



## Original Contribution

# Seasonal Associations between Weather Conditions and Suicide—Evidence against a Classic Hypothesis

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Psychiatrists, epidemiologists, and sociologists have debated the existence of an association between weather conditions and suicide seasonality since the preliminary statistical investigations in the 19th century. Provided that the effect of weather conditions on suicide operates via a dose-response-like mechanism, time-series (Box-Jenkins) analysis permits an indirect test of the hypothesis that temperature or other weather variables promote higher suicide frequencies in late spring and early summer months. The authors modeled monthly data on suicide and climatic conditions (i.e., temperature, sunshine, and precipitation data) in Switzerland. Cross-correlations between the filtered (prewhitened) residual series were calculated for the period 1881–2000, for consecutive 30-year periods, for different suicide methods, and—with regard to the seasonality hypothesis—for series relying on moving 1- and 3-month frames. Positive cross-correlations emerged between suicide and temperature data for the whole time series, as well as in all consecutive 30-year periods. However, cross-correlations of data series based on moving frames showed a minor peak in associations for summer frames and a major peak in associations for winter frames, the latter reflecting suicides performed mainly outdoors (being run over by a train and jumping from high places). The results represent a novel minor effect in seasonality of suicide, which is hardly compatible with the hypothesized role of temperature in suicide seasonality.

models, statistical; seasons; suicide; weather

Abbreviation: ARIMA, autoregressive integrated moving average.

More than 100 years ago, statisticians recognized that suicide frequencies are higher in the spring and summer than in the winter months (1). Since then, social and biopsychiatric research has attempted to understand the underlying mechanisms of seasonality in suicide (2–5). Biopsychiatric research has focused mainly on such weather conditions as duration of daylight, hours of sunlight, cloud cover, precipitation, humidity, winds, air pressure, and, above all, temperature (6–19). Psychiatrists of the 19th century (e.g., Ferri or Morselli) assumed that suicides are more frequent in warm months because of a heat-related excitability of the nervous system. Morselli, in particular, claimed that not heat per se

but the increase, that is, the change, of temperature in spring yields a cyclical increase of suicide frequencies (2, 20).

More recently, hypotheses have focused on the relation among weather variables, neuroendocrine cycles, and violent methods in suicide, as well as other violent behavior (21–24). Seasonal variation possibly associated with suicidal behavior has been shown in various components of the serotonergic system (5), but also in plasma melatonin (6), in cholesterol, and various other endocrinologic and immunologic variables (25).

So far, climatologic hypotheses in suicide research have been jeopardized by not only their wide variety but also the

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lack of compelling empirical evidence. There are quite a few biologic and behavioral variables that undergo a 12-month cycle (light-dependent processes, hormonal cycles, incidence of infectious diseases, nutritional patterns, onset of allergies, and so on). As a second problem, the range of interrelations between two seasonal cycles is fairly unlimited; it is easy to introduce leads or lags (21, 26) in order to support any putative coincidence. Therefore, the evidence based on analogy of seasonal patterns is weak.

The most straightforward approach to enhance the case for climatic conditions as a determinant of seasonality in suicide is to carry out statistical analyses on monthly suicide data while omitting the seasonal component. Provided that temperature has a dose-response-like effect on fluctuations of suicide frequencies, this effect would emerge also in fluctuations of monthly data after filtering out the seasonal component. In addition, analysis of monthly fluctuations can be restricted to subperiods within the year, that is, to *n*-month frames. Whether the associations derived from restricted series correspond to the overall effects or not may help to provide supplementary evidence. For example, if a temporary phenomenon, such as heat or the increase of temperature in spring, were really a determinant of high suicide frequencies, then the association between temperature and suicide would surely be stronger in spring and summer than in winter.

However, recent research suggests that suicide seasonality can be differentiated into distinct seasonalities related to specific suicide methods—drowning, hanging, or jumping from high places—with specific amplitudes and peak-low periods (27). Additional known effects include a holiday/festive day effect and a birthday effect (28, 29), as well as a specific effect for the Advent season (27). Suicide frequencies tend to be particularly low before or on such days. In light of these results, seasonality in suicide has a compound pattern without a biologic background but with an origin in behavioral patterns determined by context and opportunities (4). Taking up an opposite position to biopsychiatric research, no associations between temperature and suicide would be expected on the level of monthly data.

