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A Time Series Analysis of Associations between Daily Temperature and Crime Events in Philadelphia, Pennsylvania

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Abstract Urban crime may be an important but overlooked public health impact of rising ambient temperatures. We conducted a time series analysis of associations between temperature and crimes in Philadelphia, PA, for years 2006–2015. We obtained daily crime data from the Philadelphia Police Department, and hourly temperature and dew point data from the National Centers for Environmental Information. We calculated the mean daily heat index and daily deviations from each year's seasonal mean heat index value. We used generalized additive models with a quasi-Poisson distribution, adjusted for day of the week, public holiday, and long-term trends and seasonality, to estimate relative rates (RR) and 95% confidence intervals. We found that the strongest associations were with violent crime and disorderly conduct. For example, relative to the median of the distribution of mean daily heat index values, the rate of violent crimes was 9% (95% CI 6–12%) higher when the mean daily heat index was at the 99th percentile of the distribution. There was a positive, linear relationship between deviations of the daily mean heat index from the seasonal mean and rates of violent crime and disorderly conduct, especially in cold months. Overall, these analyses suggest that disorderly conduct and violent crimes are highest when temperatures are comfortable, especially during cold months. This work provides important information regarding the temporal patterns of crime activity.

Keywords Crime · Violent crime · Violence · Temperature · Heat index · Public health · Epidemiology · Time series analysis · Generalized additive models

In 1996, violence was designated a public health issue by the World Health Assembly [1]. Crime may lead to personal injury and loss of productivity, impose a financial burden on the medical system, disrupt families [1], contribute to declines in mental well-being [2], and lead to less physical activity among neighborhood residents [3]. In recent years, great attention has been given to the relationship between the social and built environment and criminal activity. For example, higher amounts of vegetation in a neighborhood have been shown to reduce rates of crime [4, 5]. Higher densities of transportation networks have been shown to be associated with higher rates of crime [6]. In addition to demonstrating spatial patterns, crimes have been shown to have seasonal trends [7]. Based on criminological and psychological theory, there is reason to believe that seasonal trends may be related to temperature effects [8, 9].

Whereas a large body of epidemiologic literature documents relationships between high temperatures and mortality and morbidity [10–12], less attention has been given to the relationship between temperatures and non-natural

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outcomes, including crime. Associations between heat and conflict have been documented on a large, ecologic scale (e.g., at the country level) [13–15]. In addition, psychologists and criminologists have investigated the association of temperature with aggression and crime. Several theories have been posited to explain the relationship [16]. The negative affect escape model suggests that aggressive behavior will be highest at moderate temperatures, but they will be lower at the highest and lowest temperatures because escape tendencies replace aggressive behaviors. In contrast, the simple negative affect model suggests a U-shaped relationship between temperature and crime. That is, the model suggests that aggressive behaviors occur at the coldest and hottest temperatures. Under a third theory, known as the general affect aggression model, heat is associated with physiologic changes, which lead directly to hostility and indirectly to aggression. This implies a linear relationship [17]. While these theories suggest that a relationship between temperature and aggression results from heat-related discomfort and aggression, the association between temperature and crime might also be artifactual; congregating among people in warmer temperatures and months could lead to an association between temperature and crime [17]. The latter idea conforms to the routine activities theory, which treats crimes as events that occur as a result of spatial and temporal meeting of motivated offenders with suitable targets, and during times when individuals who would prevent crimes from occurring are absent [8]. This theory was supported by a time series analysis of associations between annual temperatures and annual rates of crime. Higher temperatures were associated with higher rates of crimes that were more likely to occur when temperatures are warm and individuals leave their homes (assault, rape, robbery, burglary, and larceny), but not with murder, which the authors considered a crime of aggression [18].

The overall objective of this analysis was to investigate the association between daily temperature and daily crime rates in Philadelphia, PA. We used a decade's worth of crime data to conduct a time series analysis of associations of temperature with crime overall, and with select categories of crime. To understand the extent to which temperature anomalies affect crime incidence, we also evaluated the association of crime and deviations of daily temperature from the seasonal mean for that year. Key contributions of the present analysis include consideration of relationships at a daily rather than a larger aggregate time scale (e.g., monthly), consideration of associations with several categories of crime, and consideration of associations with daily temperature anomalies.

