Stress and Health

Stress and Health **21**: 3–15 (2005)
Published online 18 October 2004 in Wiley InterScience (www.interscience.wiley.com). **DOI:** 10.1002/smi.1029

Thermal stress in the U.S.A.: effects on violence and on employee behaviour

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Summary
Many researchers have claimed to find a link between temperature and aggression; we use U.S.A. data to confirm strong seasonal patterns in several types of violent crime. We also report seasonal patterns in U.S.A. workplace data (strikes, and quitting jobs). We suggest a medical explanation for these seasonal patterns, based on stress hormones (adrenaline, and perhaps noradrenaline and/or testosterone). The human body generates adrenaline in response to excessive heat; adrenaline is helpful in keeping the body within safe limits, but we think that as a side effect it leads to aggression (which is often inappropriate). We examine the shape of the curve relating temperature to aggression. Copyright © 2004 John Wiley & Sons, Ltd.

Key Words
thermal stress; employee behaviour; stress hormones

Introduction

Very hot or very cold weather are stressful to humans, and the human body reacts to extreme temperatures by producing stress hormones (catecholamines). It is vital for a human to keep the blood temperature within a narrow range of temperatures: 37°C is a typical temperature in the inner 'core' of the human body, but brain damage and death can result from a prolonged core temperature above 40°C (Brück, 1999, p. 642). Humans need stress hormones, to cope with the stressful environments in which we live; but stress hormones may have undesirable side-effects. In particular, adrenaline is associated with aggression.

There is evidence from several countries that temperature extremes are associated with violence, including the U.S.A. (Anderson, 1989), U.K. (Semmens, Dillane, & Ditton 2002, p. 798), and India and Pakistan (Simister, forthcoming). We think such seasonal patterns could be observed in any country; we focus on the U.S.A. as one of the countries with the best data for this topic. As a large landmass, U.S.A. has a variety of climates. The obvious temperature variation is from the hotter southern states to the cooler northern regions (especially Alaska), but there are many other influences—for example, locations near the Atlantic or Pacific Ocean tend to have mild climates, due to the moderating effects of sea breezes.

This article confirms previous claims that violent crime is associated with temperature extremes. We also present evidence of an apparent link between temperature and impulsive

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Received 3 May 2004
Revised 12 July 2004
Accepted 28 July 2004

behaviour at work. Despite the evidence on this topic reported in this article and elsewhere, there are many aspects which science has not yet solved: for example, what is the shape of the curve relating temperature to aggression? We offer some tentative evidence on such issues.

Previous evidence of seasonal patterns in violence

Studies in many countries indicate seasonal patterns in violent crime-rates; Anderson (1989) provides an excellent overview of the topic. Various hypotheses to explain the observed seasonality in crime rates have been proposed and rejected as explanations—for example, violence cannot be explained only by seasonal hunger (such as food shortages before harvest-time)—Rosenfeld's research on U.S.A. (cited in Anderson, 1989, p. 79) found violent crimes such as murder significantly higher in (hot) southern cities, whereas non-violent crimes such as theft showed no significant north/south difference. Maximum day length does not correspond to maximum crime rates (Anderson, 1989, p. 86). It has been claimed that the sex hormone testosterone may cause higher incidence of rape in summer, but Anderson (1989, p. 85) cites evidence casting doubt on this hypothesis. Some writers suggest a 'culture of violence' may be responsible for more aggression in areas such as southern U.S.A., but such a culture may be an effect rather than a cause (Anderson, 1989, p. 79). Perhaps extreme temperatures could also explain 'machismo' (macho) culture associated with parts of South America.

Many writers claim that temperature is related to seasonal patterns in crime rates (e.g. Jacob & Lefgren, 2003, p. 1561). 'Field studies clearly show that heat increases aggression' (Anderson, 1989, p. 74); violence and murders have been found to increase following heat waves (McGeehin & Mirabelli, 2001, p. 185). Temperature-induced violence includes political rebellions/riots, assaults, spouse abuse/domestic violence, manslaughter and murder (Anderson, 1989; Rotton & Cohn, 2001).

Evidence cited in Anderson (1989) on the link between temperature and crime comes in various different forms, such as: comparing hot with cold geographical areas (within and between countries); comparing hot years with cold years; and comparing hot months with cold months. Analysis of juvenile crime in 29 U.S.A. cities by Jacob and Lefgren (2003, p. 1568) revealed a striking pattern in which the crime rate rises steadily to a peak at about 3 p.m., and then falls steadily to the lowest crime-rate at about 6 a.m., except for a spike around midnight. This suggests that aggressive behaviour is more likely in the hottest part of the day (which we think could be 3 p.m.), and least likely at the coldest part of the day (which we assume to be just before dawn: presumably about 6 a.m.). We suspect the 'spike' around midnight may be related to closing time of venues selling alcohol.

Although there seems widespread agreement about the existence of a link between temperature extremes and crime, the details are not clear. For example, some writers have suggested a 'curvilinear hypothesis': as temperature rises, violence becomes more prevalent, but only up to a certain temperature—after that point, further increases in temperature tend to reduce violence (see Anderson & Anderson, 1984). We return below to the question of whether the relationship between temperature and violence is U-shaped, J-shaped, or some other form.

How a particular temperature 'feels' depends on many factors, include humidity; air movement; clothing; and work intensity. We consider the effects of humidity in our regression analysis, but other factors are beyond the scope of this article. In general, we expect people to cope better with cold weather than hot weather: wearing more clothes is an easy way to reduce stress from cold weather (Anderson, 1989). Acclimatization (see Brück, 1989) is also important—for example, we expect hot weather to be more stressful if the temperature rose dramatically in the last few days.

Could adrenaline explain seasonal patterns in aggression?

Medical researchers have suggested various possible mechanisms to account for the apparent link between temperature and aggression. Anderson (1989) discusses five hypotheses:

- negative affect escape;
- simple negative affect;
- excitation transfer/misattribution;
- cognitive neoassociation;
- physiological-thermoregulatory.