We investigated the temperature hypothesis by applying autoregressive integrated moving average (ARIMA) models (30) on time series of monthly mean temperature (hours of sunshine, precipitation) and monthly suicide frequencies in Switzerland in 1877–2000. Specifically, we investigated the following hypotheses.

1. Suicide frequencies are associated with weather variables. This is the unspecific adaptation of the classic biopsychiatric seasonality hypothesis.
2. The association between suicide frequencies and weather variables emerges particularly in spring/summer months, thus inducing seasonal effects in suicide. This specification reflects the common focus on the summer peak in suicide seasonality and on the notion that heat or the increase of temperature in spring plays a crucial role in suicide seasonality.
3. The association between suicide frequencies and weather variables has changed, that is, declined, during the 20th century. Seasonality in suicide has been shown to smooth out in the long run (31–34).

4. The association between suicide frequencies and weather variables differs by suicide methods. This is to account for the findings that seasonality in suicide is particularly associated with violent behavior or specific suicide methods (27, 35–37).

## MATERIALS AND METHODS

### Data

Monthly suicide data in 1877–1968 were extracted from the publications of the Swiss Federal Statistical Office (38); 1876 data were omitted since they were not recorded by sex. For the period 1969–2000, the data were derived from computerized individual records of the Swiss Federal Statistical Office, thus enabling more detailed analyses especially of suicide methods. In the period 1877–2000, there were 96,091 male suicides and 32,231 female suicides, for a total of 128,322 suicides. The monthly frequencies were standardized in regard to the number of days in each month. Modeling of suicide data by method was restricted to the period 1969–2000, since individual data records have been available in a digital format only since 1969. These analyses included poisoning by solid or liquid substances, hanging, drowning, firearms, jumping from high places, and being run over by a train.

Weather data made available by MeteoSwiss in Zurich (Swiss Federal Office of Meteorology and Climatology; <http://www.meteoswiss.ch>) included temperature, hours of sunshine, and precipitation. Data from Geneva, Zurich, and Lugano were used to represent the main centers of the western, the eastern, and the southern parts of Switzerland, respectively. The recording of the meteorologic data had started in the 1860s (39). However, measurements of hours of sunshine were documented first in the 1880s, that is, since January 1884 in Zurich, since May 1885 in Lugano, and since December 1896 in Geneva; therefore, the respective time series are limited to the years after 1896.

The overall temperature (hours of sunshine, precipitation) series was calculated as the unweighted mean of the Geneva, Zurich, and Lugano series. Basically, the differences between the different parts of Switzerland are modest, even though Lugano is located to the south of the Alps and Geneva and Zurich are to the north. For example, even after ARIMA modeling, the cross-correlations between the temperature series at lag 0 are between 0.82 and 0.95. With the exception of the mountainous regions with their small proportion of inhabitants, Switzerland has a temperate climate typical of Central Europe. The mean January temperature of our three locations for the whole period was 0.8°C (standard deviation: 1.9), and the mean July temperature was 19.6°C (standard deviation: 1.4). The average sum of hours of sunshine per year was 1,696.8 (standard deviation: 234.1), and the average total volume of precipitation per year was 1,235.5 mm (standard deviation: 187.0).

All meteorologic variables were entered as mean daily values into the analyses to correct for the different number of days in each month. Moreover, their standard deviation by month was also considered to assess the amount of change.

## ARIMA analysis

Analysis of monthly data and seasonal effects is a typical issue for time-series analyses in either the frequency domain (i.e., spectral analysis) or the time domain (i.e., ARIMA or Box-Jenkins models) (30, 40). The main statistical approach in the analyses reported below relied on cross-correlations of monthly data filtered with ARIMA models.

In empirical analysis, modeling with ARIMA aims at the following:

- correlational analysis with two or more time series (as in this study);
- regression analysis;
- forecasting;
- modeling of intervention effects.

