Climate Change, Temperature, and Homicide: A Tale of Two Cities, 1895–2015

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ABSTRACT

It has been argued that the temperature increase caused by anthropogenic climate change will produce a significant increase in violent crime. Support for that prediction is often based on statistical analyses of seasonal temperature and crime data cycles across days, months, and quarters and sometimes on large geographic areas. Within-year temperature changes are very large, however, relative to the 30-yr temperature increases employed to measure climate change. In addition, because temperature trends associated with climate change vary geographically, analyses should employ small geographic units for which temperature changes are measured over yearly intervals and for long periods of time. To address these conditions, this study examined the long-term temperature–crime association for homicides in New York and London for 1895–2015. Consistent with previous studies examining seasonal weather and crime patterns, we found a positive correlation between annual homicide rates and temperature, but only at the bivariate level. This relationship became statistically insignificant in both New York and London when gross domestic product is controlled. Moreover, the bivariate relationship between temperature and homicide is statistically insignificant when correcting for nonstationarity. Thus, it does not appear that climate change has led to higher rates of homicide in New York and London over the long term. These nonfindings are important because they suggest that studies of climate change and violence might do well to consider alternative mechanisms that mediate the relationship between climate change and violence.

1. Introduction

Research on the social impact of anthropogenic climate change suggests that long-term temperature increases could contribute 35 000 murders to the U.S. crime rate over the next 90 years (Ranson 2014). This finding and similar empirical studies are attracting significant attention among criminologists (Agnew 2012; Pease and Farrell 2011; White 2016). Agnew (2012), for example, argued that climate change might affect the temperature–crime relationship through several mechanisms, producing more crime in the future. Many studies address the temperature–crime association using seasonality analysis, that is, by examining the temperature–crime relationship within years or across months (Andresen and Malleson 2013; Cohn and Rotton 2000; Mares 2013; McDowall and Curtis 2015; Ranson 2014), or over short periods of time. One of the assumptions made from those results is that seasonal cycles can be generalized to suggest what might happen to crime during longer-term climate change–temperature cycles. Climate change cycles, however, occur over decades, and involve much smaller changes in temperature over time than the temperature change found within annual cycles. Reflecting this observation, the World Meteorological Association established the now widely accepted standard for assessing climate change effects as including

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30 years of data (Guttman 1989). Thus, longer time series temperature–crime models are required to assess the possible climate change–temperature–crime relationship. Few studies, however, examine the association between warming and crime over the long-term using annual change data (Rotton and Cohn 2003). The present study addresses the above observations by assessing 121 years of homicide and temperature data from two cities, New York (New York) and London (United Kingdom). Studying yearly temperature and homicide data over a significant period of time at lower levels of aggregation provides unique insight into the potential effect of anthropogenic climate change on violent crime.

For the purposes of the current study, we draw upon the work of Anderson et al. (2000, p. 65) and describe the relationship between temperature and violence as the ''heat hypothesis,'' which suggests that warmer temperatures lead to violence. Our annual analysis of the heat hypothesis begins with an examination of two important concepts that impinge on that suspected relationship: weather and climate, and we look at the difference between them. Next, we review existing studies of weather and climate that test the heat hypothesis in the case of homicide. We then empirically analyze the proposed hypothesis with respect to homicide to see if it stands up to empirical scrutiny in the cases of New York and London between 1895 and 2015. We conclude with some important observations about the potential role of climate change on homicide.

2. Weather versus climate

Two scientific concepts are important in the study of temperature and violence: weather and climate. One major distinction between weather and climate is time. Weather is typically defined in terms of conditions of the atmosphere such as humidity, precipitation, wind, temperature, and atmospheric pressure over a short time period, whereas climate refers to those conditions over a long period, usually a minimum of 30 years (Rohli and Vega 2017, p. 273). Thus, one (but certainly not the only) way that climate can be conceptualized is as the average atmospheric conditions in weather over a substantial period of time. Bryson (1997, p. 450) points out, for example, that an older definition of climate by Huschke (1959) identified it as the '''synthesis of weather',' and it is '''represented by the statistical collective of its weather conditions during a specific interval of time (usually several decades)'.'' Bryson, however, argues that climate is more than the aggregation of weather: it ''is the thermodynamic/hydrodynamic status of the global boundary conditions that determine the concurrent array of weather patterns'' (p. 451). Moreover, he states that, given these observations, ''the history of climate is a nonstationary time series'' (p. 454).

