Temperature and firearm violence in four US cities: testing competing hypotheses

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ABSTRACT

Introduction Firearm violence is a major public health issue in the USA. There is growing evidence that firearm violence is associated with higher ambient temperatures. The aim of this study was to test competing hypotheses that could explain associations between temperature and firearm violence: temperature-aggression theory and routine activities theory.

Methods We examined associations between elevated daily temperatures and shooting incidents in four US cities: Chicago, Illinois; Cincinnati, Ohio; New York, New York and Philadelphia, Pennsylvania. Temperature was operationalised using two different measures: daily maximum temperature and deviations of the daily maximum temperature from 30-year averages. Generalised linear autoregressive moving average models related temperature to shooting incidence while controlling for seasonal effects.

Results As maximum daily temperature deviates from the expected, there was an association with increased shooting incidents in all four cities (eg, New York: b=0.014, 95% CI=0.011 to 0.017). An interaction term created by multiplying daily maximum temperature by the daily difference of maximum temperature from a 30-year average was also found to have a positive association in all four cities (eg, New York: b=0.020, 95% CI=0.016 to 0.025).

Discussion These findings accord with previous studies demonstrating a positive relationship between temperature and firearm violence and further support temperature-aggression theory as the primary causal mechanism.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Firearm violence is a serious public health issue.
⇒ There is a well-established association between rising temperatures and violence, and an emerging body of work extending this observation to firearm violence specifically.

WHAT THIS STUDY ADDS

⇒ Using data from four US cities, there is evidence that the temperature-aggression theory may be the mechanism behind the association between firearm violence and increases in average temperatures, meaning that effects are strongest on days with extremely high temperatures.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ As more days of the year continue to reach hotter than average temperatures, we can expect a further increase in firearm violence. Effective mitigation strategies will need to be informed by relevant theory.

INTRODUCTION

Firearm violence is a serious public health issue in the USA. A total of 19 384 people died and 29 317 people were admitted to emergency departments in 2021 due to interpersonal shooting events.[1] That same year, firearm-related injuries became the leading cause of death in children and adolescents.[2] This reflects the rise in firearm-related deaths in recent years. Rates have been increasing since 2015, after remaining relatively stable from 1999 to 2014.[3] Research identifies many structural factors that contribute to firearm violence, such as historical disinvestment[4] and physical disorder.[5] Another factor that may contribute to firearm violence incidence is ambient temperature.

Research has established the effects of temperature and elevated heat on violence,[6] including firearm violence.[7 8] Given rising global temperatures from climate change, even slight increases could significantly escalate shooting incidents, posing a severe public health crisis. Since the late 1800s, the planet's average surface temperature has risen by about 1°C, largely due to human activity.[9] As these warming trends continue, it is imperative to characterise the relationship between heat and firearm violence and develop mitigation strategies.

Two competing theories explain the association between heat and shootings. One is a temperature-aggression theory, which posits that hot weather contributes to interpersonal violence by increasing discomfort, impulsivity and aggression.[10] This theory would explain increases in violence in areas that are already hot and experiencing hotter-than-average temperatures. However, temperature-aggression theory does not explain increased violence in areas where higher temperatures are unlikely to cause discomfort (eg, locations where the temperature has risen from cold to warm). Another explanation, the routine activity theory, suggests that changes in ambient temperature alter people's routine activities,[11] including at lower temperatures. Under this theory, warmer temperatures increase the chances of being outside, leading to more opportunities for crime and violence to

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Table 1 Descriptive statistics of exposures of interest by US study city: Chicago, Cincinnati, New York (2010–2019) and Philadelphia (2015–2019)

	Mean (SD)	Minimum, maximum
Maximum daily temperature (◦C)		
Chicago, Illinois	15.4 (12.0)	−23.3, 39.4
Cincinnati, Ohio	18.4 (11.0)	−14.4, 45.0
New York, New York	17.7 (10.3)	−9.4, 40.0
Philadelphia, Pennsylvania	18.9 (10.5)	−8.9, 36.7
Difference from average maximum daily temperature		
Chicago, Illinois	0.01 (5.6)	−23.2, 21.1
Cincinnati, Ohio	0.3 (5.5)	−21.5, 20.7
New York, New York	0.2 (4.6)	−14.3, 30.6
Philadelphia, Pennsylvania	0.4 (5.0)	−15.3, 17.6
Daily shooting incidents		
Chicago, Illinois	6.8 (3.9)	0, 26
Cincinnati, Ohio	1.0 (1.0)	0, 6
New York, New York	3.0 (2.3)	0, 21
Philadelphia, Pennsylvania	3.6 (2.4)	0, 17

occur. Understanding the mechanism behind the relationship between heat and firearm violence is essential in the presence of rising global temperatures.