Preliminary to these applications, modeling has to account for the inherent dynamics in the time series (trends, heteroscedasticity, and autoregressive and moving average processes). Modeling may be considered as successful if these dynamics and, in addition, relevant outstanding effects (shifts, pulses) are assessed and the residual time series is white noise. The latter can be assessed by the Ljung-Box  $Q$  test and the general adequacy of competing/alternative models by the Akaike Information Criterion or a similar measure (41). ARIMA models were commonly estimated by the maximum likelihood method. If a model did not converge, we used the conditional least-squares method that is the default in the ARIMA procedure of SAS. The short-term effects were modeled first.

In detail, an ARIMA ( $p, d, q$ ) model comprises an autoregressive component  $p$ , a moving-average component  $q$ , and a differencing term  $d$ . Filtering with ARIMA may include the following steps:

- transformation of data by calculating, for example, the root or the logarithm (yielding variance-stationary data);
- detrending of data by differencing—once, twice, or more—subsequent values (yielding mean stationary data);
- estimating and extracting autoregressive and moving-average components in the time series  $z_t$  relying on previous values at  $t - 1$ ,  $t - 2$ , and so on;
- extracting cyclical components of the time series by differencing—once, twice, or more—time-lagged values (in monthly data using lag = 12 months);
- estimating and extracting seasonal autoregressive and moving-average components in the time series  $z_t$  relying on previous values, for example, at  $t - 12$ ,  $t - 24$ , and so on.

## Cross-correlations based on the overall residual series, on subperiods, and on moving 1- and 3-month frames

Residual—that is, “prewhitened,” white noise—time series served to calculate the cross-correlations between suicide and weather variables. Cross-correlations are correlations between two time series at time lags 0,  $\pm 1$ ,  $\pm 2$ , . . . . “Prewhitening” is necessary since serial dependence in the time series can induce spurious cross-correlations (42). The approach used in this study—modeling time series separately

before cross-correlating their residual series (43–45)—is more rigorous but also more flexible than the original approach by Box and Jenkins, where the cross-correlations are calculated after applying a preliminary model of an input series A also on a series B.

Using residual time series to calculate cross-correlations proceeds on the assumption that associated time series share some fluctuation also on the level of residuals. As an implication of prewhitening, cross-correlations address short-term fluctuations and usually underestimate the real associations (45, 46). Moreover, white noise series (i.e., residual series after ARIMA modeling) implicate two simple properties: A subseries of a white noise series is again a white noise series, and, similarly, a time series composed of sequences of a white noise series is again a white noise series. This study took advantage of these properties to elicit more details of the associations between suicide and weather. With regard to analysis of seasonal phenomena, it seems promising to use specific sequences of residual time series to compose a new white noise time series. For example, cross-correlations can be calculated specifically on series composed of  $n$ -month sequences (e.g., 5 months, for instance, January–May of each year) from the preliminary residual series. The time frame for rebuilding a new series can be varied (e.g., 5 months, 3 months, and even 1 month), and it can be moved throughout the year, thus resulting in at most 12 cross-correlations. As a consequence, comparing series that incorporate subsequent time frames (e.g., January–May, February–June, and so on of each year) may clarify whether the putative association between temperature and suicide frequencies remains constant or whether it is stronger in summer frames than in winter frames.