Distinguishing between weather and climate is important to criminological studies of the heat hypothesis. For instance, if criminologists study the heat hypothesis using daily, weekly, monthly, or quarterly data then they are likely interested in some aspect of how weather impacts crime. Alternatively, if criminologists study the heat hypothesis using data collected annually over a long time period then they are likely interested in how some aspect of climate affects crime. To be sure, criminologists have studied variations in weather to draw conclusions about variations in climate (e.g., Ranson 2014). Criminologists also examine patterns and trends in weather events such as heat waves or deviations from average weather (i.e., climate) when examining homicide (Mares 2013). Nevertheless, weather and climate are different concepts, and we suggest that both types of data should be analyzed if the heat hypothesis is to be extended to understand the impact of climate change on violent crimes like homicide. Annual, time series studies of the temperature–violence hypothesis are much less common in the criminological literature as will be demonstrated below, but they have important implications for the study of climate change. It is within this backdrop of weather and climate that we now review the previous studies on this issue, noting whether the heat hypothesis has been examined using climate or weather.

3. Level of analysis

To examine the relationship between climate and crime, researchers must make a decision about the appropriate level of analysis for assessing that relationship. The level of analysis question is important because climate change, though sometimes referred to as global warming to indicate the average long-term trend in temperature, does not occur uniformly geographically. In climate change studies, the use of a level of analysis with large geographic boundaries may mask climate variations that occur within a larger geographic areas (e.g., within countries or states; Ahmed et al. 2013). It is plausible that within a country, for example, local temperatures may be rising at different rates, remaining stable, or even cooling while the global temperature trend increases (Ahmed et al. 2013). To take that possibility into account or to eliminate using the average temperature for a large area to represent all locales within that area, we selected cities as a more appropriate level of analysis. The focus on cities also makes sense with respect to the study of crime. Most crime (80% or more) occurs in urban areas. Thus, if crime is influenced by social, economic, or other conditions (i.e., weather), focusing on cities eliminates the need to control for various factors that differ between rural and urban areas.

4. Background

The relationship between temperature and crime has a rich history within the social sciences dating to the 1800s and the work of the moral statisticians [Quetelet (1984); for a review, see Hipp et al. (2004)]. Quetelet (1984) suggested that more violent crimes occurred during summer when it was warmer (see also Cohn and Rotton 2000; Rotton and Cohn 2000). A more extensive study of weather and crime examining seasonality variations in assaults, temperature, barometric pressure, humidity, wet days, and sunny days versus cloudy days was undertaken by Dexter (1904) in his book, *Weather Influences.* These early observations provided the foundation for a substantial body of social science literature on the heat hypothesis. The idea that warmer temperatures lead to crime is grounded in two different mechanisms (Field 1992, 340–341; see also Agnew 2012). One mechanism suggests that warmer temperatures produce aggression directly in individuals, through a ''psychological or physiological response'' (Field 1992, p. 340), or ''through strain or stressors conducive to crime'' (Agnew 2012, p. 27). That is, hot temperatures cause a type of discomfort that may make people behave aggressively. Agnew (2012, 27–29) includes other climate change–related stressors here, such as floods, hurricanes, droughts, forest fires, blackouts, increased sea levels, food and freshwater shortages, potential increases in poverty and economic inequality, and forced migration. Agnew (2012, p. 31) added that climate-induced strain may also promote crime through low self-control, noting that those with low self-control may be more susceptible to climate-related strain, increasing the likelihood of crime among some individuals. This heat-hypothesis mechanism is oriented toward individual behaviors, and therefore includes studies that are focused on diverse forms of violent indicators that range from aggressive driving to retaliatory conduct by sports athletes in times when heat can be measured around individuals on hot days or in laboratory conditions. Kenrick and MacFarlane (1986) found that individuals were more likely to assertively ''honk'' their car horns in warmer weather. Larrick et al. (2011) revealed that professional baseball pitchers in the United States are more likely to purposefully hit batters with a pitched ball on hot days. The hit-by-pitch effect was especially pronounced when the pitcher's teammates were previously also hit by a pitch thrown by the opposing team earlier in the game. Thus, Larrick et al. (2011, p. 423) suggest that high temperatures are especially important for lower inhibitions against retaliatory violence. These same types of heat effects and propensity for retaliatory violence have been found in other sports such as American football (Craig et al. 2016) and therefore appear to be generalizable across different settings and conditions.

A second proposed theoretical mechanism that supports the heat hypothesis is that ''temperature affects aggression indirectly, through an effect on some [other] aspect of social behavior'' (Field 1992, p. 341). For example, people spend more time away from home when the weather is warm, increase their interactions with others, which increases the probability of violent interactions. Rotton and Cohn (2000, 2003) demonstrate how this theoretical interpretation of the heat effect is consistent with the routine activities theory perspective developed by Cohen and Felson (1979) and then argued that temperature can alter social interactions to make violence more likely. Both the individual and social explanations for the heat hypothesis make it clear that warmer temperatures should lead to more violent crime through the stimulation of aggressive behavior, strain, or changes in routine activities. That change in behavior, we suggest, requires large or noticeable changes in temperature that are more likely to be witnessed within a year (i.e., seasonally) than over a long period of time, since temperature change is smaller over longer periods of time (e.g., the mean change in temperature over 30 years).

