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ORIGINAL ARTICLE

Effects of temperature variation on suicide in five U.S. counties, 1991–2001

P. G. Dixon · A. N. McDonald · K. N. Scheitlin · J. E. Stapleton · J. S. Allen · W. M. Carter · M. R. Holley · D. D. Inman · J. B. Roberts

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Abstract Effects of weather variables on suicide are well-documented, but there is still little consistency among the results of most studies. Nevertheless, most studies show a peak in suicides during the spring season, and this is often attributed to increased temperatures. The purpose of this study is to test the relationship between monthly temperature and monthly suicide, independent of months or seasons, for five counties located across the United States. Harmonic analysis shows that four of the five counties display some seasonal components in the suicide data. However, simple linear regression shows no correlation between suicide and temperature, and discriminant analysis shows that monthly departure from mean annual suicide rates is not a useful tool for identifying months with temperatures that are colder or warmer than the annual average. Therefore, it appears that the seasonality of suicides is due to factors other than temperature.

Keywords Suicide · Bioclimate · Seasonality

Introduction

Countless relationships between weather variables and human health have been documented dating back to the observation by Hippocrates that cold and warm winds affected the physical and psychological health of his patients (Deisenhammer 2003; Schory et al. 2003). Unfortunately, many of these relationships are based primarily on statistical correlations that do not necessarily equate to causal relationships, and many studies yield conflicting results due to varying methods, data sources, study periods, etc. (Deisenhammer 2003; Dixon and Shulman 1983; Driscoll 1971). However, these statistical relationships are usually among the first steps to identifying possible effects of weather on human health.

The effects of weather and climate on suicide present an even more challenging research problem since suicide is a complex, psychopathological phenomenon that is driven not only by biological variables, but also by interactions between individuals and their environments (Deisenhammer 2003). Therefore, no individual suicide can be causally related to a single event (Deisenhammer 2004). Rather, a patient's suicide risk usually increases with the number of risk factors, and some weather variables may tend to exacerbate such a risk (Deisenhammer et al. 2003; Sher 2004). In addition, suicides are quite rare, even among groups of people that are considered to be at a higher risk of committing suicide (Sher 2004). Regardless, many studies have identified significant relationships between suicide and atmospheric variables (Deisenhammer et al. 2003; Lambert et al. 2003; Nicholls et al. 2006; Partonen et al. 2004a; Preti 1997; Preti and Miotto 2000; Salib 1997).

Some studies, albeit relatively few, have found that there are no associations between meteorological variables and suicide (Chiu 1988; Deisenhammer 2003; Digon and Bock 1966; Dixon and Shulman 1983; Pokorny 1966; Pokorny et al. 1963), but even studies that identify positive weather–suicide connections often yield contradictory results. This could be attributed to the fact that some studies analyze multiple (as many as 46) meteorological variables (Deisenhammer 2003). For instance, some of the numerous studies correlating suicide with temperature claim to find an increase in the number of suicides when

P. G. Dixon (✉) · A. N. McDonald · K. N. Scheitlin · J. E. Stapleton · J. S. Allen · W. M. Carter · M. R. Holley · D. D. Inman · J. B. Roberts
Department of Geosciences, Mississippi State University, Mississippi State, MS, USA
e-mail: grady.dixon@msstate.edu

temperatures are colder (Linkowski et al. 1992; Souêtre et al. 1990; Thorson and Kasworm 1984; Tietjen and Kripke 1994) while most find just the opposite (Breuer et al. 1986; Deisenhammer et al. 2003; Lester 1986; Maes et al. 1994; Preti and Miotto 2000; Salib 1997; Salib and Gray 1997; Souêtre et al. 1987). Further, most studies show that suicide rates vary according to season with the most common peak occurring in late spring or early summer (Deisenhammer et al. 2003; Lambert et al. 2003; Parker and Walter 1982; Partonen et al. 2004a; Preti 1997; Preti and Miotto 2000).

Inconsistent methods

There are numerous possible explanations for why past studies have such varying results (e.g., actual differences in suicide patterns between countries, latitudes, economic groups, time periods, etc.), but one of the most obvious is the lack of consistent research methods. Many studies suffer from fundamental problems with respect to data collection and/or analyses. In order to confidently test relationships involving weather variables (temperature, seasonality, precipitation, humidity, etc.), the sample in question must span several years in order to avoid drawing general conclusions from a single, anomalous year. Likewise, a study of weather effects on people should certainly represent multiple locations (hopefully of varying latitude) in order to avoid unknown local variables. Unfortunately, many past studies have made claims about relationships between suicide and weather variables based on a single, relatively small study area (i.e., city or county) and/or a single year of data (Breuer et al. 1986; Chiu 1988; Deisenhammer et al. 2003; Partonen et al. 2004a; Salib 1997; Salib and Gray 1997; Schory et al. 2003; Wang et al. 1997). None of the articles listed above are published in meteorology or climatology journals.

