

## Original Investigation

## Direct Effect of Sunshine on Suicide

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**IMPORTANCE** It has been observed that suicidal behavior is influenced by sunshine and follows a seasonal pattern. However, seasons bring about changes in several other meteorological factors and a seasonal rhythm in social behavior may also contribute to fluctuations in suicide rates.

**OBJECTIVE** To investigate the effects of sunshine on suicide incidence that are independent of seasonal variation.


**DESIGN, SETTING, AND PARTICIPANTS** Retrospective analysis of data on all officially confirmed suicides in Austria between January 1, 1970, and May 6, 2010 ( $n = 69\,462$ ). Data on the average duration of sunshine per day (in hours) were calculated from 86 representative meteorological stations. Daily number of suicides and daily duration of sunshine were differentiated to remove variation in sunshine and variation in suicide incidence introduced by season. Thereafter, several models based on Pearson correlation coefficients were calculated.

**MAIN OUTCOMES AND MEASURES** Correlation of daily number of suicides and daily duration of sunshine after mathematically removing the effects of season.

**RESULTS** Sunshine hours and number of suicides on every day from January 1, 1970, to May 6, 2010, were highly correlated ( $r = 0.4870$ ;  $P < 10^{-9}$ ). After differencing for the effects of season, a mathematical procedure that removes most of the variance from the data, a positive correlation between number of suicides and hours of daily sunshine remained for the day of suicide and up to 10 days prior to suicide ( $r_{\text{maximum}} = 0.0370$ ;  $P < 10^{-5}$ ). There was a negative correlation between the number of suicides and daily hours of sunshine for the 14 to 60 days prior to the suicide event ( $r_{\text{minimum}} = -0.0383$ ;  $P < 10^{-5}$ ). These effects were found in the entire sample and in violent suicides.

**CONCLUSIONS AND RELEVANCE** Duration of daily sunshine was significantly correlated with suicide frequency independent of season, but effect sizes were low. Our data support the hypothesis that sunshine on the day of suicide and up to 10 days prior to suicide may facilitate suicide. More daily sunshine 14 to 60 days previously is associated with low rates of suicide. Our study also suggests that sunshine during this period may protect against suicide.

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The influence of season on suicide rates has been studied since the beginning of the 19th century. A seasonal pattern for suicides, with the most suicides in spring, as well as correlations of suicide incidence with climatic variables have been found in several countries. Seasonal sunshine duration and ambient temperature in France, for instance, were superior to socioeconomic factors in explaining the variance in regional distribution of completed suicides.<sup>1</sup> In Belgium, the incidence of violent suicides was positively correlated with sunshine duration, ambient temperature, and an increase in temperature during the weeks prior to a suicide.<sup>2</sup> In Australia, monthly sunshine was associated with suicides per month.<sup>3</sup>

Neurobiological effects of sunshine exposure offer the most substantiated explanation for those seasonal variations in suicide rates. Light has been shown to interact with brain serotonin systems in animals and humans and possibly influences serotonin-related behaviors.<sup>4-14</sup> Some of these behaviors, eg, mood, impulsiveness, and aggression, are known to also play a key role in suicidal behavior.<sup>15-18</sup> Moreover, recent studies have shown that medium- and even short-term changes in lighting conditions affect depression-like behavior in rodents and have a profound effect on brain monoamine transmission.<sup>19-21</sup>

Studies examining the effects of sunshine on suicidal behavior share a methodological problem: they are mostly based on the association between seasonal variation in sunshine and seasonal variation in suicide numbers.<sup>22,23</sup> However, seasons affect a number of interrelated climatic variables as well as social behaviors. Holidays, anniversaries, seasonal variation in unemployment rates, social cohesion, availability of clinicians, and other factors might have an impact on the seasonality of suicide. Examining the effects of sunshine on suicidal behavior based on seasonal variations is thus insufficient to gain insight into effects that are specific for sunshine. Assuming that sunshine has an effect on suicide numbers that is independent of the seasonal rhythms, we therefore examined whether more frequent fluctuations in sunshine exposure, such as the number of sunshine hours per day, correlate with suicide rates.

Using monthly sunshine and suicide data from a 10-year period, we have shown previously that seasonal changes in sunshine are associated with seasonal variations in the incidence of suicides, especially violent suicides, in Austria.<sup>23</sup> The aim of the present study was to further substantiate the hypothesis that sunshine has a direct role in the variation in suicide incidence. Thus, we examined the relationship between suicide numbers and duration of sunshine after mathematically removing both the seasonal—or astronomical—component in the circannual variation of sunshine and the well-known seasonal variation in suicide numbers.

