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Ambient temperature and risk of death from accidental drug overdose in New York City, 1990-2006

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Abstract

Background: Mortality increases as ambient temperature increases. Because cocaine affects core body temperature, ambient temperature may play a role in cocaine-related mortality in particular. The present study examined the association between ambient temperature and fatal overdoses over time in New York City (NYC).

Methods: Mortality data were obtained from the Office of the Chief Medical Examiner for 1990 through 2006, and temperature data from the National Oceanic and Atmospheric Association. We used Generalized Additive Models to test the relationship between weekly average temperatures and counts of accidental overdose deaths in NYC, controlling for year and average length of daylight hours.

Results: We found a significant relation between ambient temperature and accidental overdose fatality for all models where the overdoses were due in whole or in part to cocaine (all $p < 0.05$), but not for non-cocaine overdoses. Risk of accidental overdose deaths increased for weeks when the average temperature was above 24 degrees Celsius.

Conclusions: These results suggest a strong relation between temperature and accidental overdose mortality that is driven by cocaine-related overdoses rising at temperatures above 24 degrees Celsius; this is a substantially lower temperature than prior estimates. To put this in perspective, approximately seven weeks a year between 1990 and 2006 had an average weekly temperature of 24 or above in NYC. Heat-related mortality presents a considerable public health concern, and cocaine users constitute a high-risk group.

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Keywords

cocaine; climate; generalized additive models; heat; mortality; overdose

Studies have repeatedly demonstrated a relationship between higher temperature and mortality [1-5]. Hot weather results in an increased effort on the part of the cardiovascular system to enact physiological cooling, and in combination with individual susceptibilities and inadequate or inappropriate heat regulation this can result in hyperthermia [6]. The effect of high ambient temperature on mortality has become of increasing concern in light of evidence of climate change, and heat-related mortality is expected to increase [3,7-9].

Urban populations in particular may be at risk for negative health effects due to extreme heat [10]. Elevated temperatures are observed in urban relative to rural regions [8], possibly due to higher population density [11] and greater heat retention at night [12]. Northern and mid-western U.S. cities in particular show an increased mortality with high temperature compared to southern and southwestern U.S. cities [3,13], likely due to acclimatization and differences in urbanicity.

Accidental drug overdose presents a useful model for studying the effect of temperature on mortality, as the effect of drugs on the body are influenced by an interaction of endogenous and exogenous factors. The effect of cocaine use in particular on the body may be moderated by ambient temperature. Evidence from animal models [14,15] suggests that cocaine use raises the core body temperature in an environment of warmer ambient temperature, while lowering core temperature in a thermoneutral environment (20 degrees Celsius). In humans, cocaine is known to increase core body temperature, impair the ability of the cardiovascular system to cool the body, and to decrease the sense of discomfort associated with heat that would lead to heat-avoidant behaviors [16]. A series of case reports have suggested that cocaine overdoses occur at lower blood-cocaine levels than usual when hyperthermia is present [17,18]. Furthermore, in addition to urban locations having higher ambient temperatures than rural locations, cocaine use is more common in urban areas [19].

A prior study by Marzuk and colleagues [20] examined the relationship between drug overdose deaths in New York City between 1993 and 1995. The authors created a binary cut-off with a maximum daily temperature above 31.1 degrees Celsius (88 degrees Fahrenheit) indicating “hot” compared to “other” days. Using a Mann-Whitney test, they found that “hot” days had a significantly greater mean number of fatal cocaine-related overdoses than days with a lower maximum temperature. This was not true of non-cocaine-related drug overdoses. To date, this has been the only study of which we are aware to examine the relationship between temperature and drug overdose. However, this study had several limitations, including a narrow time period of study, use of parametric models, and reliance on maximum temperatures as the key temperature measure.

The objective of the present study was to revisit and extend the work of Marzuk and colleagues [20] in examining the relationship between ambient temperature and drug overdose in several ways. First, we extend the period of observation from three years to seventeen years (from 1990-2006), greatly increasing the sample size available to us. As a result of the larger sample, we were able to refine the categorization of overdose deaths to better address multi-drug use and disentangle the effect of temperature on fatal overdose risk for the use of opiates, cocaine, and other drugs. This improvement in methods is important because a substantial proportion of drug overdose deaths are attributed to opiates, cocaine, and other drugs used in combination [21]. Second, we used generalized additive models (GAM) [22], which are ideal for modeling the relationship of environmental conditions with mortality [23]. This nonparametric method is flexible, does not require assumptions about underlying distributions or risk, and allows adjustment for nonlinear confounding effects like the length of day and trends over time. Third, we used average ambient temperature rather than maximum temperatures, as evening temperatures have been shown to be important to temperature-related mortality [1].

