An Analysis of the Relationship between Weather and Aggressive Crime in Cleveland, Ohio

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ABSTRACT

This study investigated the relationship between weather and aggressive crime for the period from 1999 through 2004 for the city of Cleveland, Ohio. The majority of the analysis focused on meteorological summer (June–August), because this is the time when the most oppressive conditions occur. Citywide analysis (non-spatial) was performed for many temporal variations, which accounted for season, time of day, and day of week (weekend or weekday). The linear regression model explored the relationship between apparent temperature and aggressive crime counts. Results show that summer has the highest aggressive crime counts, while winter has the lowest crime counts. Aggressive crime generally increases linearly as apparent temperature increases, with nonaggravated assaults and domestic violence assaults having the largest response as the weather becomes hotter. The midday and early night hours (i.e., 0300–1200 LT) have the greatest significant findings relating apparent temperature to aggressive crime.

Further analysis was performed at the subcity level. A threshold of mean apparent temperature of 24°C was used in order to investigate spatial patterns of aggressive crime when it is "hot" compared to when it is "cold." Overall, the spatial patterns of crime counts are minimally influenced by hotter weather. Despite the numerous different spatial analyses that were performed, there was no significant evidence suggesting that spatial patterns of aggressive crime are greatly affected by hotter weather. Rather, it appears that warmer weather brings relatively similar percentage increases in aggressive crime activity citywide. Further exploration and analysis of the weather–crime relationship could be of significant benefit to law enforcement officials and emergency response personnel, who increasingly use geographic information system (GIS)-based tools in their work to assist in determining where and when intervention is most beneficial.

1. Introduction

Although most people attempt to avoid weather extremes, the National Weather Service (2009) estimates that hundreds of deaths in the United States per year are directly weather related. Extreme heat is just one of the facets of weather that can impact humans: 739 deaths were attributed to the 1995 Chicago, Illinois, heat wave (Klinenberg 2002); tens of thousands of deaths occurred in the 2003 heat wave across Europe (e.g., Pirard et al. 2005). Oppressive heat not only impacts human health; research has also shown that it is related to aggressive

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behavior both in laboratory and field settings (e.g., Baron and Bell 1976; Anderson and Anderson 1984; DeFronzo 1984; Harries et al. 1984; Harries and Stadler 1988; Rotton and Cohn 2000a,b, 2003).

This study aims to assess the relationship between weather and aggressive crime from 1999 to 2004 using the city of Cleveland, Ohio, as a case study. The city of Cleveland contained 478 403 people as of the 2000 U.S. Census. The city lies along Lake Erie and has a high population density (2381 people km^{-2}) that is relatively evenly distributed throughout the city. Cleveland, as is the case with many cities, is well above the national average in terms of aggressive crime levels; its violent crime rate over the period of study is 1102 cases per 100 000 residents, compared with the national average of 497 during the same period (U.S. Department of Justice 2009). Using the Köppen climate classification

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Cleveland is classified as a Dfa (humid continental) climate, with significant modification by Lake Erie evident in all seasons. Based on the 1971–2000 normal period, its annual mean temperature is 9.8°C; the mean summer (June–August) temperature is 21.0°C, with maximum temperatures on 9 days above 32°C (90°F); the mean winter (December–February) temperature is -2.0° C, with minimum temperatures on 120 days below 0°C (32°F). During the period of study, the mean temperature was slightly warmer than normal in all seasons (annual: 10.5°C, winter: -1.2° C, summer: 21.5°C).

The main purpose of this paper is to examine whether thermal comfort, especially the level of oppressiveness of summer weather, is correlated with aggressive crime. Although many studies have been performed in the past testing the heat–aggression relationship, assessment has been rare at the subdaily temporal scale and the subcity spatial scale; both are incorporated into this research. Because it is well known that the spatial distribution of people within a city changes from weekend to weekday, the potential interaction between weather and changing levels of human interaction could manifest itself in certain areas of the city, showing more significant effects of weather on crime than other areas.