Unfortunately, simply ignoring studies with flawed methods (e.g., short study period, testing a single location, etc.) does not clear up the confusion about the effects of weather on suicide. There are other studies with no obvious methodological problems that directly contradict each other (Chew and McCleary 1995; Geltzer et al. 2000; Lambert et al. 2003; Lester 1999; Linkowski et al. 1992; Preti and Miotto 2000; Zung et al. 1974). Some of these authors identify positive correlations between weather variables and suicides, some identify negative correlations, and some identify no correlations. There are even contradictory results by the same authors, as Souêtre et al (1987) found that monthly suicides in France tend to increase with increasing temperature and sunlight duration only to later find that annual suicides in France decrease with increasing temperature and sunlight duration (Souêtre et al. 1990). This widespread inconsistency might lead some researchers to the conclusion that weather variables do not significantly affect suicide risks, and that any statistics suggesting otherwise are likely coincidence. Nevertheless, it is widely accepted that suicide rates tend to peak in late spring and are lowest during winter months (Chew and McCleary 1995), and it is this well-documented seasonality that continues to lead researchers to examine the effects of weather variables on suicide.

Nonclimatic variables

Due to contradictory results of weather-related studies, suicide researchers must question whether suicide seasonality is due to bioclimatic or social causes. As listed above, many studies have been focused on the bioclimatic causes, but some seasonal social variables have also been identified as possible causes of suicide. The beginning and end of school years, agricultural cycles, and major holidays have all been cited as possible causes of suicide that would contribute to a seasonal signal (Deisenhammer 2003). Meares et al. (1981) found a single annual suicide cycle for men in England, but found two cycles for women, with a peak in autumn in addition to the usual peak in spring. This finding has been attributed to increased suicide rates among mothers of school-aged children at the beginning of the school year (Deisenhammer 2003). Further, Nayha (1982) found that the fall suicide peak in Finland is disproportionately composed of students. One common reason used to explain such temporal effects on suicide is known as the "broken-promise effect". The broken-promise effect is the result of un-met, elevated expectations, by people experiencing suicidal risk factors, with respect to anticipated events (arrival of spring, weekends, holidays, etc.) (Gabennesch 1988).

In one of the more extensive studies on suicide seasonality, Chew and McLeary (1995) found that agricultural countries experience more pronounced seasonal cycles (i.e., spring peak) than industrialized countries. This is attributed to the fact that the well-being of citizens in industrialized regions is not "linked" to natural seasonal cycles as it is for agricultural societies (Chew and McCleary 1995). These claims are supported by an earlier study that shows decreasing suicide seasonality in Finland since the 1920s, but a more recent paper argues that suicide seasonality in Finland is still evident and displays significant fluctuations (Nayha 1982; Partonen et al. 2004b).

After decades of research on this topic, it still remains unclear whether suicide is significantly affected by weather variables. It is fairly well established that many locations experience notable seasonality with respect to suicide, and the spring peak continues to be the most detected signal. However, it has been suggested that suicide becomes less seasonal as communities become more industrialized (Chew and McCleary 1995; Meares et al. 1981; Nayha 1982). Such claims are explained by the decreasing dependence on agriculture and the creation of small peaks

Table 1 Counties included in this study

County	State	Station	Elevation (m)	2000 population density (per km^2)
Orange	New York	West Point	97.5	161.3
Pierce	Washington	Tacoma	7.6	161.4
Richland	South Carolina	Columbia USC	73.8	163.5
Sedgwick	Kansas	Wichita	402.6	174.7
Ventura	California	Oxnard	14.9	157.4

throughout other parts of the year (due to social variables mentioned above). If these claims are valid, they support the concept that seasonal suicide is not directly affected by weather; at least not as much as other, more important variables. Either way, it seems very difficult for most researchers to separate seasonality and weather, especially temperature. Even though some studies have proposed nonclimatic seasonal variables as possible causes of suicide seasonality, it appears that few, if any, studies have attempted to test the relationships that suicide has with seasons and with temperature for the same location over the same time period. If it is shown that a location experiences seasonal suicide, but that suicide is not related to temperature, then a strong case can be made for the importance of seasonal social variables (e.g., school year, holidays, etc.).