The first four hypotheses are psychological, and inter-related: for example, Anderson (1989, p.

76) suggests the excitation transfer/misattribution hypothesis is a 'sophisticated version of the simple negative affect model'. But Anderson (1989, pp. 93–94) found these hypotheses do not perform well—'The bulk of the studies strongly contradicted' the 'simple negative affect' model, and the cognitive neoassociation model appears to be contradicted by evidence. Anderson (1989, p. 93) suggested that 'the failure of experimental laboratory studies' to confirm any of the four psychological hypotheses suggests we should consider abandoning them. Anderson (1989) did not test the fifth hypothesis, because it is too complex; this article investigates this (physiological-thermoregulatory) hypothesis.

Strain occurs if temperature and other stresses 'exceed the body's tolerance threshold' (Mawson, 1999, p. 177). Temperature extremes, like other forms of stress, cause the human body to produce hormones. We focus mainly on three hormones: adrenaline (also known as epinephrine); noradrenaline (also known as norepinephrine); and testosterone.

- Adrenaline level in the blood is higher in very hot conditions, in both men and women (al-Hadramy, 1989; Jezova, Kvetnansky, & Vigas, 1994); but blood adrenaline level is not raised by cold weather (Frank et al., 1997; Sramek, Simeckova, Jansky, Savlikova, & Vybiral, 2000). Effects of adrenaline include vasodilatation (expanding peripheral blood vessels, which can cool the body); increasing the rate of heartbeat; raising blood pressure; and stimulating respiration—these effects of adrenaline 'probably contributing thereby to the regulation of body temperature in mammals' (Barrington, 1983, p. 1081).
- Noradrenaline blood levels are higher in extreme heat or cold, in both men and women (al-Hadramy, 1989; Frank et al., 1997; Jezova et al., 1994; Sramek et al., 2000). In cold weather, noradrenaline has a vasoconstrictor effect—contracting blood vessels, which can reduce heat loss through the skin (Pocock & Richards, 1999, p. 541); noradrenaline also reduces the heart rate, and slightly increases blood sugar level and metabolism (Barrington, 1983, p. 1081). Noradrenaline is associated with 'nonshivering thermogenesis' (Brück, 1999, p. 633).
- Testosterone levels are higher in summer Andersson, Carlsen, Petersen, and Skakkeback (2003). Andersson et al. conclude that air temperature, rather than light level, accounts for seasonal variation of testosterone in men (testosterone levels being highest in summer). However, Anderson (1989, p. 85) reports that increase in rapes occur earlier in the year than the rise in testosterone levels.

Other hormones could be related to temperature, at least indirectly: for example, circulating adrenaline can lead to release of ACTH (adrenocorticotropic hormone), which can affect the level of glucocorticoids (the group of hormones which includes cortisol) in the blood (Barrington, 1983, pp. 1075–1076). But Kurina, Schneider, and Waite (2004) and others report that cortisol levels usually rise suddenly on waking, and then gradually fall during the day; this does not suggest a strong relationship between cortisol and temperature.

Adrenaline prepares a human to run away from, or use aggression towards, a threat. Noradrenaline could have similar effects: research by Kemper (1990, p. 31) suggests a relationship between noradrenaline and 'anger, which is a frequent precursor of aggression'. Kemper suggests the interaction of noradrenaline and testosterone cause aggression; but testosterone may be an effect—rather than a cause—of violence (Kemper, 1990, pp. 29–33). Testosterone levels are much higher in men than in women (10 times higher, on average, according to Kemper, 1990, p. 134); but there is evidence that 'women and men are equal in rates in nonlethal violence' (cited in Kemper, 1990, p. 139), which casts doubt on the importance of testosterone in violence. Mazur claimed 'testosterone affects dominance behaviour but not aggressive behaviour' (cited in Kemper, 1990, p. 29).

The remainder of this article tests the idea that adrenaline explains seasonal patterns in crime. We refer to this as the 'adrenaline hypothesis', but (as explained later) we cannot rule out the possibility that other hormones are involved. The only other study we know of which suggested adrenaline (as the cause of crime seasonality) is Simister (forthcoming).

Empirical evidence on the adrenaline hypothesis

To assess the hypothesis that violence increases at extreme temperatures, we begin with time-series temperature data from CRU (2004). This website

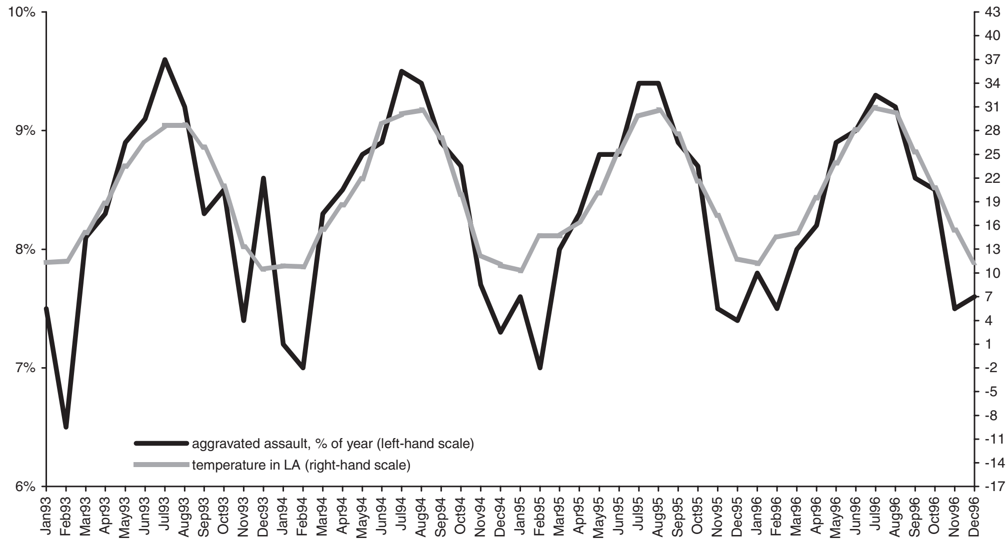

Figure 1. Aggravated assault in U.S.A., 1993 to 1996. Source: FBI (1997); CRU (2004).