2. Background

Four main theories on violent crime can be applied to the relationship between heat and violence. The Negative Affect Escape Model (Baron 1972; Baron and Bell 1976; Bell and Baron 1976) concluded that negative affect (feelings of irritation, annoyance, or discomfort) and violent acts increase as temperature increases up to a certain inflection point. Upon surpassing this inflection point, the model predicts a decrease in violence as temperature increases because a person's escape motives (avoiding the heat) will override their aggressive motives.

In contrast, Anderson et al. (1995) developed the General Affective Aggression Model. This is a complex model that takes many factors into account, including temperature. This model asserts that there are input factors, such as personal and situational variables, that determine a person's arousal, state of affect, and cognitions. Unlike the Negative Affect Escape model, this model predicts a steady linear relationship between temperature and violence with no inflection point (Rotton and Cohn 2001). Cohen and Felson (1979) developed the Routine Activity Theory to explain why crimes occur. This theory postulates that for a crime to take place a suitable target must be available, there must be a lack of a suitable guardian to prevent the crime from happening, and a motivated offender must be present. When the weather is warmer people are more likely to travel away from their homes to public places; this increase in social contact leads to more people being victimized, and thus predicts an increase in violence to be a linear function of increase in temperature (Rotton and Cohn 2001).

Cohn et al. (2004) developed the Social Escape/ Avoidance Theory, which is closely related to Routine Activity Theory and the Negative Affect Escape Model. It suggests that people will attempt to avoid conditions that *could* lead to negative affect. Therefore, days with extreme temperatures (both hot and cold) should lead to less social interaction, which leads to lesser amounts of violent crime.

A large number of studies have evaluated the heataggression relationship statistically using state- and national-level data. Rotton and Cohn (2003) compared U.S. annual national totals for assaults with mean temperature from 1950 to 1999, along with annual state totals from 1960 to 1999. At both levels, assaults are significantly correlated with temperature. A previous study (Anderson et al. 1997) concluded that "serious and deadly assaults" (i.e., assaults and homicide) are correlated with temperature. This conclusion was reached by using average annual temperature and crime data for the 50 largest U.S. Standard Metropolitan Statistical Areas (SMSAs) from 1950 to 1995. They concluded that with every 1°C increase in temperature, serious and deadly assaults increase by 6.6 per 100 000 people.

Several studies have attempted to aggregate these results to correlate a location's climate with violent behavior. Anderson (1989) looked at violent and nonviolent crimes annually across the entire United States from 1971 to 1980 and concluded that a year with 10 more "hot days" (maximum temperature $\geq 32^{\circ}$ C) than an average year would result in 7% more violent crimes. A second study used 260 SMSAs across the United States for 1980 using the number of "hot days" and the number of "cold days" (maximum temperature $\leq 0^{\circ}$ C) to see if hotter cities had higher violent crime rates. Hot days positively correlated with violent crime, while cold days had the opposite relation to violent crime. He postulated that one could use the difference in temperature between U.S. cities to predict most violent crime. However, although one can evaluate the relationship between weather and crime via numerous variables, DeFronzo (1984) suggested that "inhabitants of an SMSA 'adapt' to their city's particular climatic milieu such that their annual level of criminal behavior is relatively unaffected by the fact that their SMSA is subject to more or less cold or hot weather or days of precipitation than other American cities."

On the smaller scale, the relationship between assaults and temperature across a particular city has been studied by many researchers (e.g., Anderson and Anderson 1984; Harries et al. 1984; Harries and Stadler 1988; Perry and Simpson 1987; Anderson et al. 1997; Cohn and Rotton 1997; Rotton and Cohn 2000a,b, 2003). Analyses have been performed using a variety of temporal and spatial characteristics that led to differing conclusions, although nearly all research has shown that as temperature increases, the number of assaults generally increase as well.