Materials and methods

A major difficulty in suicide data collection and analysis is underreporting of suicide because classification requires sufficient proof of suicidal intent from the person (Timmermans 2005). For the purpose of this study, suicide was operationally defined using cause of death data from a database maintained by the Center for Disease Control and Prevention's National Center for Health Statistics (NCHS). Mortality statistics in the database are classified by causes of death using the International Classification of Disease (ICD), in particular the ninth edition (ICD-9) for deaths up to 1998 and the tenth edition (ICD-10) for deaths 1999 to the present. NCHS's multiple cause of death data were obtained from the National Bureau of Economic Research for the years 1991–2001. Individual suicides are identified by county of occurrence, county of residence, year, month, and several other variables, when available (e.g., sex, age, occupation, education, etc.). Date of suicide is not described beyond monthly resolution.

Monthly mean temperature data were obtained from the National Climatic Data Center. All of the stations used in this study are part of the National Weather Service Cooperative Observer Program. Maximum and minimum temperature values are recorded for each of these stations at least once every 24 h, and these values are used to calculate daily and monthly means.

Table 2 Total male (M) and female (F) suicides by month, mean annual suicide rates (per 100,000 people), and standard deviation for annual suicide rates for each county during the study period

Month	Orange		Pierce		Richland		Sedgwick		Ventura	
	M	F	M	F	M	F	M	F	M	F
1	7	**3**	72	15	24	5	41	7	51	16
2	8	1	**79**	*11*	21	5	42	12	56	13
3	**10**	*0*	*56*	15	28	4	40	*5*	43	**19**
4	*5*	2	71	18	*14*	6	**58**	10	51	10
5	7	1	61	12	24	7	40	7	52	14
6	6	2	74	19	30	8	49	11	54	11
7	9	*0*	68	19	23	**13**	50	8	56	*9*
8	8	1	74	23	23	12	41	**14**	43	13
9	**10**	*0*	*56*	12	27	5	38	8	54	14
10	9	*0*	57	**28**	25	10	*32*	9	**57**	14
11	9	*0*	61	16	**33**	4	46	8	*37*	12
12	6	1	70	20	**33**	*3*	34	8	48	15
Total	94	11	799	208	305	82	511	107	602	160
Mean annual suicide rate	0.44	0.05	1.84	0.48	1.53	0.41	1.77	0.37	1.27	0.34
SD of suicide rate	0.52	0.17	0.76	0.37	1.05	0.59	0.92	0.42	0.60	0.30

Highest monthly suicide totals for each county are in bold; lowest monthly totals are in italics.

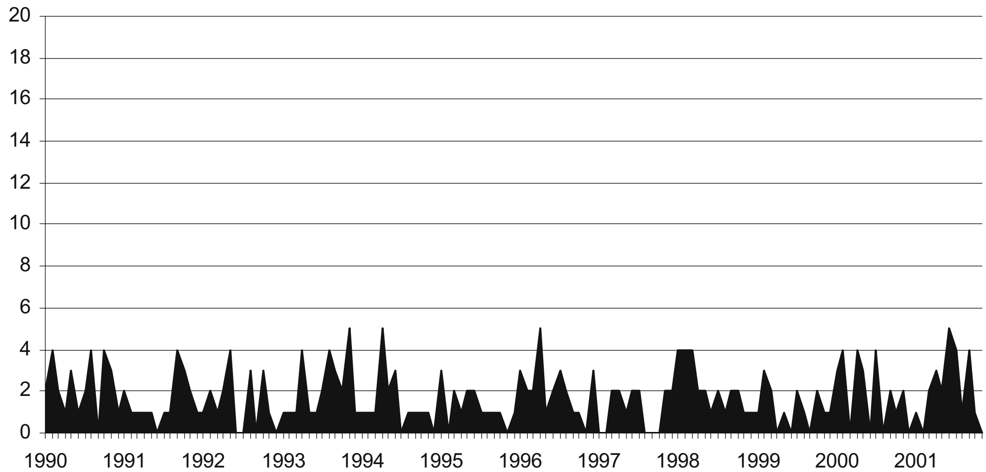


Fig. 1 Monthly suicide totals for Orange County, New York (1991–2001)

Population estimates for the years 1991–2001 were obtained from the United States Census Bureau. The annual estimates are for July of each year. Even though actual census data were available for 2000, those numbers are considered valid as of April. Therefore, the July estimate is used for 2000, just as it is for other years. These estimates do not distinguish percentages of male and female, so an even division among males and females is assumed for all locations.