The general assumptions behind the heat hypothesis have been widely assessed in criminological studies. Anderson and Anderson (1984) conducted one of the first empirical studies of the heat hypothesis in the United States, assessing temperature and assaults over a 90-day period in Chicago, Illinois, and temperature and ''aggressive'' (murder and rape) and ''nonaggressive'' (robbery and arson) crimes over a 2-yr period in Houston, Texas. Controlling for other factors, they found a linear relationship between these crimes and ambient air temperature in both locations. In a latter study, Anderson et al. (1997) examined the relationship between temperature and crime across the 50 largest U.S. metropolitan areas, 1950–95, and ''found that hotter years produced higher rates of serious and deadly assault even when age distribution, year effects, time series factors, and poverty rates were statistically controlled'' (p. 1219). In doing so they suggest that due to the method employed, ''[t]hese results cannot be interpreted in terms of seasonal events (a problem with earlier time period studies) or in terms of a culture of honor (a problem with some geographic region studies)'' (p. 1219).

More-recent studies examining the heat hypothesis focus on making comparisons over time using quarterly or monthly observations for cities or metropolitan areas. Research by Cohn and Rotton (Cohn and Rotton 2000; Rotton and Cohn 2000, 2003) suggests that there is a heat effect that can be observed for seasonal fluctuations in temperature and crime. Specifically, the researchers document heat effects by studying calls to police to report burglary, robbery, and theft in Minneapolis, Minnesota, each day between 1 January 1987 and 31 December 1988, and calls to police to report assaults in Dallas, Texas, between 1 January 1994 and 31 December 1995. In Minneapolis, the researchers found that higher temperatures were associated with more burglaries, robberies, and thefts. In Dallas, they found that warmer temperatures were linked to higher numbers of aggravated assaults for the low end of the hot temperatures and were linked to lower numbers of aggravated assaults at the higher end of hot temperatures. This finding led Rotton and Cohn (2000) to suggest that there is an inverted U-shape association between temperature and assault because more extreme hot temperatures may *reduce* social interactions and hence the probability of assault. They found that this nonlinear relationship was most predominant during daylight hours and in the spring.

Another set of studies examine the impact of temperature on crime over the long-term, using annual temperature and crime data. This second set of studies have more direct implications for climate change as they control for seasonal oscillations in temperature to test the heat hypothesis over the long term. For instance, Ranson (2014) focuses on estimating the potential impact of climate change on crime by examining the association between low and high temperature bands and crime for U.S. counties using monthly crime and temperature data over a 50-yr period in the previous century (1960–2009). Ransom found that fixed-effects regression suggests that cooler temperatures reduce crime. Based on that finding, he argued that as cooler days are reduced by long-term changes in the climate, the United States would be expected to experience an ''additional 35,000 murders, 216,000 cases of rape, 1.6 million aggravated assaults, 2.4 million simple assaults [and] 409,000 robberies between the years of 2010 and 2099'' (Ranson 2014, p. 23). Mares (2013) also use monthly crime and temperature data between 1990 and 2009 to examine the heat hypothesis in Saint Louis, Missouri. To draw conclusions about the effects of climate (as opposed to weather), Mares examines ''temperature anomalies'' or deviations from the average monthly temperature over past years to adjust for seasonality effects. The results suggest that temperature anomalies that are higher than average are positively related to violent crime. Each degree Fahrenheit increase in temperature is associated with a 0.689 percentage increase in overall levels of crime (Mares 2013). Anderson and DeLisi (2011) examined the heat hypothesis by looking at the average annual temperature between 1950 and 2008 for the entire United States. They found an overtime temperature effect on both violent crime (homicides plus assaults) and nonviolent crimes (burglary plus motor vehicle theft), and note that a 1°F increase in temperature is associated with 4.19 additional violent crimes per year per 100 000 population (Anderson and DeLisi 2011, p. 253).

Field (1992) discovered that while temperature was consistently and positively related to violent crime when examined as a function of weather in both month-to-month and quarter-to-quarter data, the same relationship was not observed for yearly data in England and Wales (1947–87). Field suggested that this inconsistency may result because there is ''insufficient variability in annual weather data'' to identify any heat effects (Field 1992, p. 345). Using annual average temperature and crime data for the United States as whole (1950–99) and for individual states using within-state analysis (1960–98), Rotton and Cohn (2003) found 1) no relationship between temperature and homicide at the aggregate level, 2) an association between temperature and assaults at the aggregate level, 3) no association between murder and temperature within states, and 4) a positive association between temperature and assault, rape, and robbery within states.