Cotton (1986) used daily violent and nonviolent crime aggregates for Des Moines, Iowa, during the summer of 1979 and Indianapolis, Indiana, for the summers of 1978–80. Both cities showed a significant correlation between violent crimes and both maximum daily temperature and average daily temperature. Similar results were found by Anderson and Anderson (1984), who analyzed daily aggregates of aggressive and nonaggressive crimes in Houston, Texas, from 1980 to 1982. In both studies, nonviolent crime was also analyzed, and had no significant relationship with temperature.

More recently, maximum temperature and sunshine hours were shown to be statistically significant predictors of sexual assaults in Manchester, United Kingdom (McLean 2007); sunny days were associated with increases in murder and hit-and-run deaths in Tokyo, Japan (Ikegaya and Suganami 2008); and monthly temperatures positively correlate with murder and attempted murders across several cities in Pakistan (Simister and Van de Vliert 2005).

Rotton and Cohn (Cohn and Rotton 1997; Rotton and Cohn 2000a,b) thoroughly researched subdaily level crime in several separate studies. They analyzed the relationship between assaults and temperature aggregated into 3-h intervals in Minneapolis, Minnesota, for 1987–88 (Cohn and Rotton 1997; Rotton and Cohn 2000a) and in Dallas, Texas, for 1994–95 (Rotton and Cohn 2000b). They observed an inflection point (\sim 24°C in Minneapolis and \sim 30°C in Dallas) where aggravated assaults decrease with increasing temperatures using 3-h time intervals. When using 24-h aggregates of assaults and temperature in Dallas, this inflection point was not present.

While many researchers have employed geographic information systems (GISs) to analyze crime within a city (see Weisburd and McEwen 1997), Harries et al. (1984) and Harries and Stadler (1988) are among the only researchers that have examined the spatial patterns of crime and weather within a city. Harries et al. (1984) choose Dallas, for a case study during the summer of 1980 (March–October). They divided Dallas into 12 regions or "neighborhoods" based on measures of residents' economic well being. They found that there is an interaction between socioeconomic status and assault rates. Assaults were higher in low-status neighborhoods compared to medium- and high-status neighborhoods (defined by using an urban pathology index). Harries and Stadler (1988) replicated this study using daily assault data for Dallas from 1980 to 1981. They found similar conclusions, but also found that an inflection point appears around 40°C (i.e., assaults decrease after crossing this temperature threshold), regardless of the day of week.

3. Methodology and data

a. Data

Crime data were obtained from Case Western Reserve University's Center on Urban Poverty and Social Change. The dataset includes approximately 540 000 records over the period of 1999-2004 for the city of Cleveland, collected originally by the Cleveland Police Department. The dataset contains fields for spatial organization (census block identification), temporal organization (the date and time that the crime occurred), and a code that describes the type of crime according to the Uniform Crime Reports (U.S. Federal Bureau of Investigation 2001) standard. If multiple crimes occur, only the crime determined to be most severe is coded. Because this study focuses on crimes that are aggressive in nature, only the following six crime types were utilized: domestic violence assault, nonaggravated assault, aggravated assault, robbery, rape, and homicide. Hereafter, the term "all aggressive crimes" group combines all of these crimes; the first three had large enough sample sizes to be analyzed individually as well, and the last four were also grouped together as "violent crimes." Of the records provided, less than 0.1% are missing dates, 0.07% contain erroneous codes, and 18.5% are missing the time of day. The records with erroneous data and missing dates were eliminated from analyses; those missing the time of day were eliminated only from analyses that rely on time of day. With nearly one in five crimes missing the time of day, there may be an issue of selection bias, because it is unknown whether crimes at certain times of day are more likely to have the time of day unrecorded. A further limitation is that this includes only reported crimes, and there may be differences across the city in terms of the likelihood that a crime is reported.