METHODS

Setting

This study included cities with populations over 300 000[12] and publicly available shooting data from their city police department. This resulted in four study cities: Chicago, Illinois; Cincinnati, Ohio; New York, New York and Philadelphia, Pennsylvania.

Data sources

We obtained daily temperature data from 1 January 2010 to 31 December 2019 from the National Oceanic and Atmospheric Administration. These were obtained from the closest first-order National Weather Service weather station to each city centroid. We extracted maximum daily temperature,[13] representing the highest temperature reported daily and US Daily Climate Normals[14] for maximum daily temperature, a 30-year average of this measure.

We acquired fatal and non-fatal shooting incidents from 1 January 2010 to 31 December 2019 from each city's police department shooting database[15–18] and calculated a count of total number of daily shooting incidents. The Philadelphia Police Department has data available starting 1 January 2015 while the remaining police departments have data available starting at least in 2010. Therefore, the analysis for Philadelphia spans 5 years (n=1826 days), and the analyses for the remaining cities consist of 10 years (n=3652 days).

Statistical analysis

Generalised linear autoregressive moving average (GLARMA) models assessed the association between daily temperature and shooting incidents for each city using the glarma package[19] in R V.4.3.[20] The models fit time series of shooting incidents that are assumed to follow a negative binomial distribution. We included year as a linear term and daily sine and cosine transformation to account for temporal trends. The trigonometric transformations were specified at time t as:

$$\sin\left(\frac{2\pi t}{365}\right) \; and \; \cos\left(\frac{2\pi t}{365}\right)$$

Table 2 Results from GLARMA models for each US study city: Chicago, Cincinnati, New York (2010–2019) and Philadelphia (2015–2019)

	Chicago, Illinois		Cincinnati, Ohio		New York, New York		Philadelphia, Pennsylvania	
		95% CI		95% CI		95% CI		95% CI
Model 1 (IRR) Maximum daily temperature (°C)	1.17***	(1.15 to 1.19)	1.10***	(1.07 to 1.14)	1.15***	(1.12 to 1.18)	1.13***	(1.09 to 1.17)
Model 2 (β coefficient) Maximum daily temperature (°C)	0.20***	(0.16 to 0.25)	0.21***	(0.096 to 0.33)	0.0013	(−0.078 to 0.10)	0.19**	(0.059 to 0.32)
(Maximum daily temperature)^2	−0.00041*	(−0.0008 to −0. 00002)	−0.00097*	(−0.0019 to −0.000015)	0.0010**	(0.00032 to 0.0017)	−0.00053	(−0.0015 to 0.00048)
Model 3 (IRR) Difference from average maximum daily temperature	1.18***	(1.16 to 1.20)	1.11***	(1.07 to 1.15)	1.15***	(1.12 to 1.19)	1.13***	(1.10 to 1.17)
Model 4 (IRR) (Difference from average maximum daily temperature)×(maximum daily temperature)	1.023***	(1.021 to 1.026)	1.015***	(1.009 to 1.020)	1.020***	(1.016 to 1.025)	1.018***	(1.012 to 1.023)

All results reported in units of 5.5°C.
*p<0.05, **p<0.01, ***p<0.001.
GLARMA, generalised linear autoregressive moving average; IRR, incidence rate ratio.