## Methods

Suicide data with information on date of suicide, sex, and method of suicide were provided by Statistics Austria (classified according to *International Classification of Diseases, Ninth Revision* codes E950-E959 and *International Statistical Classification of Diseases, 10th Revision* codes X60-X84) from January 1, 1970, to May 6, 2010. Suicide methods were classified by the most common

method of distinction as violent (hanging, drowning, shooting, jumping) or nonviolent (poisoning). Data on the average duration of sunshine per day (in hours) for the same period of 40 years were calculated from 86 representative meteorological stations in Austria (data provided by the Central Institute for Meteorology and Geodynamics). Sunshine hours were recorded with a Hänni Solar sunshine recorder and are defined as a period when the direct solar irradiance is higher than 120 W/m<sup>2</sup>.

Informed consent and institutional review board approval were not required because this was a retrospective analysis of publicly accessible data and individuals were deidentified by Statistik Austria, who provided the data to us. There were no human subjects concerns in this study.

Austria's climate can be characterized as humid continental. High temperature differences can be observed during the 4 seasons, with cold winters and hot summers. Other countries with humid continental climate are most central and eastern European states, Scandinavia, parts of Germany, Japan, and eastern North America.<sup>24</sup> The average amount of annual sunshine in Austria was 1583 hours from 1971 to 2000.<sup>25</sup>

A study investigating the illumination under natural conditions in Québec, Canada, which is also located in the humid continental climate zone, showed that there are no differences between summer and winter regarding time spent in illumination lower than 1000 lux. However, bright light exposure is substantially longer in summer.<sup>26</sup>

Our main hypothesis was that there is a positive correlation between the number of sunshine hours and the number of suicides on a daily basis, beyond what can be explained through the previously known seasonality in both sunshine patterns and suicides during the year.<sup>23</sup> Therefore, we first differenced both time series  $x_n$  (daily hours of sunshine) and  $y_n$  (daily numbers of suicides) by calculating

$$\bar{x}_n = x_n - x_{n-s}$$

and

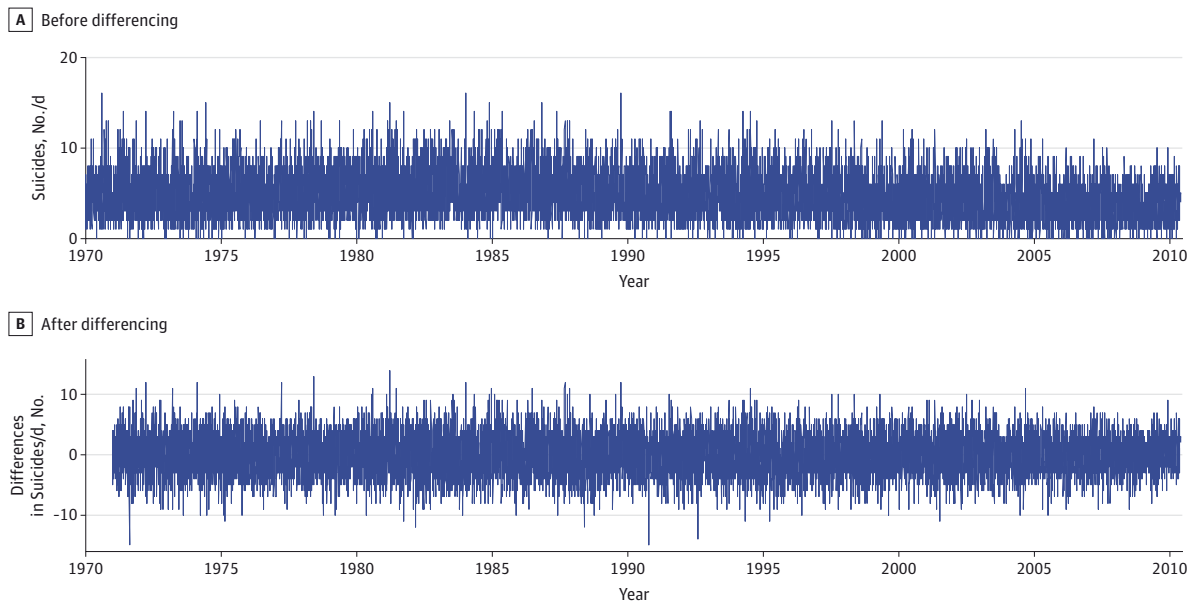
$$\bar{y}_n = y_n - y_{n-s}$$

with  $s = 365$  as (roughly) the length of 1 year. In other words, we removed the seasonality effects by taking the daily hours of sunshine or daily number of suicides on a given day ( $x_n$  or  $y_n$ , respectively) and repeatedly subtracting the corresponding values of the corresponding days from the year before ( $x_{n-s}$  or  $y_{n-s}$ ). This procedure of transferring a time series by computing the difference between corresponding time series values is called *differencing*. Then, according to the method by Papadopoulos et al,<sup>27</sup> we calculated Pearson correlation coefficients between

$$\left\langle \frac{1}{k} \sum_{i=1}^k \bar{x}_{n-l-k} \bar{y}_n \right\rangle$$

for  $l = 0$  through 50 (where  $l$  indicates the time lag of  $l$  days between the averaged sunshine duration and day of suicide) and  $k = 1$  through 50 (where  $k$  indicates the period of  $k$  days for which sunshine duration was averaged). We correlated the number of