Hourly weather data were obtained from the National Climatic Data Center (NCDC) for Cleveland Hopkins International Airport for the period of 1999–2004. This location is the only first-order weather station in the city. The hourly data utilized in this study include temperature and dewpoint. While there are microclimate issues, including the urban heat island effect, the lake breeze, and the fact that indoor conditions can vary significantly from outdoor conditions, it is assumed in this study that the weather data are representative of the entire city of Cleveland. A total of 52 608 h were incorporated into this study. There were 147 hourly weather observations that were missing. When only 1 h was missing in the sequence, the missing hour's weather variables were estimated by averaging the observations before and after the missing hour. For the remaining 65 observations (0.12%) where multiple hours were missing, values from Cleveland Burke Lakefront Airport were obtained in 57 cases, and the remaining 8 observations (0.02%) were eliminated from analysis.

An apparent temperature was calculated for each hourly observation using the formula developed by Steadman (1979). Apparent temperature was chosen because it takes temperature and humidity into account, providing a better quantification of human discomfort than either temperature or humidity alone.

b. Data aggregation

Both the hourly weather data and crime data were analyzed at the daily level as well as by 3-h intervals, for example, 1200–0259 LT (hereafter "1200–0300 LT") and 0300–0559 LT (hereafter "0300–0600 LT"). Threehour windows were chosen to incorporate time-of-day variability in crime (Cohn and Rotton 1997) while still maintaining sufficient sample sizes that would not be present if 1-h periods were used. Mean apparent temperatures were calculated for each 3-h period and each 24-h day, to correspond with crime totals for the same periods of time.

Weekends are defined as all 3-hourly periods between Friday at 1800 LT and Sunday at 1800 LT. Conversely, weekdays are defined as the period between Sunday at 1800 LT and Friday at 1800 LT. Sunday evening and nighttime crime patterns spatially more closely resembled weekday patterns than weekend patterns, and hence our decision to classify them this way. Analyses were performed separately by meteorological season (e.g., summer: 1 June-31 August). For all analyses, Independence Day (4 July) and New Year's Day (1 January) were clear outliers in terms of aggressive crime counts, and were eliminated from the study. Legal holidays associated with these two days (5 July 1999 and 2004; 31 December 1999 and 2004) were eliminated as well. While a separate analysis of these holidays was considered, because of the small sample size in the 6-yr period and their varied placement during the week (sometimes adjacent to the weekend, and sometimes not), it was decided not to evaluate these days. All of the other legal holidays (i.e., Thanksgiving, Christmas, Memorial Day, and Labor Day) were considered to be weekend days.

c. Analysis

Analysis of the relationship between heat and violence was initially performed on the city level. To test the linear relationship between heat and violence, for each 3-h interval (and daily total) a mean apparent temperature was calculated [and rounded to the nearest $1.4^{\circ}C$ (2.5°F)], and the total number of each crime type was summed. In addition to the time-of-day variable, separate analysis was done for the weekend, weekday, and all days, and for each season, along with all of the seasons combined. The significance of the relationship between crime and apparent temperature was evaluated by testing the statistical significance of the linear regression coefficient at $\alpha = 0.05$. With the five crime types studied, this provided 725 separate evaluations. Given the large number of evaluations that were performed, it should be noted that a number of these evaluations should be expected to be statistically significant because of chance.

Following the citywide analysis, the spatial variability of the crime–weather relationship was assessed. Only crimes occurring during the meteorological summer were used in the spatial analysis. Because it has also been shown that the day of week has an influence on crime, and the location of the population's social space changes from weekday to weekend, weekends and weekdays again were analyzed separately. Because sample sizes were too small for subdaily analysis, only daily analysis was performed.

To test the relationship between aggressive crime and weather, two different subsets of days were compared in the spatial analyses. Henceforth, "hotter conditions" refer to days with a mean apparent temperature either at or above 24°C; "colder conditions" refer to the grouping of days below 24°C. The value of 24°C was chosen as the threshold resulting from crime activity being closest to the summertime mean at this temperature.