Methods

Data

Crime Data

We obtained Philadelphia Police Department daily crime data for January 1, 2006 through December 31, 2015 [19]. The data include information on the date that a police officer was dispatched to the scene of a crime and the type of crime. Types of crimes represented include part 1 crimes (homicide, rape, robbery, aggravated assault, burglary, and thefts) and part 2 crimes (assaults, arson, forgery and counterfeiting, fraud, embezzlement, receiving stolen property, vandalism/criminal mischief, weapon violations, prostitution and commercialized vice, other sex offenses, narcotic/drug law violations, gambling violations, offenses against family and children, driving under the influence, liquor law violations, public drunkenness, disorderly conduct, and vagrancy/loitering).

We used the published crime codes to generate the crime categories listed in Supplemental file 1. We selected categories of crime that would conform to theories on temperature and aggression, or with the routine activities theory. In addition, we selected categories of crime for which there would be sufficient statistical power to observe an effect.

Meteorological Data and Calculated Variables

Hourly temperature and dew point data recorded by the weather monitor at the Philadelphia International Airport were downloaded from the National Centers for Environmental Information [20]. The weathermetrics package in R was used to derive the heat index, which is a metric that combines temperature and dew point and was developed to represent thermal comfort [21]. The weathermetrics package uses source code provided by the US National Weather Service [21]. In addition to investigating associations of crime with daily mean heat index values, we investigated associations with daily mean heat index deviations from the yearly seasonal mean heat index value. To do this, we first calculated the average of the daily mean heat index values for each season (spring, summer, winter, and fall) during each of the study years. We then subtracted the seasonal/yearly specific mean heat index values from the daily mean heat index (daily mean heat index − seasonal mean heat index). Values greater than zero represent days on which the daily mean heat index value was higher than the seasonal mean heat index value for that year. Values equal to zero indicate that the daily mean heat index value was equal to the seasonal mean heat index value for that year.

Analysis

We calculated daily counts for each category of crime. We used generalized additive models with a quasi-Poisson outcome distribution to derive relative rate (RR) estimates and 95% confidence intervals of the association between daily heat index and crime [22]. The quasi-Poisson specification was used to accommodate overdispersion.

We ran one model for each crime category. In preliminary analyses, we explored both constrained and unconstrained lag effects of temperature. We did not observe evidence of lagged effects. Therefore, lags were excluded from the final models.

Temperature variables were modeled using a natural cubic spline with four knots to accommodate non-linearity of the relationship with daily crimes. This parameterization was selected by examining AIC statistics from preliminary exploratory models run using the Poisson distribution; the AIC statistic is not available from models run using the quasi-Poisson specification. Final models were adjusted for seasonal patterns and long-term trends by fitting a natural cubic spline with 69 knots (10 calendar years × 7) − 1. This spline function is commonly used in time series analyses of mortality; it is believed to adequately control for seasonality and long-term time trends while providing sufficient information to allow exposure effect estimation [22]. We also included terms for day of the week and for major US holidays (New Years, Independence day, Thanksgiving, Christmas day, Christmas Eve, Labor day, Easter) in all models.

In addition to evaluating associations for all of the calendar months of the year, we repeated analyses, stratified by warm (May–September) and cold months (October–April).

For calculating RR estimates and 95% CI, we used the median of the mean daily heat index as the reference temperature. We used a value of zero as the reference value for RR estimates of association with daily deviations of the mean daily heat index value from the seasonal mean heat index value. We calculated RR estimates for the 0.1, 5th, 75th, 90th, and 99th percentiles of the distributions for each temperature metric. These values were selected to represent and show the dose-response relationship between the mean heat index and crime events. The mean daily heat index and seasonal mean heat index deviation values corresponding to these percentiles are given in Supplemental Table 1.

As a sensitivity analysis, we investigated the impact of including different numbers of knots in the spline function for heat index. We also ran analyses investigating associations with maximum daily temperature, minimum daily temperature, and mean daily temperature.

All analyses were performed with the R statistical software version 0.99.891 [23]. The dlnm software package [24] was used to run the analyses.