The five counties included in this study were chosen because of their similar population densities, which have been shown to affect suicide rates (Deisenhammer et al. 2003). The counties were also chosen because of their differing climates and relatively low elevations. The counties included in this study are: Orange County, New York; Pierce County, Washington; Richland County, South Carolina; Sedgwick County, Kansas; and Ventura County, California (Table 1). This sample should represent five distinct physical environments and climates as well as multiple types of social settings.

Monthly averages of temperature are used in this study since the available suicide data are at a monthly resolution. Monthly values are actually preferred in order to avoid the numerous problems associated with estimating possible lag times between environmental causal factors and actual suicide events (Deisenhammer 2003; Deisenhammer et al. 2003; Papadopoulos et al. 2005; Sher 2004).

The first objective was to identify any patterns, trends, and/or seasonality in suicide for each location. This was accomplished by simply plotting the number of monthly suicides in each study county for each month of the study period. Further, all locations were compared to each other in order to find any common patterns. An "average suicide" year was also established for each location based on the average number of total suicides (all counties combined) for each month. Further, harmonic analysis was used to determine any seasonality in the suicide data, by sex, for each location. The basic form of the harmonic equation used in this study is:

$$f(x) = \overline{X} + \sum_{r=1}^{N/2} A_r \cos(r\theta - \Phi_r)$$

where *f(x)* is the estimated value in each interval, $\overline{X}$ is the average value over the N observations, A_r is the amplitude

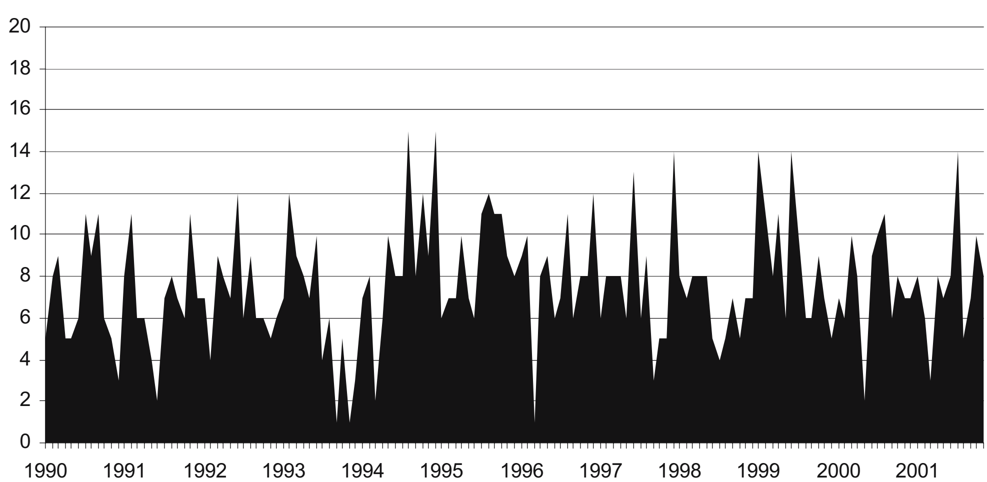


Fig. 2 Monthly suicide totals for Pierce County, Washington (1991–2001)

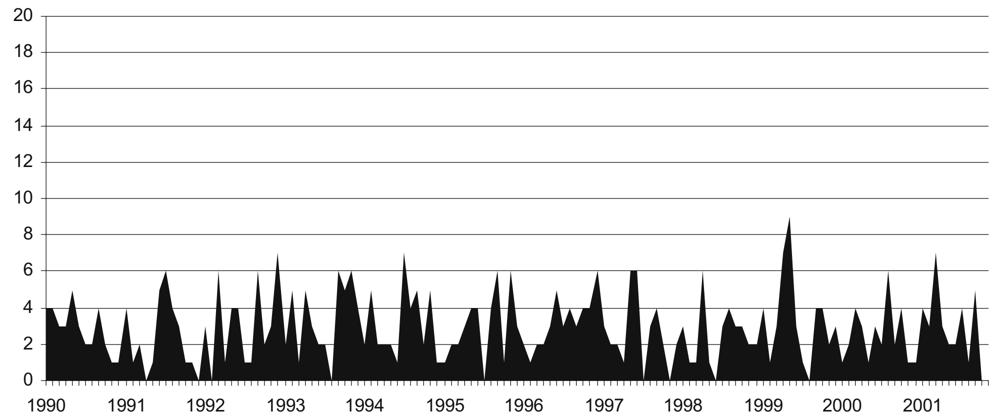


Fig. 3 Monthly suicide totals for Richland County, South Carolina (1991–2001)