Two additional spatial methods were used to investigate patterns of absolute crime differences and relative crime differences across Cleveland. Point density analysis (using a 1-mile fixed distance) was evaluated, using the methods defined by Silverman (1986). Differences using census blocks were also assessed. For both, mean absolute differences between hotter conditions and colder conditions were calculated, along with relative change in crime when hotter conditions are present. Statistical significance was assessed by utilizing a Wilcoxon rank sum test between crime counts on hotter days and colder days; *p* values less than 0.05 are considered "significant."

4. Results

a. Citywide analysis

1) OVERALL

An overview of mean crime values used in this study is shown in Table 1. Crime counts tend to follow a diurnal

TABLE 1. Mean daily crime counts for weekday, weekend, and overall average with sample size of each crime type (1999–2004).

	Weekday	Weekend	All days	Sample size
Violent crime	13.8	15.6	14.3	31 408
Aggravated assault	5.0	6.3	5.4	11 798
Non-Aggravated assault	23.4	23.0	23.3	51 108
Domestic violence assault	14.4	18.8	15.7	34 502
All aggressive crimes	51.6	56.4	53.3	117 018

cycle that mimics the social patterns of humans. There is a steady linear increase in overall aggressive crime (Fig. 1) from 0600 to 1800 LT, after which crime counts level off from 1800 LT to local midnight, and then decline until the minimum occurs from 0600 to 0900 LT. Notable seasonal variations from the annual mean occur in summer (greater than annual mean) and winter (lesser). While after 1800 LT all seasons tend to level off in crime counts, in summer crime continues to increase linearly until reaching a peak from 2100 LT to local midnight.

Aggravated assault, violent crime, and domestic violence assault all follow similar diurnal patterns. On average, there is a steady linear increase from 0900 LT to local midnight annually, although the slope of the increase does differ for each crime. Aggravated assault has the greatest relative increase during this 15-h period (a 530% increase), while violent crime (a 380% increase) and domestic violence assault (a 350% increase) have flatter slopes. After all crimes peak from 2100 LT to local midnight (for all seasons), all of the mean crime counts dramatically decline and reach their minimum from 0600 to 0900 LT.

Nonaggravated assault has a somewhat different diurnal pattern. On average there is a linear increase from 0600 to 1500 LT (a 330% increase) annually, and then the increase greatly slows with a broad peak occurring from 1500 to 2100 LT. Summer is the only season to peak from 1800 to 2100 LT; all of the other season peak from 1500 to 1800 LT.

In comparing weekdays and weekends, the temporal patterns are similar, with peak values in the late evening and early morning hours. Throughout all times of day, summer is 12% above the annual average on weekends and 9% above the annual average on weekdays, while winter is 16% below the annual average on weekdays. Figure 2 reveals some interesting differences in the relative amount of crime between weekends and weekdays; while for most of the daily cycle weekends have considerably higher totals, for the period from 0600 to 1800 LT, weekdays have 12% more aggressive crimes than weekends.

When analyzing the subsets of all of the aggressive crimes, relatively similar patterns emerge. Nonaggravated assault contains the most distinct seasonal and time-ofday variability. Domestic violence assault is the only crime subset analyzed where during all times of day the weekend rates are higher than weekday rates. This may be due to greater interaction among families with more time spent at home, and/or greater alcohol consumption on weekends compared to weekdays (Martin 1992).



FIG. 1. Mean number of crimes on all days by 3-h period and season for all aggressive crimes.



FIG. 2. Difference of mean crime counts between weekends and weekdays (positive values imply greater crime on weekends) by 3-h period and season for all aggressive crimes.