Results

There were a total of 2,035,062 crimes in Philadelphia from January 1, 2006 through December 31, 2015 (Table 1). Approximately 40% were categorized as part 1, 60% as part 2, 22% were violent crimes, 4% were robberies, and 2% were disorderly conduct. There were approximately 20,000 crime events per year. Counts of crimes demonstrated a seasonal pattern, with peaks in the middle of the year (i.e., summer months) and the fewest crimes in the early and latest portions of the year (i.e., winter months). While this seasonal pattern

Table 1 Number of total crimes and crime categories in Philadelphia, PA, 2006–2015

	N	%
Any crime	2,035,062	
Part 1 crimes	811,037	39.9
Violent crimes	435,015	21.9
Drunk driving	49,098	2.4
Disorderly conduct	38,288	1.9
Robbery	85,032	4.2
Daily heat index	Mean	SD
Spring	15.7	6.8
Summer	25.1	3.8
Fall	10.6	6.6
Winter	2.3	5.1

remained consistent for all study years, the total number of crimes decreased steadily from year 2006 to the end of 2015 (Fig. 1).

Associations with Mean Daily Heat Index

Quantitative estimates from the primary analyses are presented in Supplemental Tables 2 and 3.

The RR of most crime categories, with the exception of robbery and drunk driving, increased in association with higher mean daily heat index temperatures until a threshold value was reached, at which point the rates remained consistent or began to decrease (Fig. 2). The relationship between the mean daily heat index and rates of all crimes, part 1 crimes, and part 2 crimes was similar in shape to relationships with disorderly conduct and violent crime (Supplemental Fig. 1). The most elevated RR estimates were for rates of violent crimes and disorderly conduct. Relative to the rate at the median of the distribution of daily heat index values, the rate of violent crimes was 8 (95% CI 6–10%) and 9% (% 6–12%) higher at the 75th and 99th percentiles of the distribution of mean daily heat index, respectively. The rate of disorderly conduct was 13% higher (95% CI 6–21%) and 7% higher (−4–19%) at the 75th and 99th percentiles of the distribution, respectively. The rate of robberies increased as temperatures increased until approximately the median of the distribution of mean daily heat index values. At higher temperatures, the relationship was close to the null.

Figure 3 shows associations between the mean daily heat index and rates of robbery, violent crime, disorderly conduct, and drunk driving, stratified by warm and cold months. Supplemental Fig. 2 shows associations between the mean daily heat index and rates of all crime, part 1 crimes, and part 2 crimes, stratified by warm and cold months. During cold months, there was a nearly completely linear relationship between the mean daily heat index and rates of disorderly conduct and violent crime. For example, at the 5th, 75th, and 99th percentiles of the mean daily heat index distribution, the rate of violent crime was 12% lower (95% CI −14%, −10%), 5% higher (95% CI 3%, 7%), and 16% higher, (95% CI 12%, 21%) than the relative to the median. The rate of disorderly conduct was 19% lower (95% CI −26%, −12%), 8% higher, (95% CI 2%, 13%), and 23% higher (95% CI 10%, 39%) compared to rate at the median distribution of the heat index during cold months. There was an approximately linear relationship between the mean daily heat index and part 1 and part 2 crimes during cold months. For warm months, RR estimates were closer to the null. RR in association with violent crimes, and with all crime, part 1 crimes, and part 2 crimes were highest at the median of the distribution of the mean heat index values.

Associations with the Seasonal Mean Heat Index Deviations

We investigated the effect of unseasonably warm or cold temperature days by subtracting the seasonal mean daily heat index value for each year from the daily mean heat index. Seasonal mean heat index deviations larger than zero represent days that were warmer than the seasonal average for that year.

There was a linear relationship between the heat index deviation value and the rate of violent crimes (Fig. 4). Relative to days that had the same mean daily

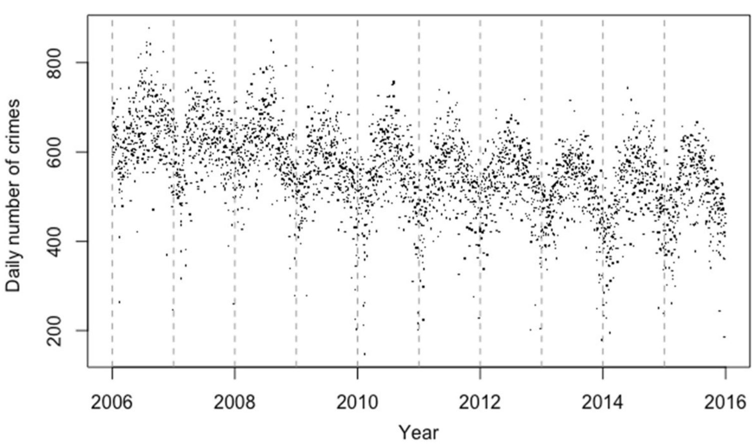

Fig. 1 Daily number of crimes in Philadelphia, PA, from January 1 2006–December 31, 2015