reports data in two files: average temperature, and deviation from average. We combined data from both files to obtain temperatures for the U.S.A., by writing a Turbo Pascal computer program (available from the authors on request). These temperatures are averages for each month, and tend to understate extremes of temperature—for example, we expect temperatures to be hottest in mid-afternoon, and to vary from one day to the next, but such extremes are averaged out. We would prefer data on the hottest and coldest recorded temperature in each month at each location, but we have not found such data. We use Los Angeles temperatures as a proxy for temperatures in the U.S.A. as a whole, on the assumption that the hottest month in Los Angeles coincides with the hottest month elsewhere in the U.S.A.; Michael and Zumpe (cited in Anderson, 1989, p. 86) claim the maximum temperature in Atlanta and Texas occur about 40 days earlier than in Oregon and California, so our assumption is far from perfect.

We use temperature data for latitudes 30° to 35° north, and longitudes 115° to 120° west, i.e. the box which includes Los Angeles, from CRU (2004). Temperatures are shown in the right-hand scale of Figure 1; the range is from −17 to 43°C, for comparability with our other charts. All temperatures in this article are measured in degrees centigrade. Figure 1 uses national U.S.A. crime data, for 1993 to 1996 inclusive, from FBI (1997, p. 6). FBI report crime occurring each month as a percentage of crime for the whole calendar year; this reduces the distraction caused by trends in crime, and we refer to it as the 'FBI method'.

Figure 1 shows a clear seasonal pattern, as commented by FBI (1997, p. 11): 'Violent crimes occurred most frequently in July and August. The lowest total was recorded in the month of February'. There is also an increase in violent crime in December or January—generally the coldest months in the U.S.A. Seasonal patterns similar to Figure 1 are apparent in FBI (1997) data, for murders and for rapes.

We cannot use Figure 1 to assess which temperatures are stressful, because of temperature differences between parts of the U.S.A. (Figure 1 temperatures apply to Los Angeles). Our next results focus on crime in Los Angeles (the second largest city in the U.S.A.: we cannot find monthly crime data for New York, the largest city). Figure 2 uses the same temperature data source as Figure 1 (but for more years). We use data on the number of 'aggravated assaults', from LAPD (2003, Table 2.3; and all equivalent reports for earlier years on the LAPD website).

A seasonal pattern of aggravated assaults in Los Angeles is clear in Figure 2: the highest number of murders per month tends to be in the hottest months (July or August). Figure 2 also suggests a slight increase in number of assaults in the cold winter months. This is an improvement on Figure 1, because Figure 2 compares Los Angeles crime with Los Angeles temperatures.

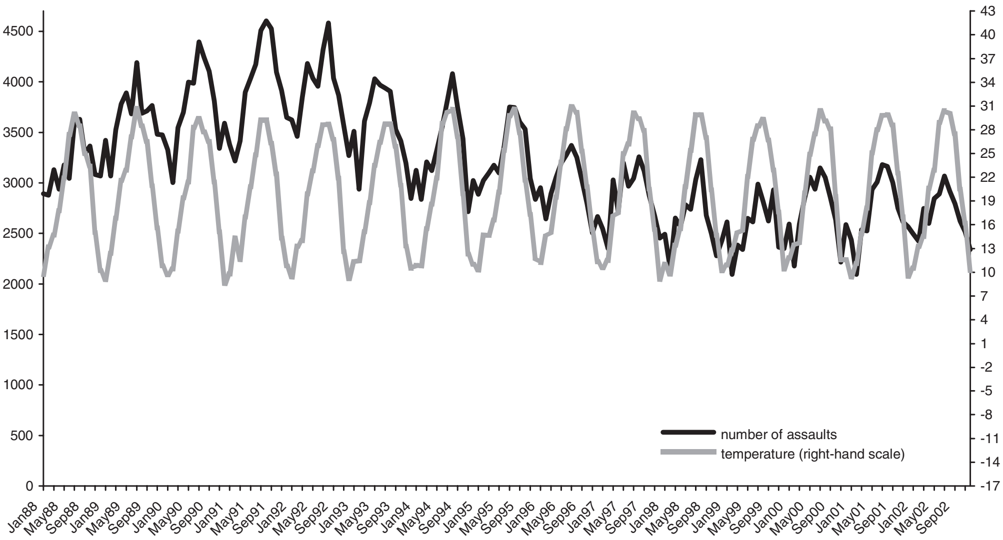

Figure 2. Aggravated assaults in Los Angeles, 1988 to 2002. Source: LAPD (2003 and earlier); CRU (2004).

However, CRU (2004) reports each temperature as an average for the whole month—averaging daytime and nighttime temperatures. Other methods of reporting temperatures would affect the scale on the right of Figure 2: for example, the extreme maximum temperature in Los Angeles is 43°C (NOAA, 1991, p. 9)—far higher than 31°C, the highest temperature in Figure 2. Figure 2 is complicated by falling crime-rates between 1991 and 2000 (this national decline in U.S.A. violent crime has been noted by various observers, including FBI, 1997, p. 6); we control for this (for Figure 8 and Table I later) using the 'FBI method'.

We now consider possible effects of thermal stress in the workplace. Figure 3 uses temperature data from the same source as our previous graphs, i.e. CRU (2004); data on numbers of people on strike in the U.S.A., from Bureau of Economic Statistics (1979, and the equivalent report for 1981); and national data on number of people quitting jobs (rate per 100 employees), from Bureau of Economics Statistics (1979, and the equivalent report for 1981). Figure 3 (like Figure 1) uses Los Angeles temperature as a proxy for temperatures in the U.S.A. as a whole.