More recently, in a direct attempt to test the heat hypothesis using annual climate data over time and different settings, Mares and Moffett (2016) examine the relationship between average annual temperature and homicide rates in 57 countries between 1995 and 2012 using multilevel modeling to account for within and between country changes in homicide. The researchers discovered that ''each Celsius [degree] increase in the average annual temperature is associated with a nearly 6% average increase in homicides'' (Mares and Moffett 2016, p. 297). They point out that these results are not consistent across global geographic regions and that countries in warmer climates are likely to face higher levels of violence because of future climate change.

Overall, then, seasonal studies provide support for the heat hypothesis, especially when monthly and quarterly data are used to examine the relationship between temperature and violence, while there is less support for the temperature–crime association using annual time series analysis. Monthly or quarterly weather data are, nevertheless, often used to imply that climate change could lead to increasing rates of crime over the long term. When annual temperature and crime data are used to examine the heat hypothesis, however, support for that hypothesis is mixed.

Given the above, it is important to continue to test the heat hypothesis over a variety of historical periods and settings. The current research adds to that body of scholarship by examining the heat hypothesis over 121 years in cities in two countries. Following prior theoretical propositions (e.g., Agnew 2012; White 2016) and considering the results from prior empirical studies, it can be hypothesized that annual temperature changes are expected to be positively correlated—either because of physical or social mechanisms—with homicide rates between 1895 and 2015 in London and New York. We study over 100 years of annual crime and temperature data because that period maximizes variability associated with average temperature changes (e.g., New York ranges from 50.7° to 57.3°F and London ranges from 47.3° to 51.7°F) and, given that existing studies find a temperature effect, is certainly large enough to adequately test the heat hypothesis in the case of homicide.

5. Data and methods

This study draws upon the notion of climate change (i.e., long-term changes in average weather) to test the heat hypothesis in the case of homicide in two different cities—London and New York. Drawing upon evidence from previous studies, it can be hypothesized that there will be a positive relationship between violence and temperature over the long run. This relationship has not been widely examined using time series data that employs a minimum of 30 years of temperature data necessary to measure climate change as suggested in climatology research [Guttman (1989); for exceptions, see Anderson and DeLisi (2011) and Rotton and Cohn (2003)]. It is entirely plausible, given that crime trends fluctuate over time, that evidence of an association between climate and crime may be an outcome of the time period employed for examination. The use of a long time series also allows for assessment of trends and the use of methods that correct for nonstationarity and heterogeneity (see below) to provide a better assessment of this relationship.

To assess the heat hypothesis, we use time series analysis (described below) to examine the correlation between annual mean temperature and homicide trends in New York and London between 1895 and 2015. We examined these two cities because they are, perhaps, the only cities in the world with temperature and homicide data over such an extended period. We obtained an estimate of homicide for each year for New York ($n = 121$) and for 86% of the years for London ($n = 105$). Climate data were available for each year ($n = 121$) for both London and New York.[1]

The homicide data come from three sources. Estimates of homicide rate between 1895 and 1962 in New York and London were derived from the Interuniversity Consortium for Political and Social Research's study number 03226 entitled ''Homicides in New York City'' (Monkkonen 2001). Homicides in New York City provides one of the best historical account of homicides and is one of the few time series datasets that record homicide as far back in time as 1895. These homicide data were supplemented with more-recent data obtained from the Federal Bureau of Investigation's Uniform Crime Reports online database system. Homicide data for London were drawn from the U.K. Home Office ''Historical Crime Data in England and Wales.''

As Fig. 1 reveals, homicide rates in New York are higher than homicide rates in London. However, in both cities homicide rates generally increased over the previous century, with spikes in homicide occurring in both New York (1975–90) and London (1985–2000). In addition, in both cities the homicide rate has declined significantly over the past 20–30 years. In both cities the downward trend is the opposite of the trend one would hypothesize from a temperature–crime hypothesis.

Data on temperature represent annual averages in degrees Fahrenheit (°F) in each city. These data come from two sources. For New York, historical temperature data come from the National Centers for Environmental Information online database back to 1895. Annual data for temperature in London come from the Met Office's Hadley Centre database, known for having one of the longest-running series of temperature data in the world.