METHODS

Data Source

Data included all fatal accidental drug overdoses that occurred in New York City between 1990 and 2006. Individuals who did not have demographic data or died of overdoses ruled suicidal or homicidal were not included. Accidental overdose data were obtained from the Office of the Chief Medical Examiner (OCME) of NYC; the OCME determines manner of death through medical records, autopsy findings, laboratory results, circumstances of death, and investigative interviews. Study protocols were approved by the local Institutional Review Board.

Measurement

Our outcome measure was the weekly count of fatal accidental drug overdose. Expanding upon the categorizations of Marzuk and colleagues [20], we categorized all fatal accidental drug overdoses into seven non-mutually exclusive groups: (a) all accidental overdoses due to any drug or combination of drugs, (b) any overdose where cocaine was present and ruled contributing to death, (c) overdoses where multiple drugs were causative of death, including cocaine, (d) overdoses solely due to cocaine, (e) overdoses where cocaine or its metabolites was present in the body at the time of death, but not ruled a cause of death, (f) overdoses where opiates were the cause of death and neither cocaine nor its metabolites were present, and (g) all other drug overdoses where opiates, cocaine and its metabolites were not present.

Our exposure of interest was weekly average ambient temperature. We obtained daily temperature data for Central Park, New York City from 1990-2006 from the National Oceanic and Atmospheric Association (http://ncdc.noaa.gov). We calculated the weekly ambient temperature as the average between the high and low temperature for each day from 1990-2006 in New York City, and then calculated the average daily ambient temperatures across a week for a total of 887 weeks. We accounted for length of the day (as an indicator for season), which may be associated with access to drugs as well as associated with temperature. We did so using a variable of the average day length over the week, based on information on time of sunrise and sunset from the Astronomical Applications Department from the U.S. Naval Meteorology and Oceanography Command (http://aa.usno.navy.mil/). As per Dominici and colleagues [23], in all GAMs we accounted for any long-term trends in overdose deaths by including a variable counting the weeks from 1 to 886, for a total of 887 weeks in all models.

Statistical Analysis

To analyze if weekly ambient temperature affected accidental drug overdose, we performed non-parametric analyses using generalized additive models (GAMs) [22]. GAM procedures account for non-linear relationships using a univariate smoother for each predictor in an additive model [22,24]. As a non-parametric method, the lack of assumptions used by GAM was particularly important to our research questions, as prior research has demonstrated that the effect of high temperature on mortality in U.S. cities is non-linear [3]. Additionally, this method derives estimates solely from the data and is resistant to inflation in cases of sparse data.

First, we conducted univariate descriptive statistics for all overdoses by year of the study, and for the whole study period by overdose category. Next, we created a series of GAMs to examine the relationship of ambient temperature with the weekly number of deaths attributed to the seven overdose outcomes. All GAMs assumed a Poisson distribution, as the outcomes were counts and were estimated using penalized maximum likelihood regression [22,24]. All smooth terms in the GAMs consisted of a penalized regression spline and a smoothing parameter; to determine the optimal smoothing parameter for the penalized regression splines, we used the generalized cross-validation method and assumed a cubic spline base [24]. After obtaining optimal smoothing parameters, we then calculated robust p-values for the smooth terms using unpenalized splines or regression splines. We used a two-sided *p*-value of 0.05 to test statistical significance, and evaluated model fit using the Akaike's Information Criteria (AIC), where smaller values indicate better fit. We estimated all GAM models using the program R.

Similar to Marzuk et al [20], we compared our models of drug overdose deaths to models examining the effect of temperature on motor vehicle accident deaths and homicides. We included all cases where cocaine or its metabolites were present, and created an additional GAM for the weekly count of deaths attributed to of each of these two causes.

RESULTS

The weekly number of accidental overdoses from any drug or combination of drugs between 1990 and 2006 in New York City ranged between 3 and 48, with a mean of 15.89 (table 1). Cocaine contributed as a cause of death to the more than half of the accidental drug overdoses observed during this period. The weekly mean number of fatal overdoses due to cocaine and other drugs was greater than the mean number due to cocaine alone.