Figure 1. Daily Numbers of Suicides From 1970 to 2010



Time series of daily numbers of suicides before differencing ( $y_n$ ) (A) and after differencing for removing seasonality ( $y_n - y_{n-s}$ ) (B). The entire 40-year period (1970-2010) is depicted.

daily suicides with the number of sunshine hours on the same day, or up to  $l$  days before, and with the average of  $k$  prior days for all  $l$  lags. This allowed us to calculate the period in days for which sunshine is hypothesized to influence suicide frequency.

We repeated all calculations by distinguishing between male and female suicides and between violent and nonviolent suicides considering the following 7 combinations of suicides: all, violent, nonviolent, male violent, female violent, male nonviolent, and female nonviolent. These sensitivity analyses further allowed challenging the stability of the results according to current hypotheses, suggesting that impulsive or aggressive states, possibly related to changes in serotonin transmission,<sup>28,29</sup> might underlie light-induced changes in suicide numbers.

## Results

A total of 69 462 suicides were registered in Austria between January 1, 1970, and May 6, 2010. Of those, 52 280 (75.3%) were violent suicides and 17 182 (24.7%) were nonviolent suicides; 49 685 (71.5%) were male and 19 777 (28.5%) were female; and 39 441 (56.8%) were male violent, 10 244 (14.7%) were male nonviolent, 12 839 (18.5%) were female violent, and 6938 (10.0%) were female nonviolent.

### All Suicides and Sunshine

The mean sunshine duration and the mean number of suicides on each day from January 1, 1970, to May 6, 2010, were highly correlated ( $r = 0.4870$ ;  $P < 10^{-9}$ ). Differencing resulted in removal of most of the seasonal trend (amplitude) of the time series, while some seasonal pattern remained in the data pertaining to the higher variance of daily sunshine during sum-

mer months (eFigure in the Supplement). **Figure 1** depicts the time series of number of suicides before and after differencing. After differencing for the effects of season, there was a positive correlation between number of suicides and hours of daily sunshine for the day of the suicide. Further, correlations after incrementing the period prior to suicide by up to 10 days remained significant ( $r_{\text{maximum}} = 0.0370$ ;  $P < 10^{-5}$ ). There was a negative correlation between the number of suicides and daily hours of sunshine for the 14 to 60 days prior to the suicide event ( $r_{\text{minimum}} = -0.0383$ ;  $P < 10^{-5}$ ) (**Figure 2**). The **Table** depicts the Pearson correlation coefficients for all suicides depending on time lag  $l$  (0-4 days) and the size  $k$  of the time window used for averaging (1-10 days).

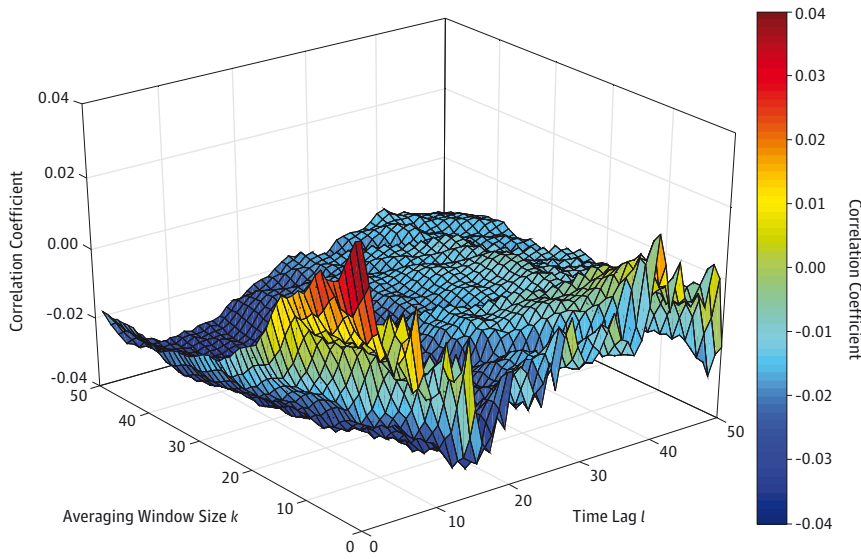
### Method of Suicide and Sunshine

There was a significant positive correlation between number of sunshine hours per day and violent suicide. This association remained significant after removal of the seasonal trend for up to 10 days prior to the suicide ( $r_{\text{maximum}} = 0.0402$ ;  $P < 10^{-5}$ ). Furthermore, as was the case for the total number of suicides, a negative correlation for the 14 to 60 days prior to the suicide event was observed ( $r_{\text{minimum}} = -0.0377$ ;  $P < 10^{-5}$ ). No association of daily sunshine with rates of nonviolent suicide was found prior to and after differencing. **Figure 3** illustrates the coefficients for violent vs nonviolent suicides at time lags 0 and 1 days.