of the r[th] harmonic wave, r is the frequency or number of times the harmonic wave is repeated over the fundamental period, θ is derived as $2\pi x/N$ where x represents the intervals through the fundamental period, and Φ_r is the phase angle of the r[th] harmonic, often reinterpreted as the time of maximum. The basic form is expanded to:

$$f(x) = \overline{X} + \sum_{r=1}^{N/2} \left[a_r \sin(2\pi rx/P) + b_r \cos(2\pi rx/P)\right]$$

where the Fourier coefficients, a_r and b_r, are calculated as:

$$a_r = \sum_{x=1}^{N} \frac{2}{N}\left[f(x)\sin(2\pi rx/P)\right]$$

and

$$b_r = \sum_{x=1}^{N} \frac{2}{N}\left[f(x)\cos(2\pi rx/P)\right]$$

The amplitude, A_r, is calculated as $\left(a_r^2 + b_r^2\right)^{0.5}$, the standardized amplitude is calculated as $A_r/2\overline{X}$, the phase angle, Φ_r, equals $\tan^{-1}(a_r/b_r)$, and the portion of variance explained by the r[th] harmonic wave, V_r, is determined as $\left(A_r^2 + 2s^2\right)$ where s is the standard deviation of the N values. A useful parameter may be generated when the standardized amplitude is multiplied by 2 and added to 1. For example, a standardized amplitude of 0.10 implies that the probability of occurrence in the peak period is 1.20 times the mean value.

Simple linear regression was used to correlate the number of monthly suicides, by sex, with mean monthly temperature. However, some normalization techniques were required to account for variation in climate and suicide rates between locations, as heat-related mortality is dominated by the difference between temperature extremes and the mean climate (Patz et al. 2005). Therefore, departure from mean annual temperature is used in addition to the actual temperature value. Likewise, in addition to using actual monthly suicide totals, monthly departure from mean annual suicide is used to normalize stations that might experience different suicide rates due to nonclimatic reasons.

Discriminant analyses were employed in order to reduce normality problems and to test the effects of temperature on suicide while limiting the effects of month, season, etc. This statistical method tests the ability to identify or predict the occurrence of one variable based on the variance in another variable. The commonly calculated statistic, Wilks' λ, is a measure (between 0 and 1) of the accuracy of the discriminant model, with a value of 0 being perfect. In this study, suicide rates, for males and females, are tested with

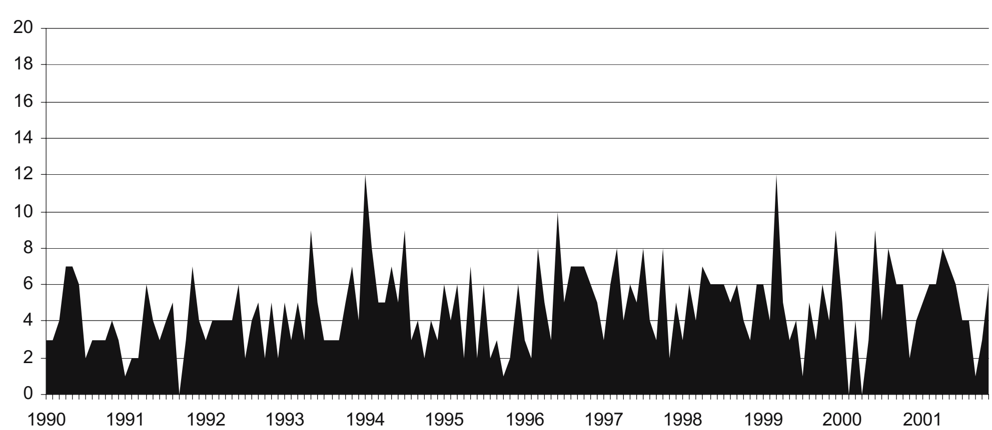


Fig. 4 Monthly suicide totals for Sedgwick County, Kansas (1991–2001)