As shown in table 2, GAMs indicated a significant relationship of average weekly ambient temperature with accidental overdose fatality for all models where the outcome was the weekly count of overdoses that were due in whole or in part to cocaine (models 1 through 4; all $p < 0.05$). Overdoses where cocaine was present but ruled not causative (model 5), overdoses due to opiates without cocaine (model 6), and accidental overdoses due to drugs other cocaine or opiates (model 7) did not have a significant relationship with ambient temperature. Similarly, the weekly count of fatalities due to motor vehicle accidents (model 8) and homicide (model 9) where the victim had used cocaine also did not have a significant relationship with ambient temperature. Cumulatively, these findings indicate that there was an increased risk of fatality due to cocaine overdose at higher ambient temperatures, but no temperature-related risk of fatality due to overdose of other drugs or the other external causes of death we examined.

Figure 1 illustrates the relationships of weekly average ambient temperature with accidental overdose fatality for the model of all overdoses (model 1 in table 2). The figures display the predicted weekly overdose rate per 1,000,0000 by temperature-level as estimated from the GAM and superimposed on the observed weekly overdose rate per 1,000,000. The dashed lines represent the 95% confidence intervals for predicted values. Removing the outlier seen at 30 degrees Celsius had minimal impact on model estimates. The model depicted in figure 1 demonstrated an increase in the count of overdose fatality at approximately an average weekly ambient temperature of 24 degrees Celsius (75 degrees Fahrenheit). This increase in overdose mortality continued to rise as the weekly average ambient temperature increased beyond this threshold.

DISCUSSION

Using mortality data for New York City between 1990 and 2006, we found strong evidence of a relationship of higher ambient temperature and accidental cocaine-related overdose mortality. In contrast with the work of Marzuk and colleagues [20], which only examined cocaine-related and cocaine-unrelated overdose deaths, we were able to categorize overdose deaths in a number of ways in order to tease apart the relationships of ambient temperature with overdoses caused by cocaine, opiate, and other substances. Specifically, for all models where the outcome included overdose deaths due to cocaine (multi-drug including cocaine and cocaine only), there was a statistically significant non-linear relationship with temperature. A similar relationship did not exist with overdoses due to opiates without cocaine, not due to cocaine or opiates, or where cocaine was present but not ruled causative of death. There was also no relationship of ambient temperature and weekly counts of death due to homicide or motor vehicle accidents where the victim had used cocaine.

We found that the weekly count of accidental overdose deaths attributed to cocaine began to increase when the weekly average ambient temperature was around 24 degrees Celsius, and continued to increase as temperature increased after this threshold. By comparison, Marzuk and colleagues [20] found a difference in mortality above a daily high temperature of approximately 31.1 degrees Celsius, compared to below 31.1 degrees Celsius, using statistical methods that did not allow an examination of whether the mortality continued to increase after this threshold was met. In New York City between 1990 and 2006, 13.6% of all weeks (i.e., approximately seven weeks of each year) had an average ambient temperature that was at or above 24 degrees Celsius, and in some particularly warm years over 20% of weeks had average ambient temperature at or above 24 degrees. In contrast, only 7.1% of all days between 1990 and 2006 in New York City had a maximum temperature of 31.1 degrees, the threshold found in the Marzuk et al. study [20]. While research has often focused on the effect of heat on mortality in “heat wave” conditions [25-29], the present findings suggest that ambient temperature impacts specific causes of mortality in less extreme conditions as well. The lower temperature at which cocaine overdose mortality increases observed here compared to what has previously been documented suggests potentially greater population sensitivity to high ambient temperature than had been previously understood.

Consistent with prior studies of New York City overdose deaths [21], many of the overdose deaths in this sample were caused by cocaine and opiates in combination. Interestingly, the relationship of temperature and overdose mortality was not as strong in the model predicting overdoses due to cocaine alone (model 4) than in models that included all overdoses (model 1) and overdoses due to cocaine and other drugs (model 3). However, the lack of relationship between temperature and fatal overdoses when cocaine did not attribute to the cause of death indicates that it is cocaine, and not other drugs, that are driving the relationship of temperature and overdose fatality in models that included cocaine as well as other drugs (models 1 through 3). A possible explanation for the stronger effect when multiple drugs including cocaine were present compared to overdoses when only cocaine was present is that the effect of cocaine on heat-related mortality is potentiated by the presence of other substances, particularly opiates; evidence suggests that opiates cause both hyperthermia and hypothermia at different stages [30].