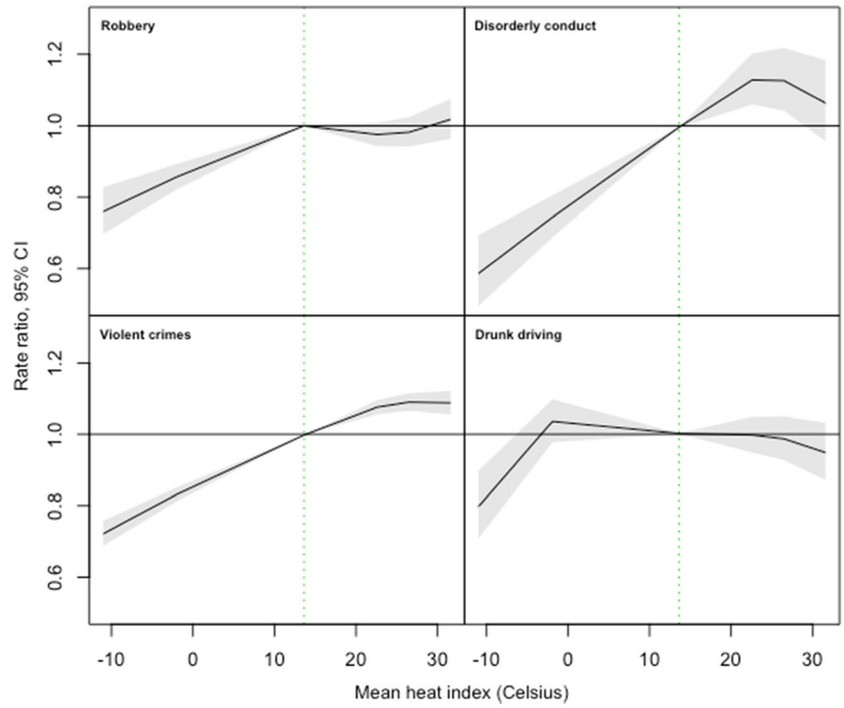

Fig. 2 Relative rate and 95% confidence intervals for the relationship between mean daily heat index and select categories of crime, Philadelphia, PA, January 1, 2006–December 31, 2015

heat index as that for the season and year, the rate of violent crimes was 5% higher for days on which the mean daily heat index was 13° higher (i.e., the 99th percentile of the distribution of temperature anomalies) than the seasonal mean (95% CI 3%, 8%). There was a linear relationship between heat index deviation values and disorderly conduct, as well. On days that were 13 °C higher than the seasonal mean daily heat index, the rate of disorderly conduct crimes was 7% higher (95% CI −1%, 15%) relative to days on which the heat index was the same as the average for that season and year. Associations between the mean heat index deviation and robbery and drunk driving were closer to the null. Relationships with part 1 crimes and part 2 crimes were approximately linear but remained close to the null when mean daily heat index values were higher than the seasonal averages (Supplemental Fig. 3).

When restricted to cold months, there was a linear relationship between the mean heat index deviation and the RR of violent crime and disorderly conduct. For example, in cold months, at the 5th, 75th, and 99th percentiles of distribution, the RR for violent crimes increased from −7 (95% CI −9%, −5%) to 2 (95% CI 1%, 3%) and 10% (95% CI 6%, 14%). The RR of disorderly conduct also increased from −12 (95% CI −8%, −6%) to 2% (95% CI −1%, 5%) and 17% (95% CI: 5%, 31%) (Fig. 5). During cold months, the relationship between seasonal mean deviation and all crimes, part 1 crimes, part 2 crimes, and robbery was approximately linear, although the RR estimates were closer to the null. When restricted to warm months, the relationship between seasonal mean heat index deviation and crime was close to the null.

Sensitivity Analyses

Relationships of maximum daily temperature, minimum daily temperature, and mean daily temperature with crime were similar to those between mean heat index and crime (Supplemental Figs. 5-7). Changing the number of knots in the spline functions for daily heat index did not have any substantial impact on the results (data now shown).