Figure 2 suggests that the average annual temperatures in both New York and London have generally increased over time. As a hypothesis, that increase should lead to increasing rates of violent crime (Anderson and DeLisi 2011; Anderson et al. 1997;

[1] We did not interpolate missing homicide data for London presented in Fig. 1 or in the regression analyses results presented in Tables 1–3. Thus, in Fig. 1 and Table 1 results are for 105 yr of homicide data in London (i.e., 16 yr of homicide data are missing). Results in Tables 2 and 3 are based on first-order differences, and so 20 first-order-difference scores are missing for London and 1 first-order-difference score is missing for New York. To determine whether missing homicide rates could affect findings for London, we interpolate missing homicide rates for the 16 yr of missing data 1) using linear estimates between the nonmissing scores and 2) by multiple imputation or the ''mi'' command in the Stata software package. Re-estimating the models with imputed homicide data in London did not change the results: coefficients and standard errors remained nearly identical for the linear and imputed models of missing data.

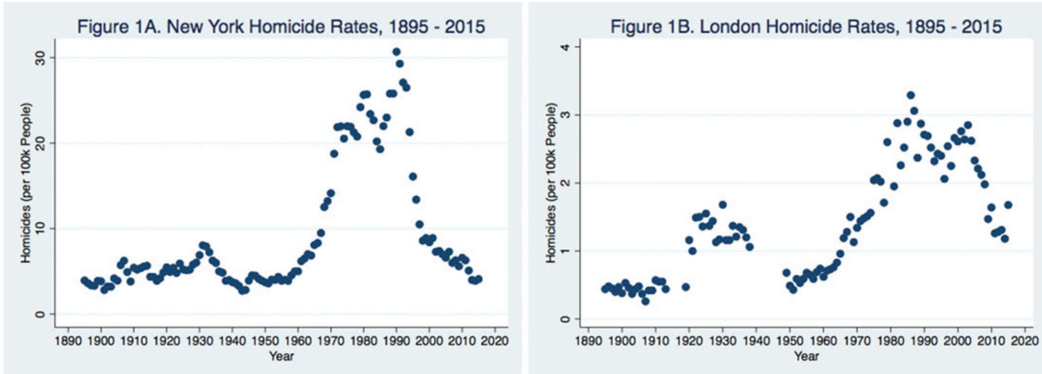

FIG. 1. Homicide rates per 100 000 residents in (a) New York and (b) London, 1895–2015.

Cohn and Rotton 2000; Mares 2013; Ranson 2014; Rotton and Cohn 2000). The temperature trends in Fig. 2 are consistent with patterns observed in global temperature changes. In New York, the average temperature between 1895 and 1920 was 53.3°, and 55.5°F between 1990 and 2015, or about 2.2° different. The lowest average annual temperature in New York occurred in 1917 (50.7°F), and the highest average New York temperature occurred in 2012 (57.3°F). In London, the annual average temperature has also increased from 48.7°F between 1895 and 1920, to 50.3°F between 1990 and 2015. Relative to New York, London's temperature change of 1.6°, was lower. The coldest average temperature occurred in 1919 (47.3°F), and the highest average temperature occurred in 2014 (51.7°F). These differences are expected, and consistent with long-term temperature anomaly data maintained by several organizations (1880–2014). Global temperature anomalies are estimated against the mean base temperatures from 1951 to 1980. Three general periods in temperature anomalies are visible for the 1880–2014 series. Anomalies were below ''0'' from 1880 to about 1938; moved around ''0'' from 1939 through about 1976 and showed a positive upward trend from 1977 on (https://earthobservatory.nasa.gov/world-of-change/DecadalTemp).

It is difficult to obtain additional variables that might impact estimates of the relationship between temperature and homicide over the entire period of data obtained for London and New York because there are significant changes in data collection over the course of a century in each city. We did, however, obtain an indicator of gross domestic product (GDP) for the countries in which these cities were located. GDP represents a measure of expenditures on personal consumption, investment, government spending, and exports in each country (the United States and United Kingdom) and has been linked to, or widely included in, studies of crime in prior research (Lynch et al. 2000; Nadanovsky and Cunha-Cruz 2009; Pridemore 2008). GDP is per capita real GDP (reference year 1990) in U.S. dollars for New York and London and is drawn from the Maddison Project (http://www.ggdc.net/maddison/maddison-project/home.htm), which estimates GDP for

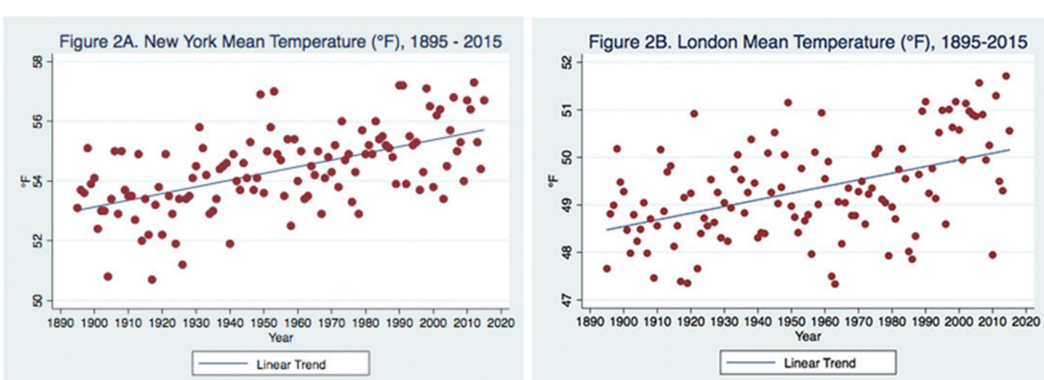

FIG. 2. Mean temperature in (a) New York and (b) London, 1895–2015.

