**0.040**
Race/Ethnicity, n (%)								
Black	5684 (82.4)	2061 (83.9)	1.02 (1.00, 1.04)	0.092	5481 (82.4)	1934 (83.3)	1.01 (0.99, 1.03)	0.341
Latinx	848 (12.3)	246 (10.0)	0.81 (0.71, 0.93)	**0.003**	820 (12.3)	239 (10.3)	0.83 (0.73, 0.96)	**0.009**
White	313 (4.5)	140 (5.7)	1.26 (1.03, 1.52)	**0.021**	300 (4.5)	140 (6.0)	6.14 (5.05, 7.46)	**<0.001**
Other	51 (0.7)	9 (0.4)	0.50 (0.24, 1.00)	**0.047**	49 (0.7)	9 (0.4)	0.53 (0.26, 1.07)	0.071
Mass shooting[b], n (%)	246 (3.6)	134 (5.5)	1.53 (1.25, 1.88)	**<0.001**	0 (0.0)	0 (0.0)	(–-)	(–-)
Fatal, n (%)	1393 (20.2)	424 (17.3)	0.85 (0.77, 0.94)	**0.002**	1356 (20.4)	415 (17.9)	0.88 (0.79, 0.97)	**0.009**
Outdoor, n (%)	6468 (93.8)	2397 (97.6)	1.04 (1.03, 1.05)	**<0.001**	6234 (93.7)	2269 (97.7)	1.03 (1.02, 1.04)	**<0.001**
Time of day, n (%)								
12:00 pm - 11:59 pm	4245 (61.6)	1734 (70.6)	1.15 (1.11, 1.18)	**<0.001**	4068 (61.2)	1629 (70.2)	1.15 (1.11, 1.18)	**<0.001**
Weekday, n (%)	4711 (68.3)	1701 (69.3)	1.01 (0.98, 1.05)	0.387	4567 (68.7)	1600 (68.9)	1.00 (0.97, 1.04)	0.837

[a] Non-mass shootings are defined as events in which 3 or fewer individuals are shot.
[b] Mass shootings are defined as events in which 4 or more individuals are shot within 100 m within 1 h.
[c] *P*-values are for rate ratios at an alpha of 0.05.

fatal (RR 0.85, 95% CI: 0.77, 0.94; $p = 0.002$) but more likely to occur outdoors (RR 1.04, 95% CI: 1.03, 1.05; $p < 0.001$). Compared to pre-containment, the proportion of mass shootings increased by 53% from 3.6% of all shootings to 5.5% of all shootings in the post-containment period (95% CI: 1.25, 1.88; $p < 0.001$).

The changes in victim and event characteristics persisted even after excluding individuals shot in mass shootings. In examining non-mass shootings (Table 1), the proportion of women and children shot was still significantly greater in the post-containment period compared to the pre-containment period (RR 1.35; 95% CI: 1.17, 1.56; $p < 0.001$ and RR:

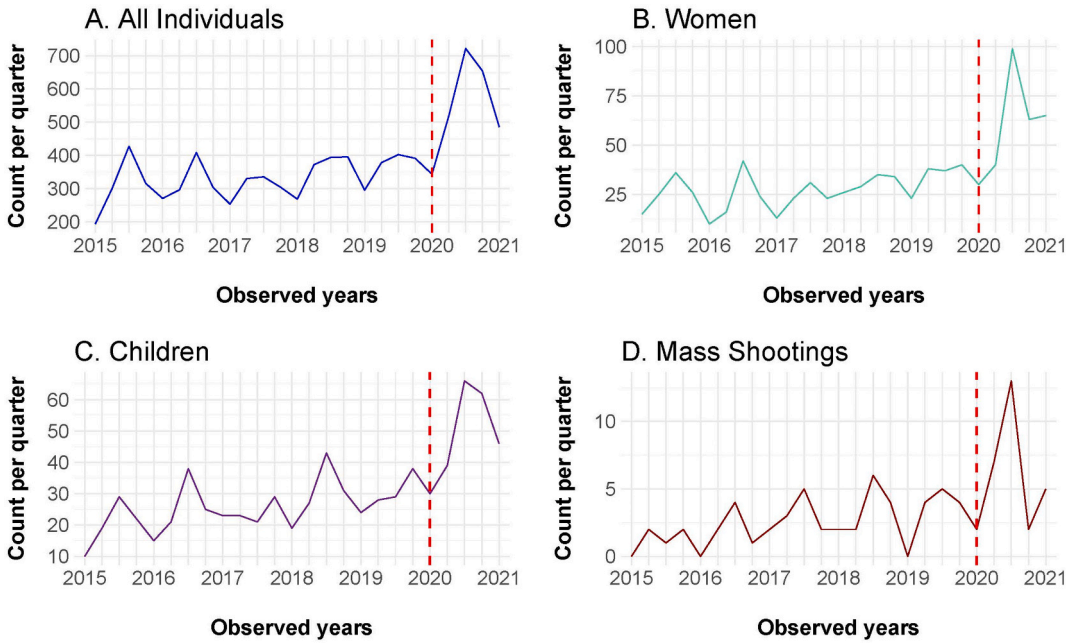

Fig. 1. Quarterly counts of all individuals shot **(A)**; women shot **(B)**; children shot **(C)**; and mass shootings **(D)**; in Philadelphia, PA from January 2015 – March 2021. The dashed red line marks the quarter during which the first containment policy was enacted in Philadelphia (March 16, 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1.18; 95% CI: 1.01, 1.38; $p = 0.040$ respectively). Similarly, the proportion of fatal shootings was 12% lower in the post-containment period compared to pre-containment among individuals shot in non-mass shootings (95% CI: 0.79, 0.97; $p = 0.009$).

The quarterly counts of all shootings, women and children shot, as well as mass shootings, are presented in Fig. 1. The dashed red line marks the quarter during which the first containment policy was enacted in Philadelphia (March 16, 2020). A sustained increase in shootings can be seen immediately following containment policy enactment, with a pronounced spike in the third quarter of 2020 across all four graphs. Less prominent spikes in the third quarter (which correspond to the summer months) are also seen in the five years prior to the pandemic onset, indicating seasonal variation in firearm injury incidence.

The pre- and post-containment quarterly counts of all individuals shot, women shot, and children shot, as well as mass shootings, are provided in Table 2. There were statistically significant increases post-containment in the quarterly counts of all individuals shot, children shot, and men shot.

The characteristics of women and children shot pre- and post-containment can be seen in Table 3. Black women and children were more likely to be shot in the post-containment period compared to the pre-containment period (RR 1.11, 95% CI: 1.02, 1.20; $p = 0.015$ and RR 1.08, 95% CI: 1.03, 1.14; $p = 0.009$, respectively). Among women, there was a 15% increase in outdoor shootings (95% CI: 1.10, 1.20; $p < 0.001$) post-containment compared to pre-containment. The proportion of individuals shot in mass shootings who were women increased from 7.4% pre-containment to 11.8% post-containment (RR 1.59, 95% CI: 1.03, 2.45; $p = 0.036$). Among children, there was a 13% increase in shootings which occurred from 12:00 pm – 11:59 pm (95% CI: 1.04, 1.22; $p = 0.009$) post-containment compared to pre-containment.

Visual inspection of kernel density maps in Fig. 2A and B suggests that shootings were found most often in North and West Philadelphia. Fig. 2C illustrates the rate ratio of all shootings post-containment to pre-containment. Values below 1 are areas with lower-than-average rates of shootings, and values above 1 have higher-than-average rates. Visual inspection of the figure suggests that there are increased rates of shootings post-containment in parts of Northeastern, Eastern, and Southwestern Philadelphia.

Similar trends can be seen among mass shootings in Figs. 2D-2F. There appears to be a higher density of mass shootings in North Philadelphia compared to other areas of the city. Post-containment, there is an increased concentration of mass shootings in Northeastern Philadelphia.

4. Discussion

This study provides further evidence that firearm violence has intensified in the U.S. following enactment of public health containment policies designed to prevent the spread of COVID-19. We found that the number of women and children shot in Philadelphia nearly doubled in the post-containment period, and that the proportion of shootings involving women and children increased significantly as well. Additionally, we found that the intensity of firearm violence increased, with a greater proportion of individuals injured or killed in mass shootings. Our geographic analysis reveals new shooting "hot spots" with relative increases in overall shootings and mass shootings in certain areas of the city. Taken together, these finding suggest a shift in the epidemiology of firearm violence in Philadelphia during the COVID-19 pandemic to increasingly impact the people who are likely to be most vulnerable as a result of existing social and structural disadvantage.