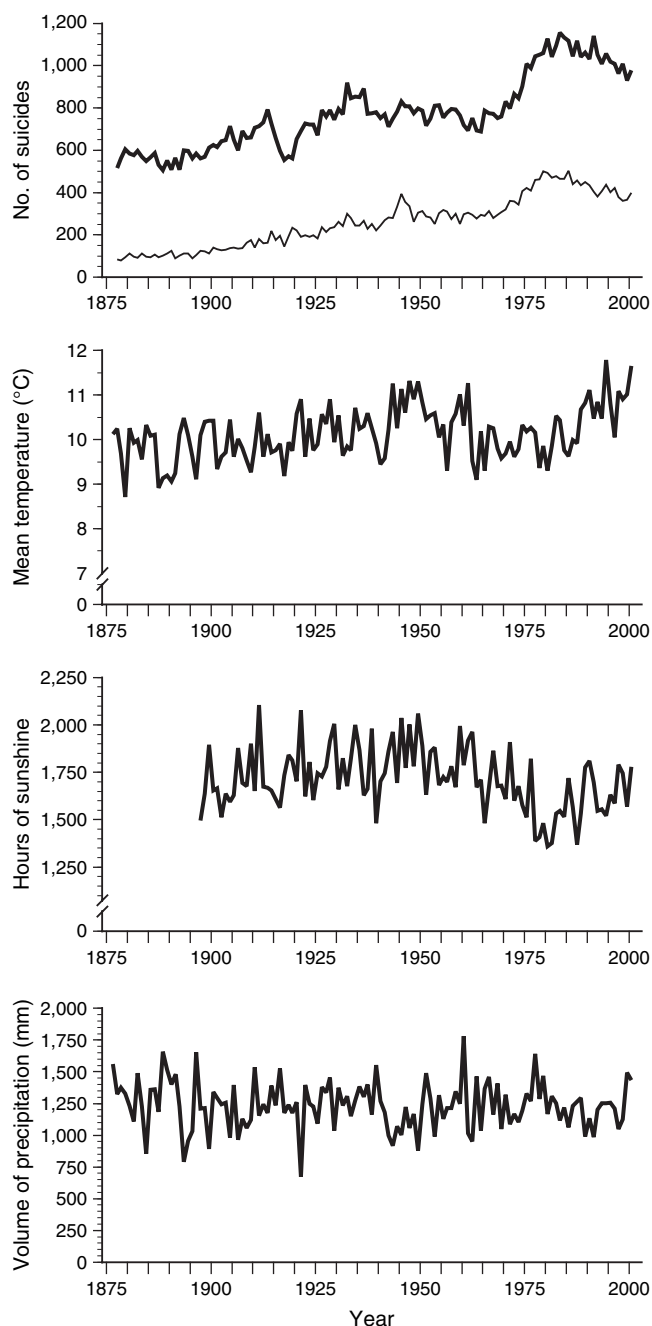
Calculation of cross-correlations was first confined to the period 1881–2000. Analyses by suicide methods were limited to the period 1971–2000 in order to remain consistent with the analyses by subperiods described below. Cross-correlations calculated within consecutive 30-year subperiods (1881–1910, 1911–1940, 1941–1970, and 1971–2000) served to provide details about eventual historical change. The subperiod series represent subsets of the complete residual series. The Ljung-Box  $Q$  test was applied on all subperiod series to ascertain that they are white noise.

Calculation of cross-correlations based on moving frames relied on 3- and 1-month frames. In analyses of subperiods, we confined the procedure to 3-month frames in order to keep a sufficient number of observations. All analyses were performed using SAS for Windows, version 8, software (SAS Institute, Inc., Cary, North Carolina).

## RESULTS

In figure 1, the yearly values are depicted to determine trends. The data transformation and the ARIMA model for each variable are reported in table 1. As the Ljung-Box  $Q$  test indicated, the modeling was fairly successful in all series except the female suicide frequencies.

The cross-correlations between the prewhitened, that is, residual, time series of monthly data are depicted in table 2. There is a consistent positive association between temperature



**FIGURE 1.** Frequency of suicides (men: thick curve; women: thin curve) (1877–2000), mean temperature (1876–2000), hours of sunshine (1897–2000), and volume of precipitation (1876–2000) in Switzerland, by year.

(means) and male suicides in the full time series ( $r = 0.197$ ,  $p < 0.001$ ) and in all subperiods. This association is weaker in women ( $r = 0.100$ ,  $p < 0.001$ ). In men, the cross-correlations are higher in the first two subperiods (1881–1910 and 1911–1940) than in the last two. However, in women, no such tendency is apparent.

The cross-correlations between hours of sunshine and suicide frequencies were lower than the ones reported on mean temperature and suicide frequencies, and the corresponding estimates smoothed down after adjustment in multivariate modeling. Precipitation did not show any noteworthy results except a moderate association with suicide frequencies in women in the last subperiod. Finally, the variables' means proved to be better predictors of suicide frequencies than the standard deviations, thus indicating that the raw levels in the data are more interesting than the variation.

Analyses accounting for specific suicide methods (1971–2000) turned out to be not so revealing. The only noteworthy association was derived from cross-correlations between drowning suicides, which is a method prevalent in women, and precipitation.