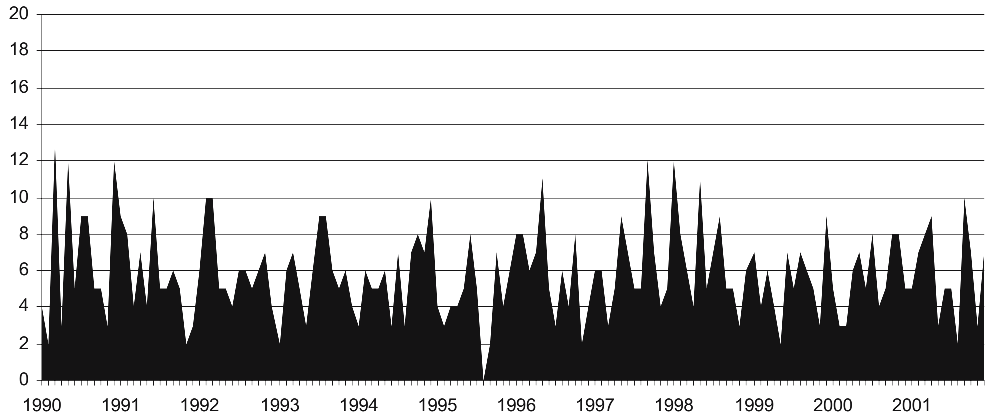


Fig. 5 Monthly suicide totals for Ventura County, California (1991–2001)

respect to their ability to predict mean monthly temperatures that are above or below normal. For further explanation of discriminant analysis statistics, see Wilks (1995).

Results

To avoid confusion and unnecessary speculation, only those suicides with the same county of occurrence and county of residence were used in this study. Over the 11-year study period, there were a total of 3,355 total suicides among the five counties. There are notable differences in total suicides and suicide rates between each county (Table 2). Pierce County, Washington, reported the most total suicides and maintained the highest average suicide rate while Orange County, New York, experienced the fewest events and the lowest suicide rate among the study counties.

None of the counties display obvious annual cycles with respect to total monthly suicides, but some increasing trends are identifiable (Figs. 1, 2, 3, 4 and 5). All the locations experience relative peaks and troughs during all times of the year; therefore, a seasonal signal is not evident from graphs of the raw data. However, results from harmonic analyses show that all the counties except Ventura County actually experience notable seasonality with respect to male and female suicides (Tables 3 and 4). Further, three of the five counties (Richland, Sedgwick, and Ventura) show peaks in male suicide (based on either or both of the harmonics) in late spring (Table 3). Only Pierce County displays a late-spring peak in female suicides (Table 4). Overall, based on all five counties, it appears that male suicides are more likely during spring and fall months, while female suicides are more likely during summer and winter months (Tables 3 and 4).

Weather variables for all of the stations vary as expected according to the climate of each location. Sedgwick County, Kansas, displays the most seasonality with mean temperatures of 0.1°C and 27.2°C in January and July, respectively (Table 5). Orange County, New York, experienced the coldest temperatures, on average, while Richland County, South Carolina, was the warmest location.

Temperature

Simple linear regression shows a very weak (R^2=0.006) statistically significant (α=0.05) relationship between mean monthly temperature and monthly suicide rates for all of the individual study counties (Fig. 6). The relationship between the two variables appears to be nearly random with only a subtle peak in suicide rates around 14°C. Of course, if monthly temperature was strongly correlated with suicide rates, warmer locations (such as Richland County, South Carolina) would have notably higher suicide rates than cooler locations (such as Pierce County, Washington). The suicide data used in this study clearly dispute such a relationship.

Table 3 Results of first and second harmonic analyses of total monthly male suicides during the study period in each study county

County	Mean	Std A_1	V_1	Φ_1	Std A_2	V_2	Φ_2	V_C
Orange	7.83	0.06	0.19	9.17	0.08	0.29	2.27	0.48
Pierce	66.58	0.02	0.09	3.00	0.06	0.45	0.48	0.57
Richland	25.42	0.07	0.25	10.12	0.06	0.19	5.28	0.44
Sedgwick	42.58	0.07	0.36	4.48	0.01	0.02	5.27	0.38
Ventura	50.17	0.02	0.07	5.49	0.01	0.02	1.06	0.09

Output listed include Standard Amplitude (Std A_r) of the first and second harmonics, variance (V_r) in monthly suicides explained by the first and second harmonics, the phase angle (Φ_r, interpreted as the month of maximum suicides), and cumulative variance (V_C) in monthly suicides explained by both harmonics.