Figure 3 indicates that people are more likely to leave their job in the hottest months: this seasonal pattern has similarities to our previous results. There are many possible influences on people leaving jobs—for example, the increase in numbers of people quitting jobs in August may be related to school summer holidays (perhaps some parents leave to mind children, and save money on childcare). We think a decision to quit a job could be influenced by impulsive behaviour—workers acting, and perhaps over-reacting, 'in the heat of the moment'. Figure 3 also shows a strong seasonal pattern in strikes (caused by employees, or unions, or employers, or a combination); there are many possible influences on strikes, but the seasonal pattern in Figure 3 has similarities with the Figures 1 and 2. We interpret Figure 3 as evidence that hot summer temperatures are stressful, and that this stress causes people to act rashly, leading to a greater risk of strikes. Figure 3 suggests that whatever causes seasonal patterns in crime may have a wide range of effects; but we cannot tell if the seasonality is due to adrenaline or another cause.

Figure 4 uses annual (cross-section) data on crime-rates in 2002: numbers of 'aggravated assaults' per thousand people, in each city for which data are available (FBI, 2003, Table 9a; and equivalent tables for 1999, 2000 and 2001). We use the latitude of the city, as a proxy for how hot or cold it is, on the horizontal axis of Figure 4. We found latitude produced a more persuasive chart than maximum temperature, or average temperature, or minimum temperature.

Cities at the bottom left of Figure 4 are in Puerto Rico; they are 'outliers', perhaps because temperatures vary little (from about 24°C in February to 28°C in July–September: CRU, 2004), so

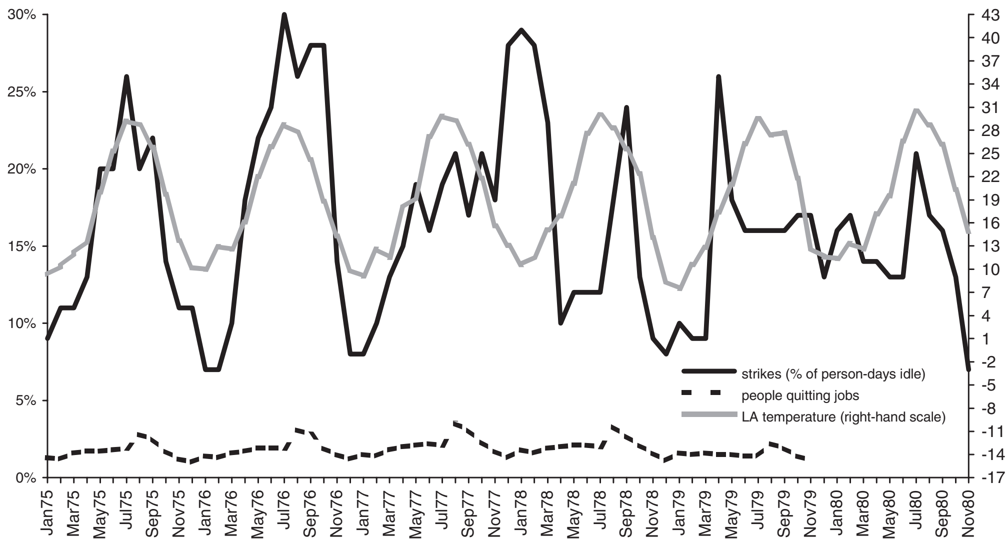

Figure 3. Effects of thermal stress on strikes and quitting jobs. Source: Bureau of Economics Statistics (1979); CRU (2004).

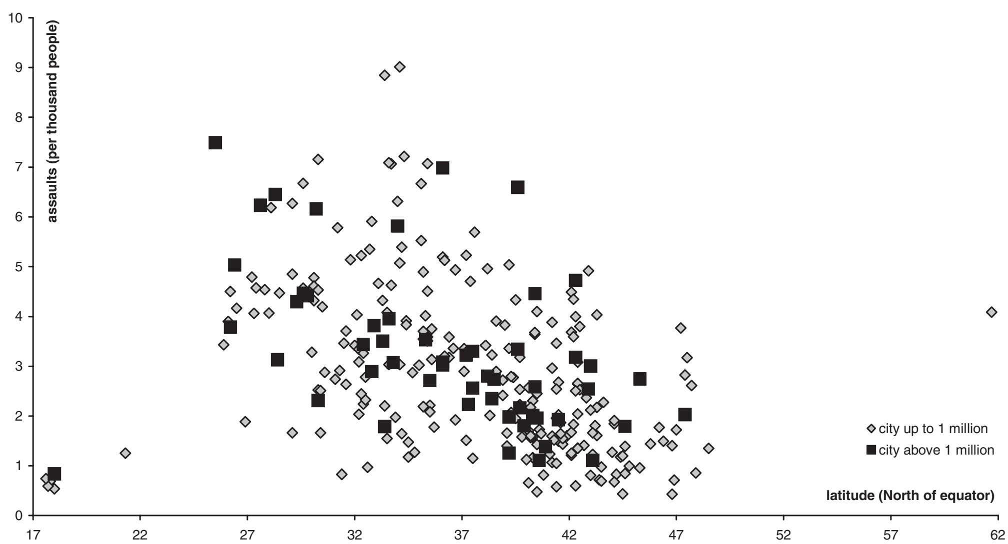

Figure 4. Aggravated assault rates (average 1999–2002) in U.S.A. cities, by latitude. Source: FBI (2003); CRU (2004).