In the analyses of time series incorporating 1-month frames, the highest cross-correlations between suicide frequencies and temperature were found in series incorporating winter month frames (figure 2). In men, the highest correlation was found in the January frame ( $r = 0.407$ ,  $p < 0.001$ ), and in women, the highest correlation was found in the February frame ( $r = 0.282$ ,  $p < 0.01$ ). A minor peak was obvious in June (men:  $r = 0.299$ ,  $p < 0.001$ ; women:  $r = 0.176$ , not significant). The correlation patterns were similar in men and women even though the women's correlations were consistently lower.

Analyses with moving 3-month frames yielded cross-correlations that represent virtually moving averages of cross-correlations based on 1-month frames. For example, in men's series, the cross-correlations derived from 3-month frames are about 0.28 in December–February; in women's series, the cross-correlations are about 0.18 in January–March. Three-month frames served to replicate the analyses by 30-year subperiods (1881–1910, 1911–1940, 1941–1970, 1971–2000). The analyses yielded consistent results with respect to the winter peak, whereas the short summer peak appeared to emerge from superimposition of accidental effects (Web figures 1–4). (This information is described in supplementary figures posted on the *Journal's* website (<http://aje.oxfordjournals.org/>.) Cross-correlations (based on moving 3-month frames) between mean temperature and frequencies by suicide method in 1971–2000 revealed that being run over by a train ( $r = 0.315$ /January and  $0.293$ /February) and jumping from high places ( $r = 0.260$ /January) probably contribute most to the fact that the associations between temperature and suicide frequencies are highest in winter.

## DISCUSSION

Suicide seasonality has been an enigmatic challenge for a long time, and many psychiatrists have hypothesized that temperature or other meteorologic variables may account for it (5). However, analytical models that might provide a proof of this notion have been lacking until recent decades. Most studies did not take advantage of time-series analysis, whereas other ones used less appropriate or less flexible models (for a methodological review, refer to the studies of Hakko (47) and Hakko et al. (48)). Given that seasonal phenomena are ubiquitous, the most natural approach to

**TABLE 1. Data transformations and ARIMA\* models of univariate time series of suicide and meteorologic variables in Switzerland, 1881–2000**

	Time series	Data transformation	Estimation method	ARIMA model ( $p, d, q$ )	Seasonal ARIMA model ( $p, d, q$ ) <sub>12</sub>	Ljung-Box Q-test (lag 6) $\chi^2$
Temperature						
Mean†	1876–2000		Maximum likelihood	(1,0,0)	(0,1,2) <sub>12</sub>	4.1 <sub>3</sub> df
Standard deviation	1876–2000		Maximum likelihood	(0,0,0)	(0,1,1) <sub>12</sub>	5.4 <sub>5</sub> df
Hours of sunshine						
Mean	1897–2000		Maximum likelihood	(1,0,0)	(0,1,1) <sub>12</sub>	8.4 <sub>4</sub> df
Standard deviation	1897–2000		Conditional least squares	(0,0,0)	(0,1,1) <sub>12</sub>	2.8 <sub>5</sub> df
Volume of precipitation						
Total‡	1876–2000	<i>sqrt</i>	Maximum likelihood	(1,0,0)	(0,1,1) <sub>12</sub>	5.8 <sub>4</sub> df
Standard deviation§	1876–2000		Maximum likelihood	(2,0,0)	(0,1,1) <sub>12</sub>	1.4 <sub>4</sub> df
Total volume of precipitation divided by days with precipitation						
	1876–2000	<i>sqrt</i>	Maximum likelihood	(0,0,0)	(0,1,1) <sub>12</sub>	9.7 <sub>5</sub> df
Suicide frequencies						
Men¶	1877–2000	<i>sqrt</i>	Maximum likelihood	(0,1,1)	(0,1,1) <sub>12</sub>	3.0 <sub>4</sub> df
Women	1877–2000	<i>sqrt</i>	Maximum likelihood	(0,1,1)	(0,1,1) <sub>12</sub>	11.4 <sub>4</sub> df
Means of suicide						
Poisoning	1969–2000		Conditional least squares	(0,1,1)	(0,0,0) <sub>12</sub>	5.2 <sub>5</sub> df
Hanging	1969–2000		Maximum likelihood	(0,1,2)	(1,0,0) <sub>12</sub>	2.9 <sub>3</sub> df
Drowning	1969–2000		Maximum likelihood	(0,1,1)	(0,1,1) <sub>12</sub>	1.5 <sub>4</sub> df
Firearms	1969–2000		Conditional least squares	(1,1,1)	(0,1,1) <sub>12</sub>	5.1 <sub>3</sub> df
Jumping	1969–2000		Maximum likelihood	(0,1,1)	(1,0,0) <sub>12</sub>	8.6 <sub>4</sub> df
Run over by train	1969–2000		Maximum likelihood	(0,1,1)	(0,0,0) <sub>12</sub>	0.8 <sub>5</sub> df