TABLE 1. OLS estimates of the effect of temperature on homicide rates in New York and London, 1895–2015. Standard errors are in parentheses. A triple asterisk indicates significance at the $p < 0.001$ level; a double asterisk indicates significance at the $p < 0.01$ level, and no other results are significant at the $p = 0.05$ level or better.

	New York		London	
	Model 1	Model 2	Model 1	Model 2
Temperature	1.697*** (0.485)	0.548 (0.557)	0.293*** (0.0710)	0.000 083 4 (0.0658)
GDP		0.303*** (0.0823)		0.0846*** (0.0103)
Constant	−82.99** (26.39)	−24.74 (29.66)	−13.05*** (3.505)	0.465 (3.188)
N	121	121	105	105
R-square	0.093	0.187	0.142	0.484
Durbin–Watson	0.15	0.05	0.32	0.19

a variety of countries throughout history (Bolt and van Zanden 2014).

6. Analysis and results

We examine the role of temperature and climate change on homicide by using time series regression methods. We began by estimating a relatively basic ordinary least squares regression model (OLS) of homicide on temperature in New York (model 1) and London (model 2) with and without GDP. In model 1 for New York and model 2 for London, the relationship between temperature and homicide is significant and positive. For example, consistent with previous research, model 1 suggests that each additional degree of temperature is associated with approximately 1.697 additional homicides per 100 000 persons each year in New York and 0.293 additional homicides per 100 000 persons each in London.

As noted above, the difference in the mean temperature between 1895 and 1920, which represents the first 25 years of our time series, and 1990–2015, which represents the last 25 years of our time series, was about 2.2° in New York and 1.6° in London. The estimated effects from the time series models suggests that temperature alone would account for 1) a difference of 3.73 homicides per 100 000 in New York when comparing 1895–1920 with 1990–2015 and 2) a difference of 0.469 homicides per 100 000 in London when comparing 1985–20 with 1990–2015. In the late 1800s, the homicide rate per100 000 in New York was about 3.7–3.8 (Monkkonen 2001). In the 1970s, the homicide rate escalated. The increase in homicides continued through the 1980s and, like crime in other places, began to decline in the mid-1990s. Over time, the majority of the positive association between temperature and crime in New York City is driven by the trend in temperature and crime from about 1972 through 1990. The long-term historical association also shows periods during which the temperature–homicide relationship is inconsistent, suggesting that other factors are important for predicting the outcome.

Above, we noted that prior studies have examined the relationship between economic activity and crime. One of the measures used in such studies in GDP. In the present study, controlling for GDP per capita (Table 1; model 2) eliminates the significant correlation between temperature and homicide in both New York and London. In addition, that model shows that GDP is significantly correlated with homicide rates in both New York and London.

There are several problems associated with the models in Table 1. First, as Figs. 1 and 2 suggest, temperature and homicide are likely to suffer from nonstationarity, a condition that may produce artificially high correlations between variables that trend together. To examine the nonstationarity in New York's and London's homicide rates, we employed augmented Dickey–Fuller (ADF) tests for a first-order autoregressive process (AR1). ADF tests suggest that homicide rates in both cities were nonstationary. Thus, we used the first-order differences of all the variables in the analysis before estimating any slope coefficients. For example, for the variable homicide we subtract the homicide rate in year t from the homicide rate in year $t - 1$. First-order differences solved the problem of stationarity, and the models in Table 1 are replicated in Table 2 with these new variables. Second, the models in Table 1 appear to suffer from heteroscedasticity. To correct for heteroscedasticity in the model we also estimate robust (Huber–White) standard errors.

Results from Table 2 suggest that changes in temperature do not predict changes in homicide when correcting for heteroscedasticity, autocorrelation, and multicollinearity [variance inflation factor (VIF) scores were 1.00 in New York model 2 (Table 2) and 1.00 in London model 2 (Table 2)]. Durbin–Watson statistics are much improved in Table 2 and closer to the ideal value of 2.0 that indicates no serial correlation. Importantly, the model residuals now appear normally

TABLE 2. AR1 robust estimates of the effect of temperature on homicide rates in New York and London, 1895–2015. Standard errors are in parentheses. None of the results are significant at the $p = 0.05$ level.