Puerto Ricans—if acclimatized—can cope easily with the temperatures. Apart from Puerto Rico, crime rates tend to decline as we go from left to right in Figure 4, i.e. from the southern U.S.A. to Anchorage (61.7° north). This is consistent with evidence reported in Anderson (1989, pp. 78–79). There are low assault rates in Figure 4 around latitude 45°, which includes parts of the Midwest; Anchorage has higher rates of assaults. This suggests the area around latitude 45° is the least stressful part of the U.S.A.: areas south of here are too hot, and areas north of here are too cold, for human comfort. This seems compatible with FBI (1997, p. 11): violent crimes (per thousand people) were 7.07 in south U.S.A.; 6.92 in west U.S.A.; 5.37 in the Midwest; and 5.55 in the north-east. It also seems consistent with Figure 1: most violent crime occurs in hot months, because most U.S.A. citizens live in areas which get too hot (most cities are on the left-hand-side of Figure 4). Figures 1 and 2 also suggest a slight increase in crimes in January, and it may seem obvious that temperature-related violence in Anchorage is associated with extreme cold in winter; but, as we show later, this interpretation is incorrect. Christmas has been suggested as a cause of increased crime in winter (Anderson, 1989, p. 80), but we find this implausible—for example, Pakistan is a mainly Muslim country, but shows a small rise in violence around January (Simister, forthcoming).

Crime rates tend to be higher in large cities: for example, FBI (1997, p. 11) reports average rates of violent crime per thousand people in 1996 as 7.15 in metropolitan cities, 4.61 in smaller cities, and 2.22 in rural counties; so we would expect large cities to be near the top of Figure 4. But this is not always the case—for example, several small cities are (approximately) vertically above Los Angeles in Figure 4. Similarly, crimes rate in Figures 1 and 2 are not smooth curves: there are many small vertical 'spikes' (increases and decreases from month-to-month), which we consider to be 'noise' due to random factors irrelevant to this article. According to the 'Central Limit Theorem', such variations are more noticeable in smaller samples; hence data from a small city will tend to show a pattern less clear than Figure 2. This suggests we cannot rely too much on the crime rate in a small town/city (where a few random assaults can noticeably distort the crime rate), and makes us cautious in interpreting Anchorage's high crime rate as evidence that Alaska has higher crime rates than (for example) latitude 45°. But Johnson (2002, p. 15) reports 4.20 aggravated assaults per thousand people for Alaska as a whole; this is close to the rate of 3.99 for Anchorage (shown in Figure 4). It may be desirable to add Canadian data to Figure 4, if suitable data can be found—but care would be needed, to ensure Canada has a comparable equivalent to 'aggravated assault' in U.S.A. law.

Figure 5 uses the same data as Figure 2, but in a different form: we use monthly data on assaults in Los Angeles, based on the average (in January, etc.) each year from 1988 to 2002. We call this the 'FBI method' of expressing data as percentage of the annual number of crimes (mentioned earlier, for Figure 1). We also show two other types of violent crime: murders and rapes. We use average Los Angeles temperatures each month (from 1988 to 2002). Figure 5 indicates a link between temperature and violent crime, and is generally consistent with our previous results: monthly crime rates vary between about 7 per cent of annual crime (in cold months) to about 10 per cent of annual crime (in hot months). The longest day-length in the northern hemisphere is in June, but crime peaks are in July or August—

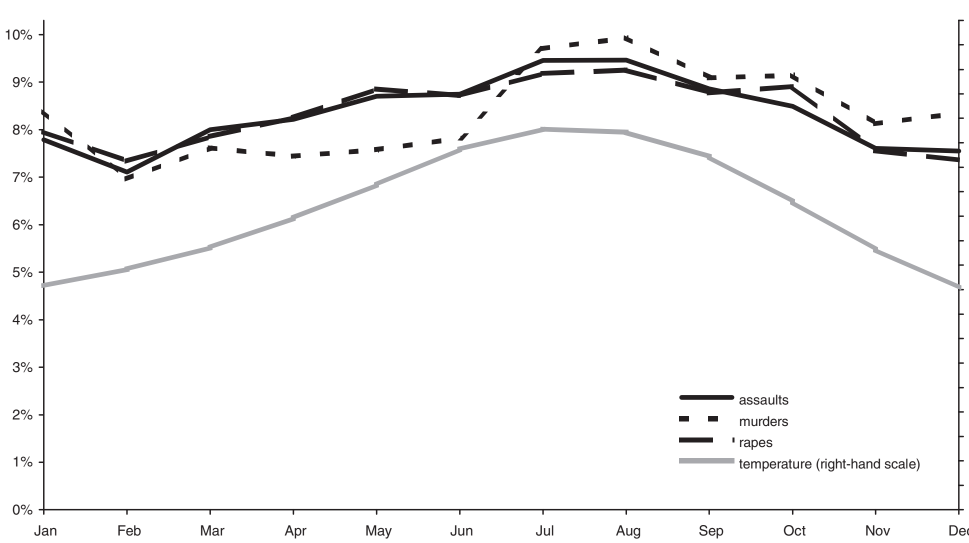

Figure 5. Violent crimes in Los Angeles, 1988 to 2002, by month. Source: LAPD (2003 and earlier); CRU (2004).

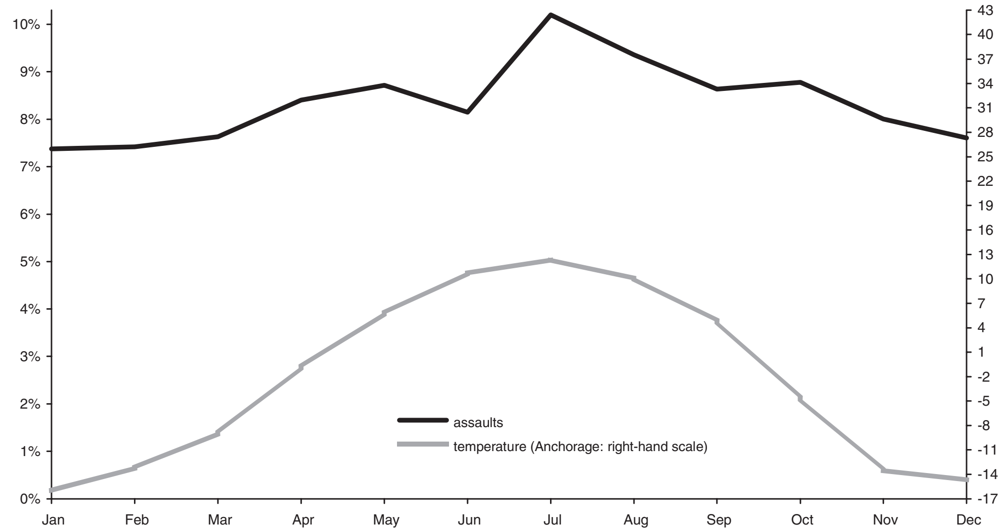

Figure 6. Assaults in Alaska, 2000 to 2002, by month. Source: Johnson (2002, and equivalent reports for 2001 and 2000); CRU (2004).

suggesting it is temperature, rather than amount of daylight, which raises violent crime rates.