Table 4 Results of first and second harmonic analyses of total monthly female suicides during the study period in each study county

County	Mean	Std A_1	V_1	Φ_1	Std A_2	V_2	Φ_2	V_C
Orange	0.92	0.34	0.21	2.64	0.31	0.18	0.00	0.39
Pierce	17.33	0.10	0.25	8.50	0.03	0.02	4.50	0.27
Richland	6.83	0.25	0.60	6.80	0.08	0.07	1.00	0.67
Sedgwick	8.92	0.06	0.11	7.08	0.06	0.10	1.23	0.21
Ventura	13.33	0.07	0.30	0.51	0.04	0.09	2.37	0.39

See Table 3 for explanation of column headings

Table 5 Mean monthly temperatures (°C) for each county, 1991–2001

Month	Orange	Pierce	Richland	Sedgwick	Ventura
1	−1.9	4.2	9.1	0.1	13.1
2	−0.4	5.3	11.5	4.1	13.5
3	3.7	6.9	14.6	7.6	14.1
4	10.0	9.2	19.3	12.9	15.0
5	16.1	12.5	23.6	19.0	16.3
6	21.0	14.8	26.5	24.0	17.7
7	23.2	17.6	28.8	27.2	19.0
8	22.7	17.8	27.7	26.7	19.5
9	18.1	15.1	24.5	21.5	19.0
10	12.0	10.2	18.8	15.1	17.6
11	6.4	6.5	13.7	6.9	15.2
12	1.2	4.1	9.7	1.8	13.3

The lack of a normally-distributed dataset, due in part to several months with no suicides, certainly has some effects on the regression results. However, this distribution might also be explained by the fact that "warm" and "cold" are relative terms dependent upon the climate of a location. This concept could allow for temperature to affect suicide rates despite the lack of a relationship between simple temperatures and suicide rates. Therefore, monthly departures from mean annual temperatures are compared to monthly departures from mean annual suicide rates, according to sex, for each county (Table 6). Table 6 shows weak, positive relationships, but only one location (Richland County, South Carolina) exhibits a statistically significant relationship. Similarly, linear regression shows a slight positive relationship between warmer-than-normal temperatures, as measured by departure from the mean, and above-normal suicide rates, as measured by monthly percentage of total annual suicides (Fig. 7). Conversely, discriminant analyses show little, if any, success in identifying months with above or below normal temperatures based on the suicide rate for each individual county over the entire study period (Table 6). This is due to the fact that there is approximately the same number of data points in each quadrant of Fig. 7. The positive relationship implied by the linear regression appears to be the result of a few more "extreme" values in the top-right quadrant. Nevertheless, the fact that the top-left and bottom-right quadrants have approximately the same number of occurrences as the other two shows that the relationship between temperature and suicide is not reliable. In other words, a month with above-average temperatures has nearly equal chances of experiencing an above- or below-average suicide rate. The same applies for a cooler-than-normal month.

Discussion

Most of the study counties display some seasonality with respect to suicides, but none of the stations show statistically significant relationships between temperature (or temperature departure from annual mean) and suicide

Fig. 6 Linear regression (with trendline) of mean monthly temperature (°C) on the x-axis and suicide rate (per 100,000 people) on the y-axis for all five counties during the study period. R^2=0.006, ρ=0.041

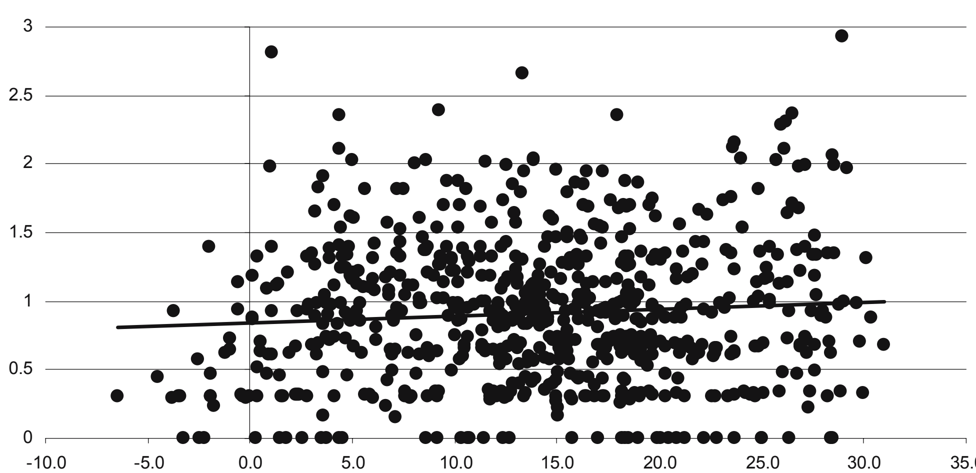


Table 6 Linear regression and discriminant analysis statistics comparing departure from mean annual temperature and departure from mean annual suicide rates