Discussion

Rates of crime, especially disorderly conduct and violent crimes, were highest when temperatures were most comfortable (mean daily heat index of 22.6–28 °C). In particular, rates of violent crime and disorderly conduct

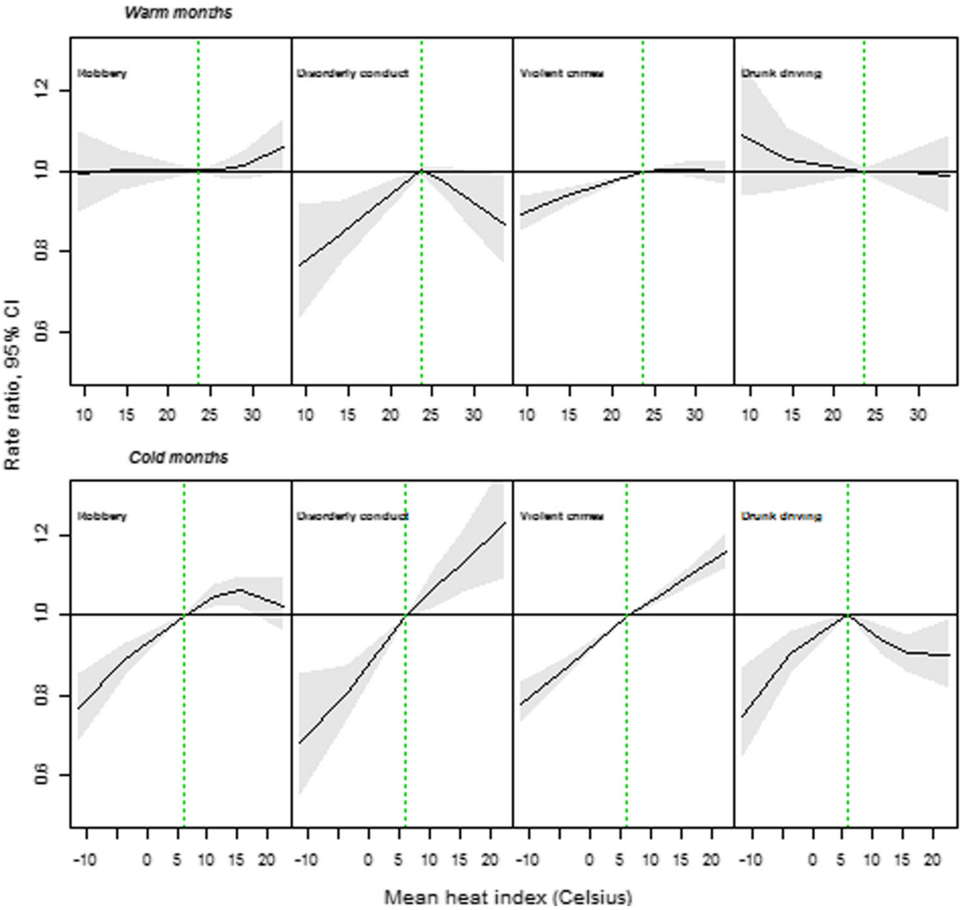

Fig. 3 Relative rate and 95% confidence intervals for the relationship between the mean daily heat index and select categories of crime, stratified by warm and cold months, Philadelphia, PA, January 1, 2006–December 31, 2015

were highest when temperatures were anomalously warm during cold months.

Similar relationships have been observed in other studies of crime and temperature. In Dallas, TX, there was a curvilinear, inverted U-shaped relationship between temperature and violence; at moderate temperatures, there was a linear relationship between temperature and higher rates of aggravated assault, homicide, and rape. At around 90 °F, this relationship became negative [25]. In Baltimore, MD, maximum temperature was associated with increased rates of total crime, violent crime, and homicides; [26] however, the authors did not investigate whether this relationship was curvilinear. In Cleveland, OH, there was a linear relationship between temperature and aggressive crime, and the most substantial association was observed with rising temperatures until approximately 18 °C [27]. In Minneapolis, a curvilinear relationship between temperature and domestic violence calls was observed. The authors found, however, that the shape of the relationship could be attributable to time of day [28].

Strengths of this work include the large dataset, which included a decade's worth of crime data, documenting over two million crime events. Our analyses adjusted for potential confounding due to long-term trends. By modeling temperature using splines, we were able to accommodate and explore non-linearity in the association between temperature and crime. An additional strength of this analysis is the inclusion of multiple categories of crime. Also, we quantified relationships of crime with daily temperature deviations, stratified by cold and warm months. This analysis provided important information about the impact of comfort and temperature anomalies on crime events.