Figure 6 uses Alaska data, from Johnson (2002, and equivalent reports for 2001 and 2000 from the same website); again, we use the 'FBI method' to remove trends, by calculating the average percentage of assaults in January (and other months) for these 3 years. Figure 6 is broadly equivalent to Figure 5. For clarity, Figure 6 shows only one type of violent crime (assaults); we found murder and rape data for Alaska (not reported here) show a similar pattern to assaults in Figure 6.

Figure 6 surprised us: it shows a clear peak in assaults in July, the hottest month. In our discussion about Figure 4, we interpreted the fairly high crime rate in Anchorage (and Alaska generally) as being due to extreme cold; but Figure 6 makes it clear that this interpretation is mistaken. Rather, Figure 6 implies crime increases due to excessive heat, even though Alaska is cold relative to the rest of the U.S.A. People react to extreme cold by wearing extremely warm clothes; if they enter a heated building without removing enough layers of clothing, they could feel very hot and react aggressively due to adrenaline. An alternative explanation for Alaskan violence is acclimatization: perhaps Alaskans get so used to cold weather that they find their summers uncomfortably hot.

Figure 5 suggests that crime rates in Los Angeles rise when temperatures fall below about 11°C; and crime is also high in Alaska when temperatures are about 11°C. Is there something special about a temperature of 11°C? The answer is no, as shown in Figure 7 which examines Phoenix, Arizona. Figure 7 uses the same method as Figures 5 and 6 (but for a different time-period, due to data availability in Phoenix Police Department, 2004). Figure 7 does not show a peak in crime rates at 11°C.

Figures 5–7 all show a broadly similar seasonal pattern, in which more violent crimes occur in summer. So we are left with a puzzle: how can we explain the unexpectedly high crime-rate in Anchorage in Figure 4? Because Alaskan summers are not hot, we would expect little crime in Alaska. Perhaps crime is higher than expected simply due to random variation; but our regression results (later) suggest that crime rates do increase in very cold weather. More data would be helpful, to settle this issue.

Next, we turn to the question of the shape of the curve relating temperature to aggression. Anderson (1989, p. 75) suggests several possible shapes for the curve:

- Inverted-U: aggression is highest at a particular temperature, and then declines.
- M-shaped (two inverted Us): cold or heat cause aggression, but aggression declines at very extreme temperatures.
- Linear: aggression increases steadily as temperature increases.

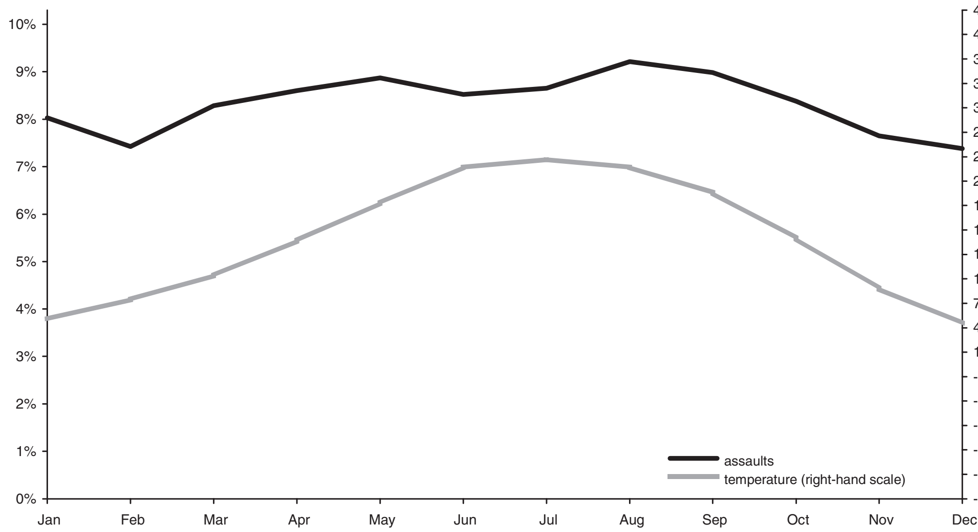

Figure 7. Assaults in Phoenix, 1996 to 2003, by month. Source: Phoenix Police Department (2004), CRU (2004).

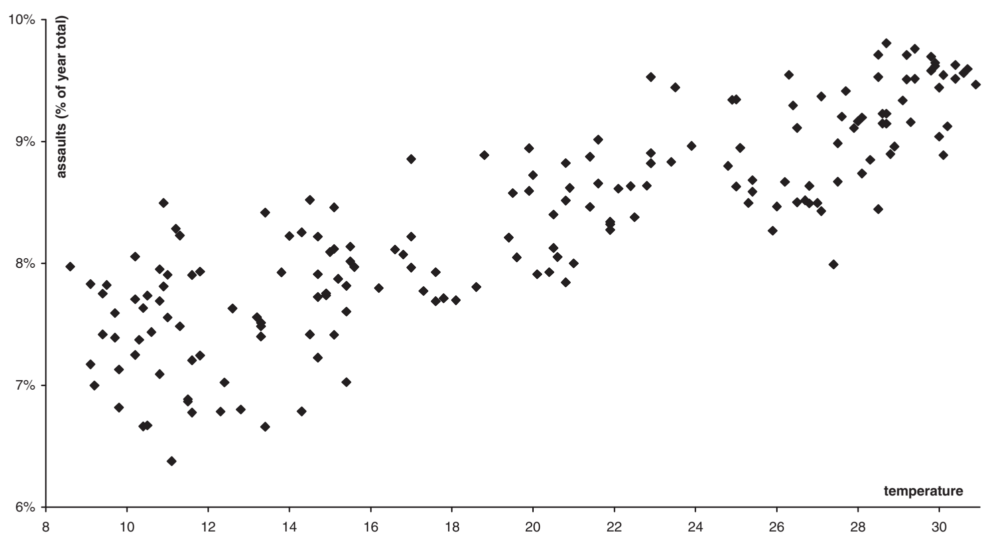

Figure 8. Aggravated assaults versus temperature in Los Angeles, 1988–2002. Source: LAPD (2003 and earlier); CRU (2004).