2) APPARENT TEMPERATURE ANALYSIS

In examining the apparent temperature-crime relationship across the entire season cycle, a positive linear relationship between all aggressive crime types and daily mean apparent temperature is observed (Fig. 3). For the aggregate of all aggressive crime as well as for all individual categories examined in this study, mean crime levels are approximately 50% higher when mean apparent temperature is 25°C compared with when it is -10°C. Slopes calculated for time-of-day, seasonal, and crime subsets of the database reveal a complex set of relationships (Table 2). Spring contains the largest number of significant positive relationships, which is largely reflective of its transitional nature, and the fact that a very wide range of meteorological conditions is observed over the 3-month period. In terms of time of day, it is the times of peak crime activity (from the late afternoon to early morning) that contain the largest number of statistically significant relationships between apparent temperature and crime. Winter, which has the least number of significant relationships, is the only season to show a small temperature-crime relationship between local midnight and 0600 LT (1 of 16 tests); in each of the other three seasons, between 6 and 8 tests are significant. There was little distinction between weekend and weekday in terms of statistically significant relationships, except in summer (discussed further below). It should be noted that while there were several negative slopes

between apparent temperature and crime, none of these were statistically significant.

Because crime rates peak during the summer, this season alone was further analyzed. As with the full-year analysis, a general linear increase of all aggressive crime types with apparent temperature is noted; however, it is far more evident on weekdays compared to weekends (Fig. 4). In fact, on weekends, the positive linear relationship between mean daily apparent temperature and daily all aggressive crimes is confined to the coldest summer days, when the mean apparent temperature is below 18°C. Above 18°C the slope is not significant. In terms of subsets of aggressive crime, nonaggravated assaults and domestic violence assaults have the greatest response to temperature (Table 3), with nearly a 7% $^{\circ}C^{-1}$ increase on weekends, and 9%-11% °C⁻¹ on weekdays. Aggravated assaults have a statistically significant 4% $^{\circ}C^{-1}$ increase on weekends, with no significant slope on weekdays. For both weekdays and weekends, violent crime has no statistically significant relationship with apparent temperature in the summer across the entire temperature range, although a decrease in violent crime can be seen on weekends when the mean apparent temperature exceeds 28°C.

In subdividing the summer's apparent temperature– crime relationship by time of day, between 1500 LT and local midnight all of the statistically significant slopes are found in the weekday subsets. Indeed, during the 2100 LT to local midnight period, all of the weekday crime subsets



FIG. 3. Mean daily ("everyday") crime counts by 2.5°C apparent temperature groupings.

that were analyzed had statistically significant positive slopes. Later in the evening, between local midnight and 0600 LT, statistically significant results occur in both the weekend and weekday subsets, with the largest slopes found with nonaggravated assaults and domestic violence assaults.

b. Spatial analysis

A mean all aggressive crime map for the city is presented in Fig. 5; the spatial pattern of crime generally resembles the population density of the city. Analysis of the all aggressive crime differences between hotter and cooler summertime conditions shows little difference from the overall crime density map, because the most crimeaffected areas are associated with the largest increases in crime during hot weather (Fig. 6). A substantially different spatial pattern emerges on weekends, with hotter conditions associated with much higher crime increases in the Flats/Warehouse District entertainment areas (a popular area of bars and clubs at the mouth of the Cuyahoga River); during weekdays this increase is absent, and the largest increases are found in more residential areas.

In terms of crime types, domestic violence assaults have the greatest variability. Weekends show more areas with greater relative increases during hotter conditions, most notably in several residential areas. Weekend crime increases in the Flats area are largely increases in nonaggravated assault.

At the census tract level, only the all aggressive crimes category is analyzed (Fig. 7). The majority of the significant results (p value < 0.05) are found in census tracts that have increases in crime during hotter conditions. There is some clustering to the significant tracts, most notably to the southeast and southwest of the downtown area. There is greater variation on weekends compared to weekdays, although overall there is little spatial cohesiveness in the results.

TABLE 2. Number of significant (p < 0.05) positive slopes between crime and apparent temperature by 3-h period (LT) and season. Eight assessments were done for each box; weekend and weekday for each of the four crime types (all subsets except all aggressive crimes).