Our finding of increased shootings of women adds to existing scholarship on rising rates of interpersonal firearm violence against women in the U.S (Olufajo et al., 2021). Some have hypothesized that pandemic-related lockdowns which confined family members to their homes may have precipitated increased rates of intimate partner violence (IPV) against women (Boserup et al., 2020; Gosangi et al., 2021). This phenomenon is a potential explanation of our findings and warrants further research along ongoing efforts to prevent intimate partner violence and support IPV survivors. The spike in mass shootings post-containment may also partially explain the increase in shootings of women we observed. In line with our previous research, we found that mass shootings in Philadelphia disproportionally involve women both pre- and post-containment (Beard et al., 2019a).

The post-containment period in Philadelphia saw a significant increase in both the number and proportion of children shot. This may be related to the combined detrimental effects of socioeconomic deprivation, school closures, and lack of social support and services such as childcare which occurred as a result of unmitigated COVID-19 containment policies (Hoffman and Miller, 2020). Several recent studies have demonstrated the association between structural factors such as poverty, concentrated disadvantage, low-quality education, and firearm injury among children (Beardslee et al., 2021; Carter et al., 2017; Kalesan et al., 2016; Tracy et al., 2019). For children in lower-resourced settings, schools are a source of physical and mental health services, food assistance, internet access, childcare and supervision (Hoffman and Miller, 2020). Containment-related school closures disproportionately affected the most economically and socially vulnerable children in Philadelphia, removing this safety net, deepening structural inequities, and in turn, increasing their risk for firearm injury during COVID-19 containment (Carter et al., 2017; Cohen et al., 2021; Hoffman and Miller, 2020; Tracy et al., 2019).

Mass shootings increased following COVID-19 containment. Our prior research found that individuals shot in mass shootings in Philadelphia are younger, more likely to be women, and less likely to be fatally injured (Beard et al., 2019a). Interestingly, many of the epidemiologic changes we observed in the present study mirror the demographic profile of mass shootings in Philadelphia, however the rise in mass shootings does not fully account for the demographic shifts we observed. The higher rate of mass shootings, which represent the most extreme form of community firearm violence, likely reflects an overall escalation in the severity of firearm violence in the city during the pandemic.

Our analysis of the geographic distribution of firearm violence shows that it continues to be concentrated in certain areas, but with a relative increase in places that had lower rates of firearm violence prior to the pandemic. Research on firearm violence "hot spots" has highlighted the importance of place-based structural factors in determining the spaces where firearm injuries occur (Branas et al., 2017). Interventions to increase neighborhood green spaces and remediate vacant lots show promise in reducing firearm violence (Branas et al., 2018; Garvin et al., 2013; Moyer et al., 2019; Shepley et al., 2019). It is possible that pandemic containment policies placed new socioeconomic burdens on places that were previously spared from a significant burden of firearm violence. Additionally, decreased access to green spaces due to park closures and stay-at-home orders may have increased place-based risk for firearm violence. Finally, it is worth noting that the area in

Table 2
Mean number of individuals shot and mass shootings per quarter before and after containment policy enactment in Philadelphia, PA.

Variable	Pre-Containment January 1, 2015 - March 15, 2020 *Mean per quarter (SE)*	Post-Containment March 16, 2020 - March 31, 2021 *Mean per quarter (SE)*	P-Value[a]
All individuals	331 (13.9)	545 (66.4)	0.031
Women	27 (2.1)	59 (11.9)	0.054
Children	26 (1.8)	49 (6.8)	0.026
Men	304 (12.1)	485 (56.6)	0.031
Mass shootings[b]	3 (0.4)	6 (2.0)	0.221

[a] *P*-values are for two-sample *t*-tests at an alpha of 0.05.
[b] Mass shootings are defined as events in which 4 or more individuals are shot within 100 m within 1 h.

Table 3
Characteristics of women and children shot before and after COVID-19 containment policy enactment in Philadelphia, PA.