Limitations of this work include the fact that the data only represented crimes that were reported. If there was a relationship between temperature and crime reporting,

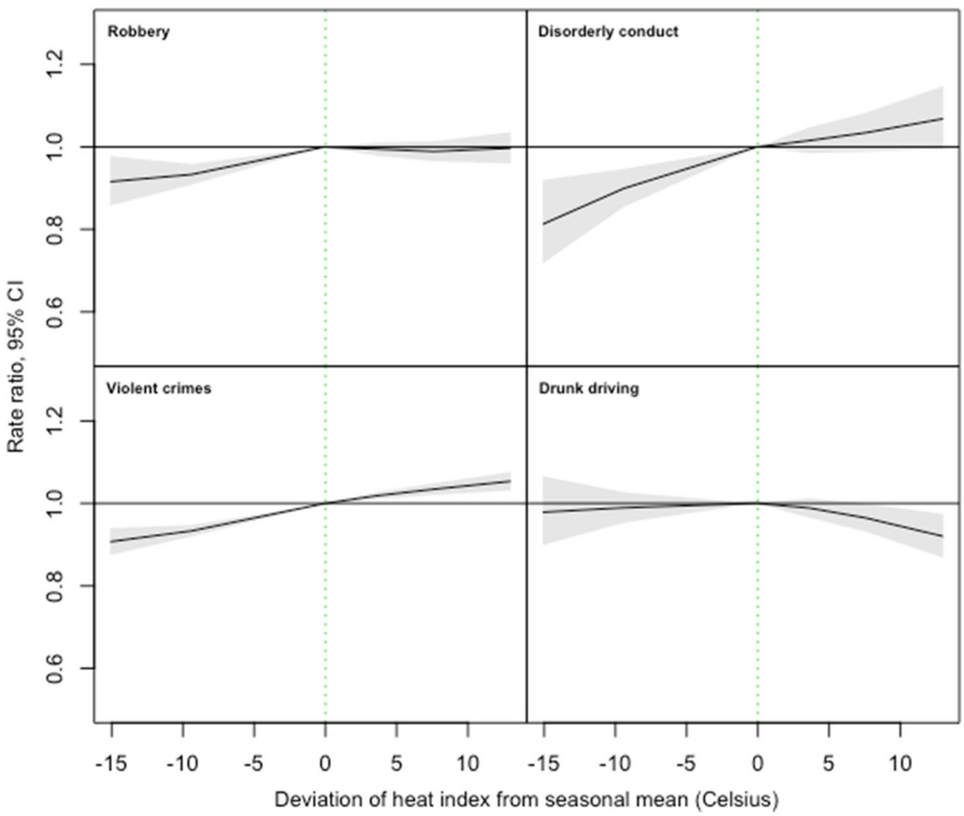

Fig. 4 Relative rate and 95% confidence intervals for the relationship between the difference of the yearly seasonal mean heat index from the daily mean heat index and select categories of crime, Philadelphia, PA, January 1, 2006–December 31, 2015

this would have biased the analysis results. Because we did not have information about the perpetrator of each crime, we were not able to investigate the potentially modifying impact of individual level sociodemographic characteristics of the relationship between temperature and crime.

In this analysis, we investigated variability in crime rates related to daily variations in temperature from the year-specific seasonal mean values. We did not investigate spatial heterogeneity in the effect of the association between temperature and crime. This will be an important extension of the analyses reported here. Indeed, the routine activity theory suggests that a convergence of a variety of factors in both space and time contributes to higher rates of crime [8]. While our analysis supports the temporal aspect of this theory, it will be interesting to extend this work to include spatial aspects, as well. Information about spatial heterogeneity in the association between temperature and crime could provide insight into the mechanisms that underlie the relationship and could have implications for structural and social preventative measures that can be taken to prevent crime. A handful of studies considered the combined effects of temperature and neighborhood level characteristics on crime. In St. Louis, temperature anomalies, defined as higher temperatures than the seasonal long-term average, were associated with higher monthly rates of violence, especially in the most socially disadvantaged neighborhood groups [29]. In analysis of the relationship between monthly mean temperature and monthly street robbery events in Philadelphia, there was intra-urban variability in the relationship, with a stronger, positive relationship between higher temperatures and robbery in higher SES neighborhoods [30].

Results from these analyses have relevance to the interpretation and conduct of epidemiologic analyses on the impacts of temperature. Most of the epidemiologic literature has focused on respiratory and cardiovascular health impacts of extreme temperatures.