	0600–0900 LT	0900–1200 LT	1200–1500 LT	1500–1800 LT	1800–2100 LT	2100–2400 LT	2400–0300 LT	0300–0600 LT	Total
Winter	1	2	2	4	6	2	1	0	18
Spring	0	1	2	5	7	7	3	3	28
Summer	2	1	2	1	2	4	4	4	20
Fall	1	2	2	3	3	4	1	5	21
Total	4	6	8	12	18	17	9	12	87



FIG. 4. Mean daily crime counts on (top) weekends and (bottom) weekdays in summer by apparent temperature groupings.

5. Discussion and conclusions

This study has evaluated the relationship between weather and aggressive crime in Cleveland from 1999 to 2004 in both a citywide and spatial fashion. This study generally supports past research (e.g., Falk 1952; Perry and Simpson 1987; DeFronzo 1984; Cohn 1990; Field 1992; Rotton and Cohn 2003) in finding that hotter temperatures relate to higher amounts of aggressive crime (e.g., Fig. 4). Along these lines, summer has the highest aggressive crime counts, while winter has the lowest crime counts. When exploring aggressive crimes throughout

	Weekends			Weekdays		
	Slope	Mean	Slope/mean	Slope	Mean	Slope/mean
All aggressive crime	2.74	64.25	0.043	4.82	56.31	0.086
Violent crime	-0.54	17.36	-0.031	0.61	14.88	0.041
Aggravated assault	-0.09	7.45	-0.013	0.32	5.70	0.061
Nonaggravated assault	1.86	26.91	0.069	2.83	25.56	0.111
Domestic violence assault	1.40	19.98	0.070	1.39	15.87	0.088

TABLE 3. Slope, mean, and slope/mean for each aggressive crime derived from Fig. 4.

all 3-h periods, the primary periods that experience a notable linear increase of aggressive crime with hotter temperatures occur between 2100 and 0300 LT.

Weekends generally have higher mean aggressive crime counts than weekdays, supporting the idea that interaction between people, likely outside of the workplace, will lead to the opportunity for higher amounts of aggressive crime to occur. Alcohol consumption likely contributes to higher aggressive crime counts occurring during the above-mentioned nighttime hours (e.g., Pernanen 1991).

Although alcohol *may* be the main reason for high aggressive crime counts during the late-night hours, aggressive crime counts do increase somewhat linearly as the apparent temperature increases during these same time periods. This suggests that hotter temperatures *may*

irritate people further and could provide a catalyst toward violent behavior. The fact that weekday crime–weather relationships are somewhat stronger than weekend crime– weather relationships suggest that warmer weather may increase social contact during the week more so than it does on the weekends. Interestingly, on weekends, it appears that it is largely anomalously cold summertime apparent temperatures (below 18°C) that are associated with a (negative) change in aggressive crime rates; above 18°C there is no statistically significant further increase in crime with temperature.

The results were somewhat inconclusive when trying to relate meteorological conditions to changes in the spatial patterns of aggressive crime. Most of the regions of Cleveland that have the greatest absolute increase in crime during hotter conditions tend to occur in areas



FIG. 5. Mean all aggressive crime annual rate per 100 000 population for 1999–2004, by census tract.



FIG. 6. Mean difference in crime counts (hotter conditions minus colder conditions) for all aggressive crimes on weekends and weekdays.

that have significantly higher amounts of crime. Preliminary analyses of the relationship between different measures of socioeconomic status and the crime-weather relationship were performed, but did not yield statistically consistent results, and hence were not presented. Much of the difficulty in addressing socioeconomic status may relate to the fact that criminal activity may occur in places where the perpetrator and/or the victim is not a resident. This problem is particularly acute in places of significant weekend social activity (e.g., the Flats/ Warehouse Districts in Cleveland), where there are no permanent residents.