\* ARIMA, autoregressive integrated moving average.

† Model (0,0,2)(0,1,2)<sub>12</sub> with similar outcome.

‡ Model (0,0,1)(0,1,1)<sub>12</sub> with similar outcome.

§ Model (0,0,2)(0,1,1)<sub>12</sub> with similar outcome.

¶ Model (0,1,1)(1,0,1)<sub>12</sub> with similar outcome.

seasonal data—that is, spectral analysis—provides only limited help. To our knowledge, only one study has applied an appropriate methodology such as ARIMA to examine directly the associations between meteorologic variables and suicide frequencies (11), but it used daily data and provided no approach to tackle seasonal effects.

The approach used in this study proceeds on the assumption that the hypothetical relation between temperature (and other weather conditions) and seasonality in suicide depends on a dose-response mechanism, that is, that heat (light, and so on) enhances susceptibility to suicide, and cold (darkness, and so on) smoothens it. Then, it is reasonable to expect associations not only with regard to seasonal cycles but also on other scales, for example, in yearly or monthly fluctuations. Analysis of monthly fluctuations has a technical advantage, for it allows the analyzed time frames to vary and thus to confine the analysis also to particular seasons.

In this work, ARIMA methods served to model long series of monthly data on suicide and meteorologic variables in Switzerland. Cross-correlations were calculated among the filtered (prewhitened) residual series:

- for the whole period 1881–2000 and for consecutive 30-year periods (1881–1910, and so on);
- for different suicide methods (1971–2000); and
- with regard to the seasonality hypothesis, for recombined residual series relying on (moving) 1- and 3-month frames.

### Hypotheses and answers

The results serve to answer our initial hypotheses:

1. A preliminary positive association between temperature and suicide frequencies was found in men and in women; however, no consistent results could be shown for other

**TABLE 2. Cross-correlations at time lag 0 between filtered suicide and meteorologic time series in Switzerland, monthly data in 1881–2000 and in subsequent 30-year periods (1881–1910, 1911–1940, 1941–1970, 1971–2000)**

	Suicide frequencies									
	1881–2000		1881–1910		1911–1940		1941–1970		1971–2000	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Suicide frequencies										
Men		0.057*		–0.036		0.156**		0.046		0.067
Women	0.057*		–0.036		0.156**		0.046		0.067	
Temperature										
Mean	0.197***	0.100***	0.279***	0.049	0.235***	0.115*	0.135*	0.099	0.133**	0.139**
Standard deviation	–0.053*	–0.045	–0.082	–0.057	–0.084	–0.065	–0.048	0.004	0.002	–0.066
Hours of sunshine†										
Mean	0.124***	0.070*	0.248*	0.087	0.103	0.126*	0.116*	0.076	0.094	0.007
Standard deviation	0.071*	–0.006	0.129	–0.022	0.022	0.039	0.109*	0.029	0.063	–0.079
Volume of precipitation										
Mean	–0.038	–0.011	–0.071	–0.034	0.003	–0.094	–0.039	–0.045	–0.039	0.136**
Standard deviation	–0.006	–0.009	–0.007	–0.066	–0.001	–0.040	–0.008	–0.105	–0.009	0.158**
Total volume of precipitation divided by days with precipitation										
	–0.000	–0.016	0.005	–0.041	0.029	–0.099	–0.024	–0.062	–0.008	0.150**
Standard errors										
Suicide, temperature, and precipitation	0.026	0.026	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
Hours of sunshine	0.028	0.028	0.059	0.059	0.053	0.053	0.053	0.053	0.053	0.053