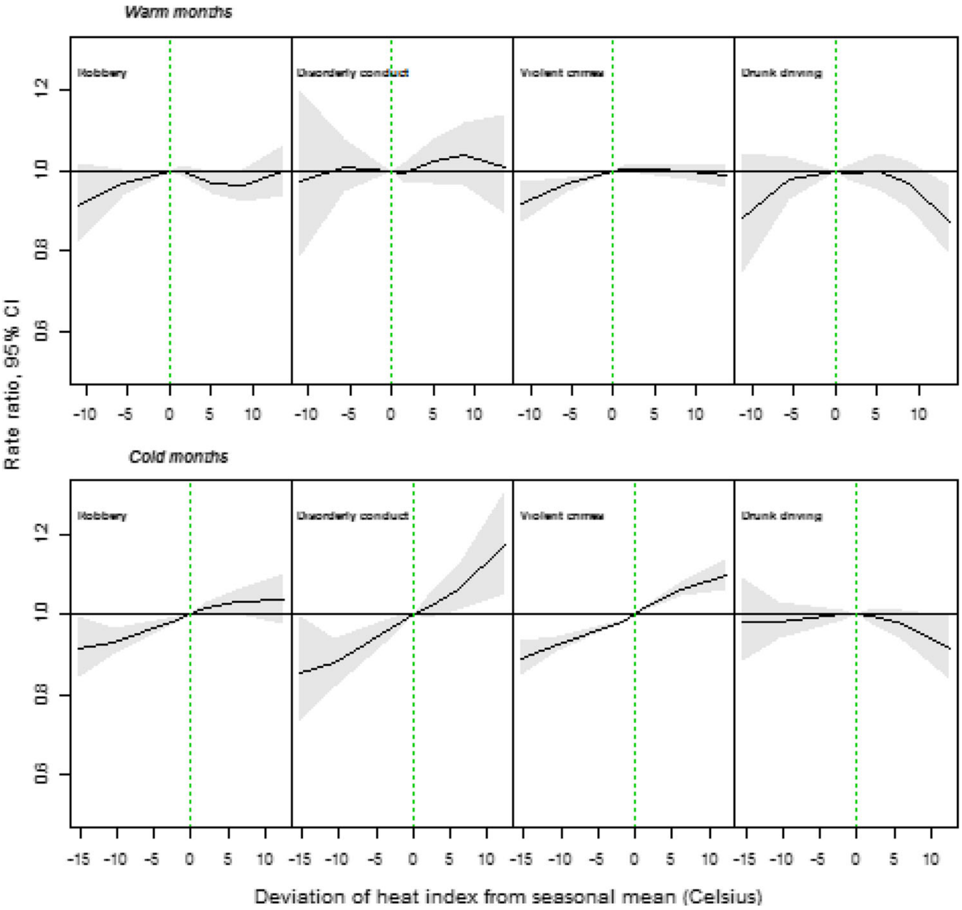

Fig. 5 Relative rate and 95% confidence intervals for the relationship between the difference of the yearly seasonal mean heat index from the daily mean heat index and select categories of crime, Philadelphia, PA, January 1, 2006–December 31, 2015, stratified by warm versus cold months

Additionally, many epidemiologic analyses are restricted to natural cause mortality; non-natural and accidental cause mortality cases are often excluded. [10] However, this restriction ignores the potential impacts of temperature on crime and other behavioral factors, which might lead to non-natural cause morbidity and mortality.

This work is particularly relevant considering our earth's well-documented warming temperatures. NASA reported that year 2016 experienced the hottest February on record; global land surface temperatures were 3.2 °C higher than the twentieth century mean [31]. In its fifth assessment, the IPCC projected that temperatures for the months of December, January, and February would warm from 0.3 to 1.8 °C [32]. These analyses suggest the need to understand how temperature anomalies in combination with structural and social factors impact the incidence of crime.

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References

1. Krug EG, Mercy JA, Dahlberg LL, Zwi AB. The world report on violence and health. *Lancet*. 2002;360(9339): 1083–8.
2. Dustmann C, Fasani F. The effect of local area crime on mental health. *Econ J*. 2016;126(593):978–1017.
3. Evenson KR, Block R, Diez Roux AV, McGinn AP, Wen F, Rodriguez DA. Associations of adult physical activity with perceived safety and police-recorded crime: the multi-ethnic

study of atherosclerosis. *The International Journal of Behavioral Nutrition and Physical Activity*. 2012;9:146.