Variable	Women				Children			
	Pre-Containment January 1, 2015 - March 15, 2020 ($n = 564$)	Post-Containment March 16, 2020 - March 31, 2021 ($n = 279$)	RR (95% CI)	P-Value[b]	Pre-Containment January 1, 2015 - March 15, 2020 ($n = 535$)	Post-Containment March 16, 2020 - March 31, 2021 ($n = 222$)	RR (95% CI)	P-Value[b]
Age in years, mean (SE)	30.0 (0.6)	28.8 (0.7)	(—)	(—)	15.0 (0.2)	15.3 (0.2)	(—)	(—)
Women, n (%)	564 (100)	279 (100)	(—)	(—)	62 (11.6)	36 (16.2)	1.40 (0.96, 2.05)	0.084
Children (< 18 years), n (%)	62 (11.0)	36 (12.9)	1.17 (0.80, 1.72)	0.416	535 (100)	222 (100)	(—)	(—)
Race/Ethnicity, n (%)								
Black	405 (71.8)	222 (79.6)	1.11 (1.02, 1.20)	**0.015**	454 (84.9)	204 (91.9)	1.08 (1.03, 1.14)	**0.009**
Latinx	102 (18.1)	30 (10.8)	0.59 (0.41, 0.87)	**0.006**	58 (10.8)	16 (7.2)	0.66 (0.39, 1.13)	0.126
White	51 (9.0)	27 (9.7)	1.07 (0.69, 1.67)	0.765	17 (3.2)	2 (0.9)	0.28 (0.07, 1.22)	0.068
Other	6 (1.1)	0 (0)	(—)	(—)	6 (1.1)	0 (0.0)	(—)	(—)
Fatal, n (%)	103 (18.3)	37 (13.3)	0.73 (0.51, 1.03)	0.067	75 (14.0)	29 (13.1)	0.93 (0.63, 1.39)	0.728
Outdoor, n (%)	476 (84.4)	270 (96.8)	1.15 (1.10, 1.20)	**<0.001**	504 (94.2)	216 (97.3)	1.03 (1.00, 1.06)	0.073
Time of day, n (%) 12:00 pm - 11:59 pm	359 (63.7)	194 (69.5)	1.09 (0.99, 1.21)	0.091	385 (72.0)	180 (81.1)	1.13 (1.04, 1.22)	**0.009**
Weekday, n (%)	373 (66.1)	191 (68.5)	1.04 (0.94, 1.14)	0.500	370 (69.2)	156 (70.3)	1.02 (0.92, 1.13)	0.763
Mass shootings[a], n (%)	42 (7.4)	33 (11.8)	1.59 (1.03, 2.45)	**0.036**	55 (10.3)	24 (10.8)	1.05 (0.67, 1.65)	0.828

[a] Mass shootings are defined as events in which 4 or more individuals are shot within 100 m within 1 h.
[b] *P*-values are for rate ratios at an alpha of 0.05.

Northeastern/Eastern Philadelphia where shootings increased post-containment is a part of the city often characterized as the epicenter of Philadelphia's opioid crisis (Newall, 2021; Percy, 2018). This is the location of the city's largest open-air drug market where embedded social and structural dynamics have long coincided with exceptionally high rates of firearm violence (Friedman et al., 2019; Newall, 2021; Percy, 2018). Therefore, it is possible that the intensification of the opioid crisis during pandemic containment led to increases in firearm violence in areas where the crisis is most severe.

Our observed increase in the proportion of firearm-injured Black women and children adds to the existing evidence that Black people are disproportionately affected by firearm violence in the U.S (Beard et al., 2017; Fowler et al., 2015; Houghton et al., 2021; Jacoby et al., 2018). Structural racism, in the form of social stress, discrimination, and policies that result in racialized segregation and socioeconomic deprivation, is a fundamental driver of race-based disparities in health, including firearm violence (Beard et al., 2017; Benns et al., 2020; Formica, 2021; Jacoby et al., 2018; Khazanchi et al., 2020; Knopov et al., 2019; Wong et al., 2020). Before the onset of the pandemic, research demonstrated that socioeconomic deprivation is empirically linked with firearm violence incidence (Abaza et al., 2020; Beard et al., 2017; Choi et al., 2020; Dalve et al., 2021; Friedman et al., 2019). Increased social services, including broader access to medical assistance, have been shown to be protective (Choi et al., 2020; Sipsma et al., 2017). Nationally, COVID-19 containment measures were associated with increased levels of unemployment along with loss of income and health insurance (Gaffney et al., 2020a, 2020b; Galea and Abdalla, 2020; Matthay et al., 2021a, 2021b; Bureau of Labor Statistics, 2021; Woolhandler and Himmelstein, 2020). The findings of this study suggest that unmitigated COVID-19 containment policies, absent robust social and economic support, may have worsened structural inequities. In Philadelphia and across the U.S., the incidence of COVID-19 infection and death has been highest among Black people (Bassett et al., 2020; City of Philadelphia Department of Public Health, 2021; Gravlee, 2020; Khazanchi et al., 2020). Increasing firearm violence among Black women and children in Philadelphia is one manifestation of the differential impact of the pandemic and its containment policies on already disadvantaged Americans living in places with a long history of disinvestment.