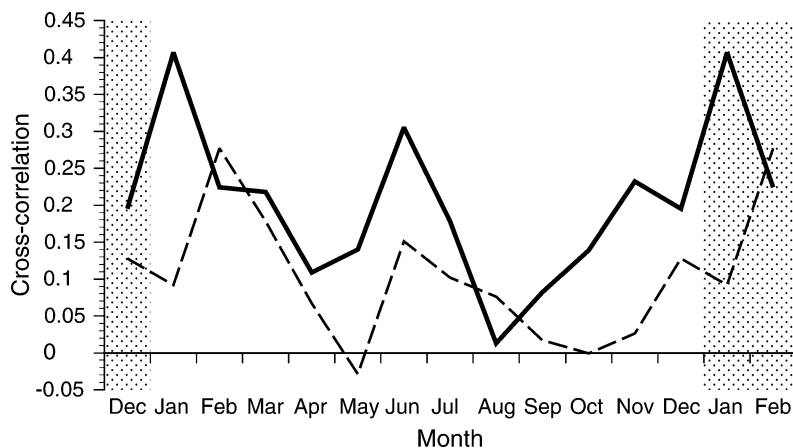
\*  $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ .

† 1897–2000/1897–1910.

meteorologic variables, such as hours of sunshine or precipitation (hypothesis 1).

2. Intriguingly, the positive association between temperature and suicide emerges mainly during the winter

months, supplemented by an intermediate peak in summer. Essentially, the association between temperature and suicide is not due to warm temperatures but is due to mainly the lack of low temperatures (hypothesis 2). In

**FIGURE 2.** Cross-correlations between suicide frequencies and mean temperature in residual time series based on moving time frames of 1 month after modeling with the autoregressive integrated moving average, Switzerland, 1881–2000. Men: thick curve; women: dashed curve. Standard error = 0.091. Each month is represented by its first three letters.

other words, not “heat” but “lack of cold” contributes mostly to the association between temperature and suicide on the level of monthly residuals.

3. We found no consistent changes in the association between suicide frequencies and meteorologic variables over time (hypothesis 3), in either the overall data or in the series relying on moving 3-month frames. This contrasts with the historical evidence that seasonality in suicide is smoothing out (31, 33, 49).
4. Two suicide methods, that is, jumping from high places and being run over by a train, have the highest associations with temperature (hypothesis 4). It seems that outdoor suicides depend on agreeable temperatures and, in some suicide methods, this issue is particularly relevant in winter. This implies that the effect of temperature on monthly fluctuations of suicide is not of a general and direct nature. In contrast to the winter peak, no method-specific associations could be found for the summer peak. Plausible interpretations of this short peak are lacking.

#### The dose-response relation and the range of conclusions

To sum up, the results are paradoxical. At first glance, the analyses with complete monthly series support the classic seasonality hypothesis that suicide frequencies are positively associated with temperature. However, more detailed analyses using restricted time frames have uncovered associations that are compatible with neither the classic view nor our “null hypothesis.” Therefore, the implications of the analysis design deserve a second glance.

The analysis design encounters two kinds of multilevel problems. First, there is the common issue of analyzing data on a societal level in order to make inferences about individual behavior, about which we will not comment further. Second, the analyses are bridging different temporal scales, that is, seasonal patterns and short-term monthly fluctuations. The bridge is the hypothesized dose-response relation between temperature and suicide frequencies.

A range of conclusions is possible, depending on the dose-response relation. The simplest type, that is, a linear relation, would be suited for making inferences between seasonal patterns and fluctuations in the complete monthly series. However, it does not imply changing associations throughout the year. The situation is different regarding a sigmoidal relation, in particular, if involving a no-observed-effect level and thus a temporary effect during a certain period of the year. We do not know how the founders of the “classic hypothesis” would comment on this literally. Like most later scholars, they commented only on the peaks in the seasonality of suicide and never on the lows. Hypothesized causal factors for the peaks, such as heat or increase of temperature, come along with the notion of a temporary effect.

In our study, the analyses of fluctuations in monthly series with restricted time frames have addressed such temporary effects. The results have showed a bimodal cross-correlation pattern over the year with a major peak in winter months.

There is no apparent coincidence with the seasonal cycle in suicide. Provided that the formal model (a temporary dose response) is appropriate, the results suggest that temperature is not a major driving force in overall suicide seasonality.