- J-shaped: aggression is not affected until a critical temperature, above which further temperature rises raise aggression rates.
- U-shaped: there is an optimal range of temperatures, but extremes of heat or cold cause aggression.

To examine this issue, we create Figure 8 from Los Angeles data. We consider this the best dataset we have to explore this issue, because Los Angeles is a big city (we would prefer New York City data, if it were available). Figure 8 uses the same data as Figure 2, but Figure 8 is a scatter graph rather than a time-series graph.

Does Figure 8 suggest an inverted-U, M, linear, J, or U-shaped graph? We think probably not. A casual glance suggests a linear graph (with a positive slope); but we think Figure 8 is actually V-shaped, with the minimum level of violence at about 11°C. This optimal temperature will differ from 11°C in other geographical locations, due to acclimatization (as Figures 5–7 indicate). Another puzzle is why Los Angeles residents do not acclimatize in such a way that the minimum point of the V-shape is about the middle of Figure 8. But no doubt acclimatization does occur, and this will have affected Figure 8 (we cannot tell what shape Figure 8 would have been, if acclimatization had not occurred).

The V-shaped graph in Figure 8 surprised us, because we expected a wide range of temperatures at which humans feel comfortable—suggesting a U-shaped curve. For example, a temperature of 20°C does not sound particularly hot, and yet Figure 8 suggests there is more crime at 20°C than at 11°C. Note, however, that a month in which the average temperature is 20°C includes days much hotter than 20°C. Daily data (if available) would be preferable, but still imperfect: temperatures also vary during each day.

Above a set-point (usually a blood temperature around 37°C), the human body's mechanisms promoting heat loss operate; whereas at temperatures below the set-point, heat-conserving and heat-generating systems operate (Pocock & Richards, 1999, p. 541). This suggests we should expect a V-shaped curve in Figure 8. Roberts (1986, pp. 238–239) suggests that for a naked man, 29°C is comfortable (Roberts does not indicate whether a woman has different preferences to a man); Brück (1989, p. 631) suggests a seated, lightly clothed person in 50 per cent humidity will prefer a temperature around 25 to 26°C (but other factors such as work and acclimatization also affect preferences). Humphreys (1995, p. 8) claims that humans prefer temperatures ranging from 17 to 33°C. These preferred temperatures are all hotter than the minimum-crime temperature in Figure 8, which we think is about 11°C; why are these temperatures so different?

Roberts (1986, pp. 238–239) describes an 'efficiency range', in which the body can control temperature by physical means (such as vasodilatation and sweating); if the temperature is hotter or colder than this end of the efficiency range (implying that the lower end of the efficiency range is about 11°C in Los Angeles in winter).

Regression analysis on household survey data

To investigate the effects of temperature on crime, we use regression analysis on the data displayed in Figure 8: number of assaults in Los Angeles. We processed assault data from January 1988 to December 2002, using the 'FBI method' as explained for Figure 1 (to remove any trend). We then calculate the square of temperature, to assess the 'curvilinear hypothesis'—that extremely hot temperatures are less associated (than moderately hot temperatures) with crime. We calculate a measure of 'too cold', equal to (9—temperature) if temperature is below 9°C, or zero otherwise. The choice of below 9°C as 'too cold' is arbitrary: we chose it by trial-and-error, to maximize the statistical significance in our regression (We could have used 11°C, to match in Figure 8). This cut-off temperature would need to be changed if studying a city in a different climate, due to acclimatization. We have not obtained data on humidity, but use rainfall per month based on NOAA (1991, p. 9); this gives us average rainfall in Los Angeles for January, for February, etc., but we would prefer data for each year and month. We also created the 'Day length' variable as a proxy for amount of daylight in each month: a sine wave (equal to −1 each December; zero in March; 1 in June; zero in September).

Because of seasonal patterns in the data (see Figure 2), we use ARIMA regression. After experimentation, we decided the most appropriate functional form is to include one autoregression term (AR1: to control for the fact that this month's crime-rate is similar to that of last month), and two seasonal autoregression terms (SAR1 and SAR2: because crime in one month is similar to the crime level 12 or 24 months ago). Adding these autoregressive terms reduces the risk of finding a spurious result. Almost all autocorrelation in the residuals was removed by adding AR1, SAR1 and SAR2 terms. Our regression results are shown in Table I.

There are several lessons we learn from the regression results in Table I:

- hot months tend to have more crime, and this pattern is statistically significant;
- the 'temperature squared' term is about zero, which casts doubt on the 'curvilinear hypothesis' (that violence diminishes at very high temperatures)—but Los Angeles never gets as hot as some places where humans live, so data from hotter locations is needed;
- there is a statistically significant coefficient for 'Too cold', indicating that Los Angeles crime rates rise if temperatures fall below about 9°C;

Table I. Regression analysis of assaults in Los Angeles.

Variable	Coefficient	*t*-Ratio
Temperature	0.001	2.5*
Temperature^2	–0.000003	–0.2
Too cold	0.020	2.2*
Day length	–0.001	–0.7
Rainfall	0.001	1.0
AR1	0.19	2.6*
SAR1	0.38	5.1**
SAR2	0.22	2.8**
Constant	0.05	7.9**

N = 180 cases; adjusted R^2 = 0.004; * indicates statistically significant at 5 per cent; ** significant at 1 per cent.