There are several limitations to the present study. The measure of average ambient temperature in Central Park provides only an estimate of the environmental temperature experienced by overdose decedents in NYC at the time of overdose. Individual-level differences, such as presence in an air-conditioned building compared to a crowded public building without air conditioning (such as a rave party), likely further explain risk of overdose. Given the small number of overdoses where cocaine and opiates were not involved (a mean of 0.9 per week), it is not possible to test if a similar phenomena exists for amphetamines and other stimulants. As cities in the northeast and mid-west have lower thresholds at which increases in temperature-related mortality occurs [3,13], this relationship may not be as strong in cities in other regions. We had limited data on characteristics of the drug user and drug, such as the dose of drugs taken before death, frequency of use in the time leading up to death, and the decedents' level of tolerance. The analysis examined general trends in the relationship between ambient temperature and cocaine overdose-related mortality; consequently the role that personal vulnerabilities may play in this relationship is beyond the scope of the study.

Notwithstanding these limitations, the present findings provide strong evidence for an increase in cocaine-related mortality when ambient temperatures rise beyond 24 degrees Celsius. This relatively low temperate at which an increase in mortality was observed indicates the importance of intervention during periods of warm weather, and not just in heat-wave conditions. Public health interventions to decrease mortality in periods of high ambient temperature include delivering health-protection messages to high-risk groups, including cocaine users, and making air conditioning available in public locations [5] in regions where cocaine use is common.

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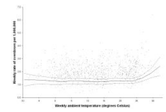

Figure 1.
GAM of temperature and drug overdose mortality in New York City, 1990-2006, including all overdoses due to any drug or combination of drugs.
Note: The prediction line represents only the effect of temperature on the count of overdose deaths, when all other covariates were held constant. The scatterplot represents the count of overdose deaths based on temperature and other covariates.

Table 1

Descriptive Statistics of New York City Drug Overdoses, 1990-2006.

	Weekly Count of Overdoses		
Year	**Mean (SD)**	**Min.**	**Max.**
1990	10.58 (3.55)	3	20
1991	14.62 (4.08)	6	27
1992	15.52 (4.67)	7	28
1993	20.17 (6.64)	11	48
1994	19.79 (5.18)	10	32
1995	19.57 (5.07)	10	33
1996	17.35 (5.09)	7	29
1997	16.38 (4.67)	5	33
1998	15.08 (4.76)	8	29
1999	13.37 (5.07)	3	28
2000	15.58 (4.22)	3	27
2001	15.04 (4.55)	4	25
2002	15.13 (4.33)	5	26
2003	16.08 (3.89)	7	24
2004	14.38 (4.22)	8	28
2005	14.38 (3.72)	9	25
2006	16.96 (4.91)	6	31
N=887 weeks	Mean	Min.	Max.
Overdoses per week (total)	15.89 (5.19)	3	48
-cocaine as a cause of death	9.89 (4.07)	1	34
-multiple drugs as a cause of death, including cocaine	6.54 (3.29)	0	26
-only cocaine	3.34 (1.90)	0	10
-opiates as a cause of death, cocaine and its metabolites not present	4.92 (2.51)	0	16
-cocaine, its metabolites, and opiates not present	0.90 (1.00)	0	5

Table 2

Generalized Additive Models of the Effect of Ambient Temperature on Weekly Mortality due to Drug Overdose, Motor Vehicle Accidents, and Homicide in New York City, 1990-2006.

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	All accidental overdoses	**Overdoses with cocaine as a cause of death**	**Multidrug, with cocaine a cause of death**	**Cocaine only**	**Cocaine present but not a cause of death**	**Any opiate, no cocaine present**	**Other overdose**	**Motor vehicle deaths[a]**	**Homicides[a]**
Non-linear components	**(DF)**	**(DF)**	**(DF)**	**(DF)**	**(DF)**	**(DF)**	**(DF)**	**(DF)**	**(DF)**
Temperature	8.04 **	7.33**	6.10*	2.66*	3.39	1.00	1.22	1.00	1.00
Time	23.0**	20.82**	20.63**	10.58**	8.38**	21.51**	2.27**	9.31**	6.00**
Length of day	17.92**	17.61**	13.88*	11.94	1.11	10.46*	1.00	1.00*	4.81
Deviance explained[b]	36.10%	38.10%	34.40%	9.99%	4.98%	13.10%	6.45%	14.30%	72.50%
AIC	5129.968	4652.189	4263.286	3549.937	2105.345	3897.273	2077.42	1676.647	3554.610

AIC is Akaike's Information Criteria; DF is degrees of freedom for the non-linear smoothing parameter.

** *P*-value < 0.01

* p-vale < 0.05.

[a] Where cocaine or its metabolites were present.

[b] The Deviance explained is the difference between the maximum achievable log likelihood and the model log likelihood based on the maximum likelihood estimates.