#### Alternative interpretations

However, the results represent a novel minor effect in the seasonality of suicide. This effect is to be located in a category similar to the holidays or birthday effects (28), that is, minor or short-term effects which are lost in the overall seasonal pattern. They are detectable because of large databases and also appropriate statistical modeling.

Our findings require a new interpretational attempt. From a formal point of view, the major peak in cross-correlations in winter and the minor peak in summer are obviously departures from a baseline level. They might rely on a *U*-shaped relation. However, the discrepancy between the effect sizes in winter and in summer makes this interpretation not so promising. Alternatively, the peaks might rely on different mechanisms working in winter and in summer, whether a dose-response relation or another mechanism.

From a substantial point of view, parallels to known seasonal effects in suicide provide a preliminary orientation. Recent research has shown that the major part of variation in seasonality in suicide is associated with specific suicide methods, such as drowning, hanging, and jumping from high places (27). Seasonality is absent in other methods, and this was largely also the case 100 years ago (34). For the most part, the seasonal change in suicide is determined by suicide methods susceptible to warm and pleasant weather during the summertime, such as drowning and jumping from high places. The timing of the peaks varies according to the suicide method: The peak in hanging occurs earlier than the peak in drowning. The presumable background is outdoor activities that suicidal persons and nonsuicidal persons share. Essentially, seasonality in suicide appears to be driven by seasonal behavioral opportunities.

Because of the analogy with major seasonal patterns in suicide, it was not surprising to realize that monthly fluctuations responding to “lack of cold” during the wintertime involve outdoor suicides, such as jumping from high places and being run over by a train. The parallelism between the overall seasonal patterns and the monthly fluctuations is not perfect. There is no noteworthy overall seasonality in railway suicides (27), whereas drowning and hanging depict no noteworthy associations with temperature on the level of monthly fluctuations.

With respect to a common theoretical background, it seems to be most promising to return to the model proposed by Chew and McCleary (4), who determined suicide risk by a combination of motivation, accessibility of lethal means, and surveillance (i.e., social regulation). Their model relies on the opportunity structure concept of Cloward and Ohlin (50), from which we may trivially derive that opportunity not only “makes the thief” but also facilitates or impedes suicides. Implicitly, the opportunity concept is inherent in most method-specific prevention programs. It applies to unplanned suicides (51), that is, to impulsive suicides, as well as to suicides relying on ambivalent behavior. Suicidal

behavior is largely an ambivalent behavior and responds to opportunities determined by such circumstantial conditions as temperature or, within a negative association, holidays or birthdays.

With the exception of the winter peak in cross-correlations between suicide and temperature, we have no promising clues with which to interpret the minor peak that occurs in summer.

### Limitations and implications

The methodological advantages of this study—analysis of long time series and adaptable methodology—are contrasted with several limitations that should be kept in mind. First, it cannot be excluded that meteorologic variables other than the ones analyzed here might contribute differently to suicide frequencies. Nevertheless, in most analyses reported so far, temperature has been the favorite meteorologic variable (5). Second, this study is restricted to Switzerland, that is, a region with temperate climate in Central Europe. It cannot be excluded that the results would differ in regions with different temperature ranges or, with regard to cutoff effects, higher or lower minima/maxima in temperature. Third, a putative but not realistic limitation relates to the low magnitude of the cross-correlations. In fact, cross-correlations after prewhitening of time series are usually low, because the main components of the series—linear and curvilinear trends, cycles, or, rather, autoregressive and moving average processes—are victims of the modeling procedure. Associations between residual time series rely on the assumption that associated series also share some random fluctuation. From this point of view, cross-correlations after prewhitening underestimate the similarities between time series and, therefore, constitute a conservative approach to determine associations between time series.

### Conclusions

To summarize, the results show unexpected associations between monthly suicide and temperature data. Contrary to overall seasonality, the associations based on monthly residuals emerge mainly during the winter months. In analogy to the overall seasonality, suicides that are performed outdoors appear to play again a major role. The results suggest that temperature and similar meteorologic variables contribute little to our understanding of the overall seasonality in suicide, even though the meteorologic variables are involved indirectly in various ways.

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