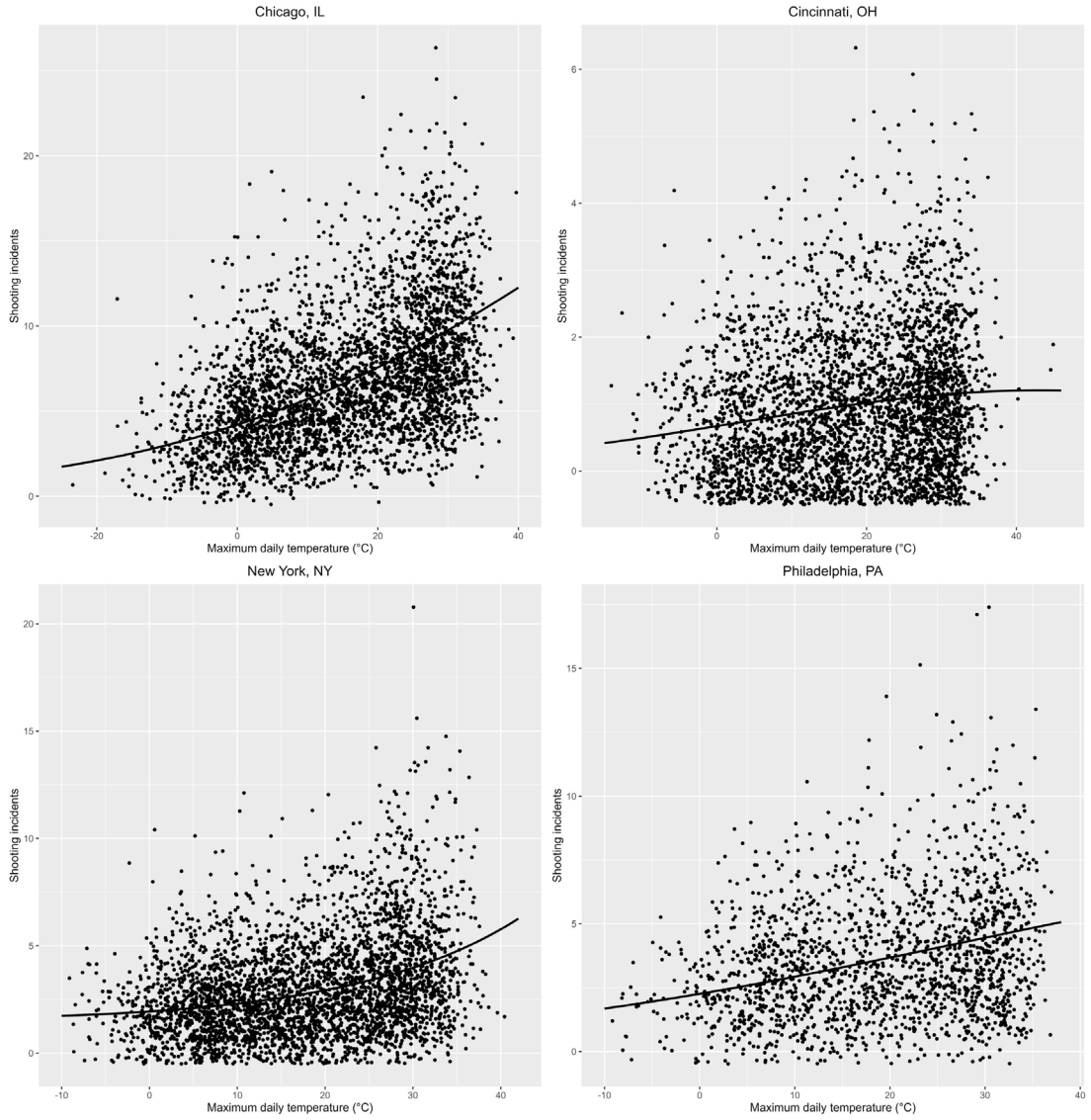

Figure 1 Estimation of shooting incident count by temperature increase overlaid on observed shooting incidents and temperature from model 2 by US study city: Chicago, Cincinnati, New York (2010–2019) and Philadelphia (2015–2019). Points have been jittered due to overplotting of discrete data.

Four models with different temperature-related independent variables for each city were used to investigate the association between temperature and shootings. Model 1 included maximum daily temperature. Model 2 used a quadratic term for daily maximum temperature to investigate possible nonlinear associations between temperature and shooting incidents. Model 3 examined the maximum temperature deviation from the average. This term was created by taking the difference of the climate normals for day-specific maximum daily temperature from the actual, observed maximum temperature on a given day. Like model 2, a sensitivity analysis was conducted to test possible nonlinear associations. For models 2 and 3, using routine activities theory, we expect these associations to follow a parabolic curve. Theoretically, at extremely low and high temperatures,

Table 3 Results from model 3 sensitivity analysis for each US study city: Chicago, Cincinnati, New York (2010–2019) and Philadelphia (2015–2019)

	Chicago, Illinois		Cincinnati, Ohio		New York, New York		Philadelphia, Pennsylvania	
	β coefficient	95% CI	β coefficient	95% CI	β coefficient	95% CI	β coefficient	95% CI
Model 2 Difference from average maximum daily temperature (°C)	0.16*	(0.14 to 0.18)	0.10*	(0.063 to 0.13)	0.15*	(0.11 to 0.18)	0.13*	(0.092 to 0.16)
(Difference from average maximum daily temperature)^2	0.0019	(–0.009 to 0.013)	0.017	(–0.009 to 0.043)	–0.010	(–0.033 to 0.012)	–0.007	(–0.034 to 0.021)