In comparing differences across the crime groups studied, nonaggravated assaults and domestic violence



FIG. 7. Independent sample t tests by census tract using all aggressive crimes on weekends and weekdays. Absolute differences (hotter conditions minus colder conditions) are displayed, along with the census tracts that were significant.

assaults are more significantly correlated with hotter temperatures, as noted in the greater linear increase of crime with apparent temperature increases (Table 3). The irritation associated with hotter temperatures could cause people to become aggressive. This is what Anderson (2000) calls affective aggression, where the aggressive behavior is generally caused by annoyance, frustration, or anger and the sole purpose is to inflict harm on another person.

In contrast, aggravated assaults and the violent crime index (homicide, rape, robbery, and aggravated assaults) have a lesser response to hotter temperatures. These types of aggressive crimes are more severe in nature and occur with much less frequency than either nonaggravated assaults or domestic violence assaults. As Anderson (2000) noted, these types of crimes are usually instrumental in nature, meaning they are incentive driven (e.g., revenge, financial gain, etc.). If someone is going to commit a serious aggressive crime, the results from this research suggest that meteorological conditions play little, if any, role in influencing such serious aggressive behavior.

This study provided support for the Routine Activity Theory and the General Affective Aggression Model, because more aggressive crime occurs during warmer periods (both seasonally and hotter temperatures). This study found that aggressive crime tends to increase fairly linearly as the temperature increases (Fig. 3), although time of day is still the most significant factor. The Social Escape/Avoidance Theory was perhaps supported by the decreased crime activity during cold summer days, but no decrease in crime appears with excessively high temperatures, aside from the weekend subset of violent crime in summer. Similarly, there was little evidence to support the Negative Affect Escape Model, with its predicted inflection point. This may relate to the incorporation of time of day into this research; however, it may also relate to the fact that excessive heat is relatively uncommon in Cleveland compared with other cities where inflection points have been observed (e.g., Dallas).

Several limitations need to be acknowledged in this research. This study assumed that weather conditions from Cleveland Hopkins International Airport were valid for the location where each crime occurred. Apparent temperature is not the only meteorological variable that can be associated with crime; with a longer dataset available in the future, other associations, including precipitation and snowfall, may also be explored. This study also assumed that the time a crime was reported is actually the time it occurred and that there was no systematic bias in missing times. Also, because many crimes go unreported for various reasons, these data must be considered a subset of the true amount of crime activity that takes place. Last, crime data were aggregated into census blocks and tracts, which can lead to generalizations. The modifiable areal unit problem (Openshaw 1984) is always an issue when using GIS for analysis. This states that the geographic unit chosen for analysis can cause different statistical results in the same dataset. Research suggests (Ord and Getis 1995) that a fixed-distance band is the "best" way to take the spatial structure of crime data into account, but using another method (e.g., contiguity matrices) likely would yield different results. Therefore, it should be reaffirmed that extreme caution should be used while evaluating the results in the spatial analysis. Future availability of crime data on the subcensus block level would ameliorate some of the concerns with spatial aggregation.

This study represents just a 6-yr "snapshot" of Cleveland from 1999 to 2004; Cleveland is a city whose economy has been in significant transition resulting from industrial decline. During the 6-yr period of study, unemployment rates in Cuyahoga County generally ranged between 4% and 6%. The results of this work for Cleveland must be viewed in the context that the population has continued to decline since the end of the study period, and unemployment rates are significantly higher. Crime rates are presently approximately 10% higher than the mean values during this study period.

While the associations of weather and criminal activity have been explored for years, the results of research such as this study could be of significant benefit to law enforcement and emergency medical response authorities. For example, GIS-based analysis has already been performed to assess the role of weather in the spatiotemporal variability in ambulance calls (e.g., Bassil et al. 2009; Dolney and Sheridan 2006), with the express purpose of assisting in real-time emergency medical personnel staffing and intervention plans. GIS analyses are being increasingly incorporated into spatial analyses of crime (e.g., Andresen 2006; Zhang and Peterson 2007), and thus associations between crime patterns and weather conditions can be similarly incorporated to assist in determining where and when intervention is most useful.

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