Unprecedented increases in firearm ownership and availability since the start of the pandemic may partially explain the concurrent rise in rates of firearm injury (Donnelly et al., 2021; Hoops et al., 2020; Lang and Lang, 2021; Schleimer et al., 2021). A recent cross-sectional study of state-level firearm purchasing found that while increased purchasing may have contributed to additional firearm injuries from domestic violence, it was not associated with the magnitude of the overall increase in firearm violence observed during the pandemic (Schleimer et al., 2021). A potential explanation for this finding is that the social and structural factors which have contributed to the pandemic-related rise in interpersonal firearm violence have also contributed increased firearm purchasing, but more research on this topic is needed. Still, the rise in firearm access is noteworthy, given evidence that firearm access and possession are known risk factors for firearm injury and death (Anglemyer et al., 2014; Miller et al., 2002a, 2002b, 2002c).

4.1. Study limitations and strengths

Our study has several limitations. We included only one major U.S. city due to the limited availability of comprehensive data on non-fatal shootings on a state or national level, therefore our findings may not be generalizable to the entire U.S. population. Additionally, the PPD dataset does not include self-inflicted injuries, therefore no conclusions may be made on the epidemiology of these types of shootings. Moreover, the PPD registry of shooting victims includes only limited demographic variables about firearm-injured individuals, and does not allow for elucidation of other characteristics, such as sexual orientation, gender identity, education level, or other social determinants of health, which may affect vulnerability to firearm violence. Our study does not examine the changes in epidemiology that may be related to the lifting of COVID-19 containment policies. We did not include this analysis for several reasons. First, the easing of containment policies has occurred gradually, therefore the social and economic impacts are likely not as immediate as those seen following the enactment of containment policies. In addition, our previous research did not identify any association between the incidence of shootings and the partial lifting of containment policies in June of 2020 (Beard et al., 2021). Finally, this descriptive study cannot prove causal association between COVID-19 containment policies and the changes in firearm violence epidemiology we observed. The causes