All results reported in units of 5.5°C.
*p<0.001.

shootings would decrease but during more pleasant temperatures they would increase because individuals and populations would be less likely to be outdoors during extreme temperatures. Conversely, a linear association would support temperature-aggression theory: as temperature increases, the risk of a shooting would increase. Model 4 included an interaction term which was the maximum daily temperature multiplied by the daily difference from the average term. A positive association would provide evidence for temperature-aggression theory, as it would demonstrate that shooting incidents are increased on days of high heat and not just on those with warmer-than-average temperatures.

Patient and public involvement

The public was not involved in the conduct of this study. All data are publicly available and deidentified.

RESULTS

From 2010 to 2019, there were 24 927 shooting incidents in Chicago, 3562 in Cincinnati and 11 085 in New York. From 2015 to 2019, there were 6548 shooting incidents in Philadelphia. Table 1 provides descriptive statistics for each city's daily maximum temperatures and shootings.

Table 2 presents the results by city and model. Model 1 verified the previously observed positive association between maximum daily temperature and shooting incidents in all four cities. A 5.5°C increase in maximum daily temperature was associated with a 10%–17% increase in shooting incidents.

Model 2 tested the assumption that the association between temperature and shooting incidents is linear and included a quadratic term for temperature. The model was statistically significant for Chicago and Cincinnati, but only one quadratic term was significant in New York and Philadelphia. The coefficients of the quadratic terms were log-transformed and used to create an equation estimating the number of shooting incidents for each city. Figure 1 shows the estimated equations superimposed on a plot of observed maximum daily temperatures against shooting incident counts.

For model 3, in every city, as maximum daily temperature deviates from the average there is a positive association with shootings. The association between a 5.5°C increase in the difference-from-expected maximum daily temperature ranged from an 11% (95% CI 7% to 15%) in Cincinnati to an 18% (95% CI 16% to 20%) increase in shootings in Chicago. For the sensitivity analysis, the quadratic term for the difference from the average was not statistically significant for any city (table 3).

In model 4, the interaction term was found to be positively associated with shooting incidents in all four cities. For example, in Chicago, the interaction of a 5.5°C increase in the maximum daily temperature and that day's difference-from-expected maximum temperature in units of 5.5°C was associated with a 2.3% increase in shooting incidents (95% CI 2.1% to 2.6%).

DISCUSSION

This study found that increasing ambient temperatures are associated with increased shooting incidents in Chicago, Cincinnati and New York from 2010 to 2019 and in Philadelphia from 2015 to 2019. These findings agree with previous studies documenting a positive relationship between heat and firearm violence.[7 8] Additionally, our study found that increases in maximum daily temperature from the expected average are also associated with increases in firearm violence, adding nuance to potential firearm violence mitigation strategies.

The findings from the testing of interaction terms (model 4) support temperature-aggression theory as the primary mechanism connecting temperature to firearm violence. The interaction between increasing daily maximum temperatures and increasing differences from average maximum temperature was associated with increases in shooting incidents in all four cities. This provides evidence that the association between maximum daily temperature and shooting incidents is seen primarily on days that are already elevated in heat, like the summer, and not just on days that are hotter than average. Importantly, these four cities are in a similar geographic region. These findings may differ across cities in different areas that regularly experience extremely hot days or cities that infrequently experience them.

Our analysis has some limitations to note. First, the temperature data for each city was sourced from a single weather station, which may not accurately reflect temperature variations across the city. Additionally, we used daily temperature data rather than hourly measurements. As a result, the temperature attributed to each day's shootings does not account for intraday temperature fluctuations. Such potential misclassifications could lead to an underestimation of the observed associations. Despite these constraints, our analysis benefits from the precision of the shooting incident data and the incorporation of adjustments for seasonal temperature variations, enhancing the robustness of our findings.

This study adds to the growing body of literature demonstrating a positive association between heat and firearm violence. Our findings lend support to the temperature-aggression theory as a plausible explanation for this link. As the planet continues to warm, and more days of the year are hotter than average, we can expect a further increase in firearm violence, so developing mitigation strategies will be critical. Future work should investigate interventions informed by the temperature-aggression theory.

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