- the 'Day length' coefficient is not statistically significant, which suggests it is temperature (rather than daylight) which causes crime rates to rise in summer;
- the 'Rainfall' coefficient is not statistically significant; but this is not a persuasive result, because we really need humidity data to assess if damp heat is more stressful than dry heat.

The shape of the curve in Figure 8 may tell us about the underlying process: Anderson (1989, p. 75) explores four psychology-based explanations for seasonal crime patterns, and suggests they predict an inverted-U-shaped or M-shaped relationship (at very extreme temperatures, aggressors do not confuse irritation due to uncomfortable temperature with irritation caused by a nearby person). Baron and Bell's research (cited in Anderson, 1989, p. 76) suggests a peak in aggression about 29°C. We do not see a fall in crime above 29°C in Figure 8, but Figure 8 does not tell us what happens above 31°C, and hence does not convincingly reject Baron and Bell's ideas. Research (cited in Anderson, 1989, pp. 88–89) on Houston, Texas, which is generally hotter than Los Angeles, also failed to support the curvilinear hypothesis. It would be interesting if future researchers analyse locations experiencing a wider range of temperatures than Los Angeles, to assess whether crime really does increase below about 11°C, and whether crime rates fall at temperatures over 31°C.

In summary, our evidence (from Figure 8 and regression) seems consistent with the adrenaline hypothesis, and seems difficult to reconcile with psychological models. However, we expected the adrenaline hypothesis to predict a U-shaped (not V-shaped) curve. In addition, assuming adrenaline is not produced at low temperatures, there must be a different cause of aggression (such as noradrenaline) below 11°C.

Conclusion

This article reports evidence to confirm the hypothesis that violent crime rates vary from month-to-month in a seasonal pattern, and this evidence is consistent with the hypothesis that the seasonal pattern is caused by temperature. We think this seasonal pattern is due to the side-effects of stress hormones (which the body generates to cope with thermal stress). We also apply the hypothesis (that thermal stress causes aggression) to the workplace, and find seasonal patterns in two forms of work-related behaviour: strikes, and quitting jobs. We interpret our findings in terms of the effect of thermal stress, and hence effects of stress hormones, in causing violent crime and impulsive behaviour at work.

If there is a link between temperatures and violence, our evidence suggests adrenaline is more likely to be involved than noradrenaline, because violence is associated more with hot than cold weather (and adrenaline is associated with extreme heat). Our evidence (in charts and regression) suggests some increase in violence in extreme cold; this cannot be explained by adrenaline, but might be explained by noradrenaline. However, the evidence for increased violence in extreme cold is not persuasive—for example, Alaskan violence is more common in summer than in winter (Figure 6).

The temperature at which violent crimes increases is not fixed at a particular temperature: our Figures 5–7 indicate violent crimes rise in summer, but the same figures indicate that these three cities have very different temperatures. If there were some absolute temperature above which the human body is unable to cope, we would expect a very high crime-rate in Los Angeles, but little or no seasonal pattern in cooler places such as Phoenix and Alaska. We think Los Angeles residents adapt to the range of temperatures in their city, and can cope fairly easily with a temperature of (for example) 20°C—whereas Phoenix residents are not used to temperatures as high as 20°C, and appear to experience stress, leading to increased crime-rates.

In summary, we think there is strong evidence that adrenaline causes the summer peak in violence; but we cannot tell if noradrenaline has similar effects which explain increasing crime in winter. We cannot tell whether testosterone is implicated in violent crimes. Testosterone is associated with the sex drive, so some observers might interpret rape statistics as indicators of the effects of testosterone; or perhaps rape is more a form of violence against women, than a sexual act. Our research using U.S.A. data (not all reported here) suggests that seasonal patterns of rape are very similar to seasonal patterns in other types of violent crimes (such as murders, assaults, and robberies). Evidence from India in Simister (forthcoming) suggests rapes are less likely to occur at very high temperatures; this could plausibly explain the 'curvilinear hypothesis' discussed earlier, if testosterone-related crime is reduced at very high temperatures. Crime data from a small town would generate 'noisy' (and hence unreliable) findings, and the largest U.S.A. cities tend to be in areas which do not experience very high temperatures.

There are many questions to which this article can only offer tentative answers. For example, Figure 1 suggests that there are also more violent crimes in cold months, but much less pronounced than the effect of hot weather. This is incompatible with our Figure 6, showing that most crime in Alaska is in the summer months, despite the fact that Alaska never reaches temperatures we consider 'hot'. We think there is strong evidence that adrenaline is involved in seasonal aggression, but we cannot tell if noradrenaline or testosterone (or both) are also causing violence. More research is needed.

Ethical problems prevent some types of research (for example, it would be impossible to inject every citizen of a city with adrenaline, to see if the homicide rate rose); so epidemiological research may be appropriate. We encourage the FBI and other agencies to make monthly crime data available for as many cities and/or states as possible, to help criminologists investigate these issues further. More information on time-of-day crimes occur would also help.

Of course, thermal stress is no excuse for violence: no reasonable person would carry out murder, rape, or similar violence at any temperature. But we advise people to be aware of the increased risk of rape or other violence when the temperature is unusually hot (compared with temperatures usually experienced in that location). This problem, and hence our advice, is not limited to the U.S.A. Although humans tend to react violently to thermal stress, people can learn to control this response (Kemper, 1990, p. 133). Perhaps violence can be reduced if schools and workplaces explain the effects of extreme temperatures (and how to spot warning signs).

Acknowledgements

We are grateful to the organizations mentioned in this article, for making data available: in particular, we found Los Angeles Police Department, Alaska Police Department, and FBI especially helpful. The Climatic Research Unit (University of East Anglia, Norwich, U.K.) provides very useful temperature data. We are also grateful to Judith Makowiec (Nurse Practitioner) and Dr Ruth Clancy. Any mistakes in this article are the responsibility of the authors, not these organizations or individuals.

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