	New York		London	
	Model 1	Model 2	Model 1	Model 2
Temperature	0.136 (0.0826)	0.138 (0.0824)	−0.0108 (0.0236)	−0.0111 (0.0236)
GDP		−0.299 (0.243)		−0.003 01 (0.003 99)
Constant	−0.002 74 (0.127)	0.0714 (0.141)	0.0225 (0.0270)	0.0566 (0.0527)
N	120	120	101	101
R-square	0.022	0.035	0.002	0.008
Durbin–Watson	1.24	1.27	2.29	2.31

distributed. While all the diagnostic tests adequately satisfy model assumptions (or could be adjusted in the model), it can be argued that the models suffer from significant misspecification since temperature and GDP alone are not adequate predictors of homicide over time. This finding is bolstered by the fact that changes in temperature and homicide are positively correlated in New York (but not statistically significant) and negatively correlated in London, but again, they are not statistically significant.

To determine whether the potential misspecification may have to do with temperature, we added temperature squared to the model. Squaring temperature accounts for a potential curvilinear function or inverted U-shape function of temperature on homicide previously identified (Rotton and Cohn 2000).

As Table 3 indicates, squaring temperature did not reveal any nonmonotonic correlation between temperature change and homicide change. In fact, temperature change is still statistically insignificant and unrelated to homicide rate change in both New York and London. We also logged temperature and homicide (results not shown), and the results again indicated that temperature is unrelated to homicide. Despite several adjustments, we were unable to uncover a relationship between temperature and homicide in New York or London, and we suggest that such an association is likely not to exist in these data. Thus, we conclude that in our century-long analysis of temperature and homicide in New York and London there appears to be little support for the heat hypothesis.

7. Discussion and conclusions

Criminological explanations of crime have long suggested that weather and temperature may affect crime. Researchers suggest that increased temperature may promote crime through several mechanisms reviewed above. Prior temperature–crime studies have primarily employed seasonality assessments to determine whether temperature affects crime and have largely supported a temperature–crime association. Generalizing from those results, researchers have suggested that because climate change increases temperature, the progression of climate change may produce an increase in crime (Agnew 2012). Our analysis of trends and change in New York and London do not support this argument.

We strongly caution readers not to interpret our findings of no association between long-term changes in temperature and annual homicide rates as a rejection of the empirical results of previous studies that find an association between temperature and homicide in shorter-term monthly or daily data. In fact, recent research by Mares and Moffett (2019) suggests just the opposite. The researchers make it clear that warmer years with excessively hot summers could produce less

TABLE 3. AR1 robust estimates of the effect of temperature and temperature squared on homicide rates in New York and London, 1895–2015. Standard errors are in parentheses. None of the results are significant at the $p = 0.05$ level.

	New York		London	
	Model 1	Model 2	Model 1	Model 2
Temperature	−6.354 (3.362)	−6.099 (3.325)	0.0191 (1.844)	−0.0396 (1.851)
Temperature squared	0.0598 (0.0314)	0.0574 (0.0310)	−0.000 302 (0.0186)	0.000 288 (0.0187)
GDP		−0.276 (0.184)		−0.003 01 (0.003 71)
Constant	−0.004 89 (0.126)	0.0637 (0.119)	0.0225 (0.0270)	0.0566 (0.0426)
N	120	120	101	101
R-square	0.046	0.056	0.002	0.008
Durbin–Watson	1.18	1.21	2.29	2.31

crime annually than cooler years with excessively balmy winters. So, when it comes to homicide, the seasonal temperature fluctuations may matter while annual fluctuations do not. This observation is important because, at the very least, their observations combined with our findings point to a "seasonal suppressor effect." We suggest additional investigation into this issue in future studies to determine how temperature interactions between and within years might be related to the long-term association between climate change and homicide. We also suggest that temperatures produced by climate change must be examined over long periods of time (30 years or more), and thus annual time series data are needed to assess whether a temperature–crime relationship may exist and be due to climate change. The present study addressed that point, using more than 100 years of time series data on temperature and homicide for New York City and London. Correcting for autocorrelation and controlling for gross domestic product, no association between temperature and homicide (or changes in those variables) was evident for New York or London. That result is consistent with Rotton and Cohn's (2003) results but contradicts those by Anderson et al. (1997), and Anderson and DeLisi (2011). In the latter studies, however, homicide and assaults were added together to measure violent crime, and thus the difference in results may reflect the inclusion of assaults as part of the dependent variable.