County	R^2		ρ		Wilks' λ		ρ	
	Male	Female	Male	Female	Male	Female	Male	Female
Orange	0.002	0.017	0.636	0.138	0.999	0.992	0.758	0.321
Pierce	0.001	0.015	0.732	0.156	1.000	**0.963**	0.903	**0.026**
Richland	0.004	**0.058**	0.469	**0.006**	0.998	**0.930**	0.644	**0.002**
Sedgwick	0.006	0.006	0.381	0.399	0.998	0.988	0.586	0.207
Ventura	0.006	0.010	0.362	0.252	0.974	1.000	0.066	0.908

Significant relationships are bold (α=0.05)

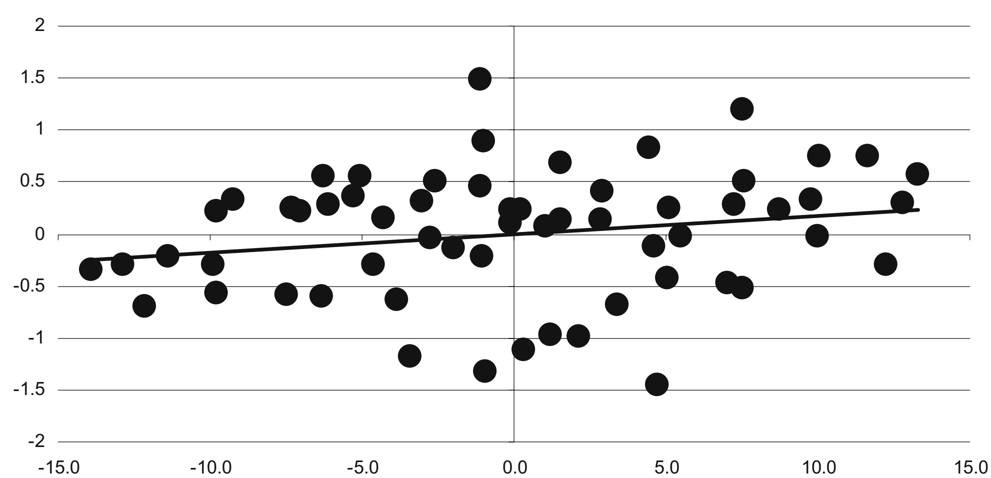
rates. Therefore, it appears that suicide seasonality is due to factors other than temperature.

Due to the fact that temperature is so closely related to the seasons, it can be difficult to separate the two during analyses. If a seasonal signal exists in a dataset, temperature is usually one of the first explanations. Further tests of the relationship between temperature and the dependent variable often yield positive results, even if there is no significant relationship, simply because temperature covaries with seasons. This mistake can be made simply by testing the wrong hypotheses or using the wrong statistical methods. The different results yielded in this study by linear regression, harmonic analysis, and discriminant analysis make a great example. A simple linear regression shows that there is a weak, positive correlation between above-normal temperatures and above-normal suicide rates. Likewise, harmonic analysis results show some seasonality in the suicide data, which usually implies a relation to temperature. However, further inspection of the scatterplot and implementation of discriminant analyses show that departure from mean suicide rates provide little or no success in correctly identifying months with above or below mean annual temperature. Similarly, detailed analysis of the first and second harmonics of monthly suicide for each county shows that male suicides reached peaks primarily in spring and fall months, while female suicide peaks occurred in summer and winter.

This study has provided evidence of the lack of a direct relationship between temperature and suicide rates for five counties in the United States. This is despite seasonal signals in suicide rates, which means that suicides are affected by seasonal variables other than temperature. These findings are relatively consistent with results from Finland showing that geophysical effects on suicide, while detectable, cannot explain the seasonality, nor are they as important as social and psychological factors (Partonen et al. 2004a). Nevertheless, it is likely that different locations around the world experience various suicide rates for many different reasons. According to Chew and McCleary (1995), suicide seasonality tends to decrease as areas become more industrialized, so most locations in the United States, even those in predominantly agricultural regions, might experience less suicide seasonality than other countries. However, more recent studies have shown increases in suicide seasonality with time in industrialized countries (Bridges et al. 2005; Rock et al. 2003).

The primary purpose of this study is to separate the relationships that suicide has with temperature and with seasons. The varying results shown here reinforce the idea that seasonal suicide rates do not automatically infer a

Fig. 7 Linear regression (with trendline) of monthly departure from annual mean temperature (°C) and monthly percentage of total annual suicides. R^2=0.040, ρ=0.123



dependence on temperature. Furthermore, these results suggest that any correlations between temperature and suicide are not strong enough to detect consistently and, therefore, are likely much less important than biological and social factors. However, these conclusions are based on only five counties in one country. Further study is certainly warranted, but care must be taken to not identify temperature as a causal factor in suicides simply because it covaries with the seasons.

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