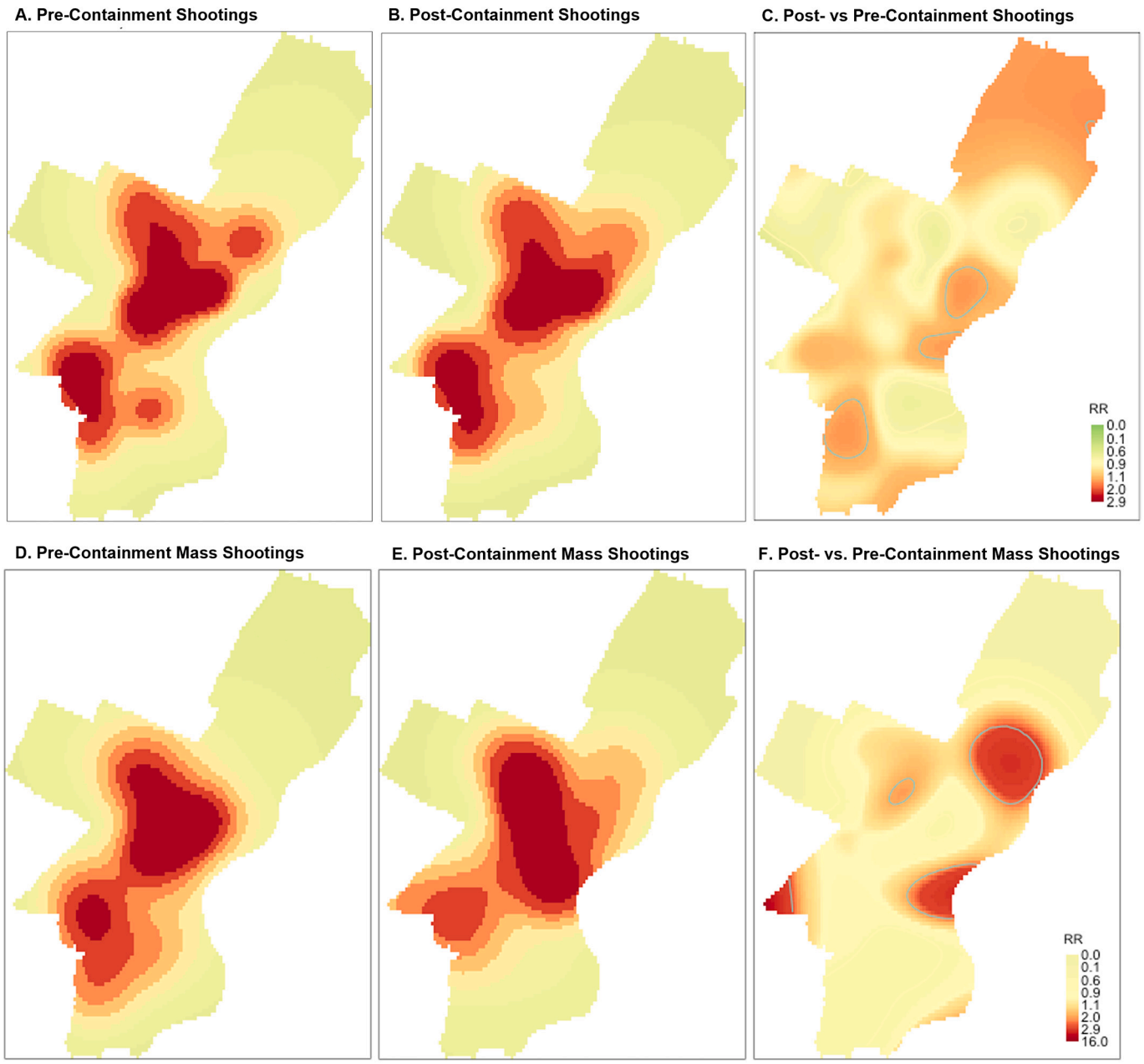

Fig. 2. Kernel density maps of all shootings pre-containment (January 1, 2015 – March 15, 2020) **(A);** all shootings post-containment (March 16, 2020 – March 31, 2021) **(B)**; ratio of shootings post-containment to pre-containment **(C)**; mass shootings pre-containment **(D)**; mass shootings post-containment **(E)**; ratio of mass shootings post-containment to pre-containment **(F)**. Mass shootings are defined as 4 or more individuals shot within 100 m within 1 h.

for these relative changes are likely multifactorial and could also include civil unrest related to the police murder of George Floyd.

Our study has a number of important strengths. The PPD registry reliably captures a greater proportion of firearm injuries compared to other available sources, such as trauma registries (Kaufman et al., 2019). Our study provides a substantive, multidimensional understanding of the shifting epidemiologic patterns of interpersonal firearm violence in Philadelphia during the COVID-19 pandemic. It is important to understand these changes in order to evaluate the indirect or unintentional harms of widespread public health containment measures and to further uncover some of the root causes of interpersonal firearm violence.

5. Conclusion

The COVID-19 pandemic and its containment policies have been associated with significant increases in firearm violence globally. In this study, we sought to explore the epidemiology of the surge in interpersonal firearm violence in Philadelphia. While our study cannot determine the causes of the changes in firearm violence epidemiology we observed, our findings suggest that containment policies likely worsened structural inequalities, ultimately increasing the risk of firearm injury for women and children, and Black women and children in particular. The increasing rate of mass shootings represents an intensification in the severity of firearm violence in Philadelphia, which will likely have a sustained impact on chronically traumatized communities in the years to come (Hoops et al., 2020; Schleimer et al., 2021). Addressing firearm violence with effective solutions requires an understanding of its root causes, and how these may have changed over time. The changes in interpersonal firearm injury epidemiology during COVID-19 containment that we observed are consistent with existing knowledge about the

structural determinants of interpersonal firearm violence, and reiterate that investment in structural solutions, including public education, employment, social support and services are required to mitigate the impact of firearm violence in the United States.

Author contributions

Dr. Afif, Ms. Gobaud, Dr. Morrison, and Dr. Beard had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Iman Afif: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Reviewing & editing, Visualization.

Ariana Gobaud: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Reviewing & editing, Visualization.

Christopher Morrison: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Reviewing & editing, Visualization, Supervision, Project administration.

Sara Jacoby: Formal analysis, Writing – Reviewing & editing.

Zoe Maher: Formal analysis, Writing – Reviewing & editing.

Elizabeth Dauer: Formal analysis, Writing – Reviewing & editing.

Elinore Kaufman: Formal analysis, Writing – Reviewing & editing.

Thomas Santora: Formal analysis, Writing – Reviewing & editing.

Jeffrey Anderson: Formal analysis, Writing – Reviewing & editing.

Lars Sjoholm: Formal analysis, Writing – Reviewing & editing.

Abhijit Pathak: Formal analysis, Writing – Reviewing & editing.

Amy Goldberg: Formal analysis, Resources, Writing – Reviewing & editing.

Jessica Beard: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Writing – Reviewing & editing, Visualization, Supervision, Project administration.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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