The lack of an association between temperature and crime over time suggests that seasonality-based studies may not be generalizable to a temperature–crime effect over time measured annually. This result should not necessarily be surprising. In our data, the difference between the coldest and hottest years for New York and London differed by only 6.6° and 4.4°F, respectively. In contrast, mean seasonal or monthly temperature difference are 41° for New York (January vs July) and 25° for London (January vs July). These large within-year seasonality differences could potentially affect crime, whereas relatively small cross-year differences may not. Individual tolerance to long-term, annual changes in temperature may be very different than short-term tolerance to temperature changes across months or weeks, with the latter potentially generating frustration, aggression (Anderson 1987), psychological and physiological responses (Field 1992), strain (Agnew 2012), or modification of routine activities (Rotton and Cohn 2000), as suggested in prior research. Fluctuations in day-to-day weather, then, may feel extreme, but these same changes may be hardly noticeable over decades and centuries. In short, the effect produced by small annual fluctuations in weather and climate may be unique.

It is possible that our results may be the result of conditions found in New York and London that make residents in those locations "immune" to the effects of temperature on homicide. In these environments, the impact of temperature on homicide could be overwhelmed by other factors, such as population density, that increase social interactions more than temperature does. Both New York and London are highly dense cities, and it is likely that this fact alone increases social interactions. Thus, changing patterns of behavior with respect to hot temperatures may matter little in such densely packed cities. If possible, therefore, the results of this study should be replicated for other cities using annual rather than seasonal data.

It is also possible that our results are affected by measurement errors associated with the reporting of homicides by police (Loftin et al. 2017). Homicide data are the most valid and reliable crime type measurement, but there could be random error or underreporting error in homicide measurements (Loftin et al. 2017) that serves to reduce the association between temperature and homicide. Such a finding would hardly be surprising given the likelihood of errors in coding homicides. More likely, however, older estimates of homicide are undercounted because there are no formal record-keeping practices until law enforcement and media became more professionalized. Thus, undercounting is likely to artificially *increase* rather than decrease the correlation between temperature and homicide. Thus, results are likely somewhat conservative because undercounting is likely to produce an artificial and positive association between temperature and homicide.

It may also be the case that, even though they have been collected over a long period, temperature data still lack sufficient variation to detect an effect. That is, while some scholars have found correlations between temperature and homicide using yearly data, Field (1992) notes that annual variation in temperature is just not sufficient for detecting an effect.

In the end, our results suggest that there is little support for the heat hypothesis in New York and London when annual data are examined. Thus, for criminologists interested in climate change (and not weather) and crime we recommend three areas that we believe are in need additional investigation. First, criminologists might study climate change regulations by examining the creation and application of relevant regulations. Such studies might include an examination of how those laws are enforced and whether they are enforced differentially across nations. Second, criminologists might research aspects of climate *injustice* (Tekayak 2016). Specifically, a concern that is still largely unaddressed in the criminological literature relates to the way in which climate change disproportionately harms the world's poor and indigenous peoples [for an exception, see Mares and Moffett (2016)]. This potential source of inequality and environmental injustice deserves additional consideration because climate change may disproportionately harm the most disadvantaged people because of rising coastal seas, desertification, and migration. These effects are not easily solved even over the long term and may lead to the kinds of impacts on crime associated with social disorganization. Third, criminologists could study the politically powerful actors that contribute to climate change. This power may involve collusion between those with economic and political power in the form of state–corporate crimes against the environment (Kramer 2013; Lynch et al. 2010, 2015b; White 2016). In addition, as green criminologists note, humans are not the only victims of climate change, and additional criminological attention can be directed toward the green victimization of nonhuman species and ecosystems through the consequences of climate change (Lynch et al. 2015a; White and Kramer 2015). In short, even if climate change does not affect homicide directly, there is still reason to be concerned with other climate change–related effects. Temperature is but one indicator of climate.

The study of the heat effect in the context of climate change is still in its infancy, and we suggest that more studies of long-term annual temperature and violence studies are needed. These studies should continue to provide additional evidence of the role of climate change on crime and, perhaps, help establish if the relationship is conditional upon other important social or environmental factors. For this reason, we suggest that our study offers a starting point for debating the logic of analyzing yearly temperature and crime data as opposed to seasonal temperature and crime data. As we have suggested, there is theoretical justification for analyzing the heat hypothesis in the context of climate change, which needs to be measured over the long term.

In the end, although temperature and homicide are not found to be related over time in this particular study, this result does not mean that the relationship between climate change and crime should be dismissed. Climate change is more than temperature change. Thus, our research should be viewed as aiding in the direction of future studies of crime and climate change to other areas of study where climate change might matter. For instance, it is possible that climate change may increase crime through mechanisms such as inequality, scarce resources, conflict related to changes in land use, extreme weather events, and environmentally induced migration. These areas of study deserve future investigation.

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