4. Garvin EC, Cannuscio CC, Branas CC. Greening vacant lots to reduce violent crime: a randomised controlled trial. *Inj Prev*. 2013;19(3):198–203.
5. Wolfe MK, Mennis J. Does vegetation encourage or suppress urban crime? Evidence from Philadelphia, PA. *Landsc Urban Plan*. 2012;108(2–4):112–22.
6. Du Y, Law J. How do vegetation density and transportation network density affect crime across an urban central-peripheral gradient? A case study in Kitchener-Waterloo, Ontario. *Isprs Int J Geo-Inf*. 2016;5(7):118. doi:10.3390/ijgi5070118.
7. Linning SJ, Andresen MA, Brantingham PJ. Crime seasonality: examining the temporal fluctuations of property crime in cities with varying climates. *Int J of offender therapy and comparative criminology*. 2016. doi:10.1177/0306624X16632259.
8. Miro F. Routine activity theory. The encyclopedia of theoretical criminology. 2014:1–7. doi:10.1002/9781118517390.wbetc198.
9. Anderson CA, Anderson DC. Ambient temperature and violent crime: tests of the linear and curvilinear hypotheses. *J Pers Soc Psychol*. 1984;46(1):91–7.
10. Basu R. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environ Health*. 2009;8:40.
11. Basu R, Pearson D, Malig B, Broadwin R, Green R. The effect of high ambient temperature on emergency room visits. *Epidemiology*. 2012;23(6):813–20.
12. Green RS, Basu R, Malig B, Broadwin R, Kim JJ, Ostro B. The effect of temperature on hospital admissions in nine California counties. *Int J Public Health*. 2010;55(2):113–21.
13. Hsiang SM, Burke M, Miguel E. Quantifying the influence of climate on human conflict. *Science*. 2013;341(6151):1235367.
14. Hsiang SM, Burke M. Climate, conflict, and social stability: what does the evidence say? *Clim Chang*. 2014;123(1):39–55.
15. Hsiang SM, Meng KC, Cane MA. Civil conflicts are associated with the global climate. *Nature*. 2011;476(7361):438–41.
16. Anderson CA. Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. *Psychol Bull*. 1989;106(1):74–96.
17. Anderson CA. Heat and violence. *Curr Dir Psychol Sci*. 2001;10(1):33–8.
18. Rotton J, Cohn EG. Global warming and U.S. crime rates: an application of routine activity theory. *Environ Behav*. 2003;35(6):802–25.
19. Philadelphia Co. OpenDataPhilly. https://www.opendataphilly.org Accessed 10 Jan 2017.
20. Information NNCfE: Datda access. https://www.ncdc.noaa.gov/data-access (2016). Accessed 12 Feb 2016.
21. Anderson BG, Bell ML. Methods to calculate the heat index as an exposure metric in environmental health research. *Environ Health Perspect*. 2013;121(10):1111–9.
22. Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. *Int J Epidemiol*. 2013;42(4):1187–95.
23. RStudio: Integrated Development for R. *Computer program.* Boston, MA: RStudio, Inc; 2015.
24. Gasparrini A. Distributed lag linear and non-linear models in R: the package dlnm. *J Stat Softw*. 2011;43(8):1–20.
25. Gamble JL, Hess JJ. Temperature and violent crime in Dallas, Texas: relationships and implications of climate change. *West J Emerg med*. 2012;13(3):239–46.
26. Michel SJ, Wang H, Selvarajah S, et al. Investigating the relationship between weather and violence in Baltimore, Maryland, USA. *Injury*. 2016;47(1):272–6.
27. Butke P, Sheridan SC. An analysis of the relationship between weather and aggressive crime in Cleveland, *Ohio. Weather Clim Soc*. 2010;2(2):127–39.
28. Rotton J, Cohn EG. Violence is a curvilinear function of temperature in Dallas: a replication. *J Pers Soc Psychol*. 2000;78(6):1074–81.
29. Mares D. Climate change and levels of violence in socially disadvantaged neighborhood groups. *J Urban Health*. 2013;90(4):768–83.
30. Sorg ET, Taylor RB. Community-level impacts of temperature on urban street robbery. *J Crim Just*. 2011;39(6):463–70.
31. State of the climate: global analysis for February 2016. http://www.ncdc.noaa.gov/sotc/global/201602 (2016). Accessed 17 Jan 2017.
32. IPCC. Climate change 2014: synthesis report. *Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Switzerland: IPCC;2014.