### Suicide, Sunshine, and Sex

**Figure 4** illustrates the differences in correlations when splitting the data into male and female suicides. For females the most highly significant correlations are the positive ones for up to 10 days prior to the suicide ( $r_{\text{maximum}} = 0.0388$ ;  $P < 10^{-5}$ ), while for males the most highly significant correlations are the negative

Figure 2. Correlation Coefficients Between Duration of Sunshine and Suicide Numbers



Correlation coefficients between the mean duration of sunshine and suicide numbers depending on  $k$  (period of  $k$  days for which sunshine duration was averaged) and  $l$  (time lag of  $l$  days between the averaged sunshine duration and day of suicide) during the entire ranges from 1 to 50 days and 0 to 50 days.

Table. Pearson Correlation Coefficients Between Daily Hours of Sunshine and Daily Number of Reported Suicides From 1970 to 2010

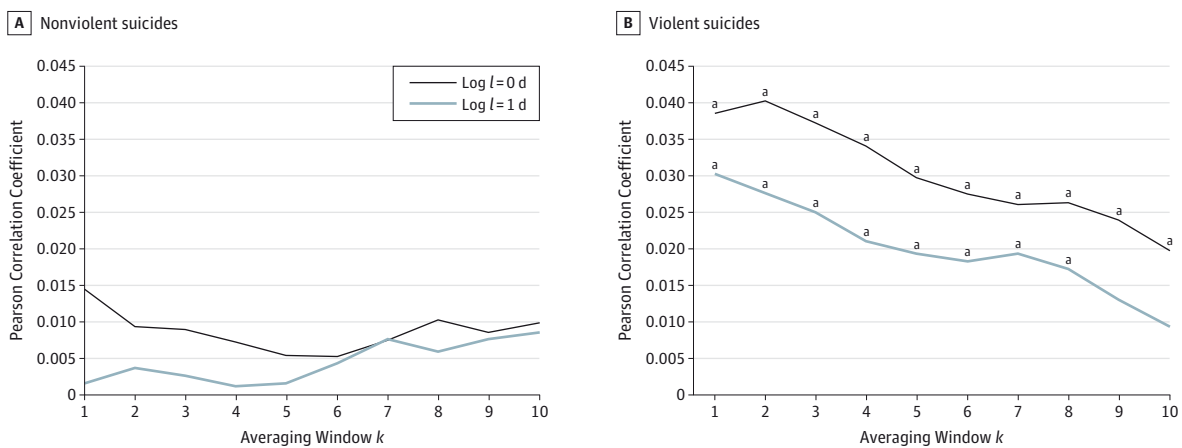
Time Window $k$ for Average, $d^a$	Correlation Coefficient for Time Lag $l$ , $d^b$				
	0	1	2	3	4
1	0.0370 <sup>c</sup>	0.0247 <sup>c</sup>	0.0117	0.0054	-0.0009
2	0.0360 <sup>c</sup>	0.0213 <sup>c</sup>	0.0100	0.0026	0.0035
3	0.0319 <sup>c</sup>	0.0181 <sup>c</sup>	0.0070	0.0050	0.0062
4	0.0279 <sup>c</sup>	0.0145	0.0082	0.0070	0.0107
5	0.0237 <sup>c</sup>	0.0146	0.0096	0.0108	0.0084
6	0.0229 <sup>c</sup>	0.0151	0.0127	0.0089	0.0047
7	0.0227 <sup>c</sup>	0.0176 <sup>c</sup>	0.0109	0.0055	0.0020
8	0.0244 <sup>c</sup>	0.0155	0.0077	0.0030	0.0027
9	0.0221 <sup>c</sup>	0.0123	0.0053	0.0037	0.0010
10	0.0188 <sup>c</sup>	0.0097	0.0057	0.0020	-0.0002

<sup>a</sup> The time window size  $k$  for averaging sunshine shows the number of days for which a mean sunshine level was calculated.

<sup>b</sup> Time lag  $l$  represents the distance in days between the day of suicide and the averaged sunshine window.

<sup>c</sup> Statistically significant at  $P < .05$ .

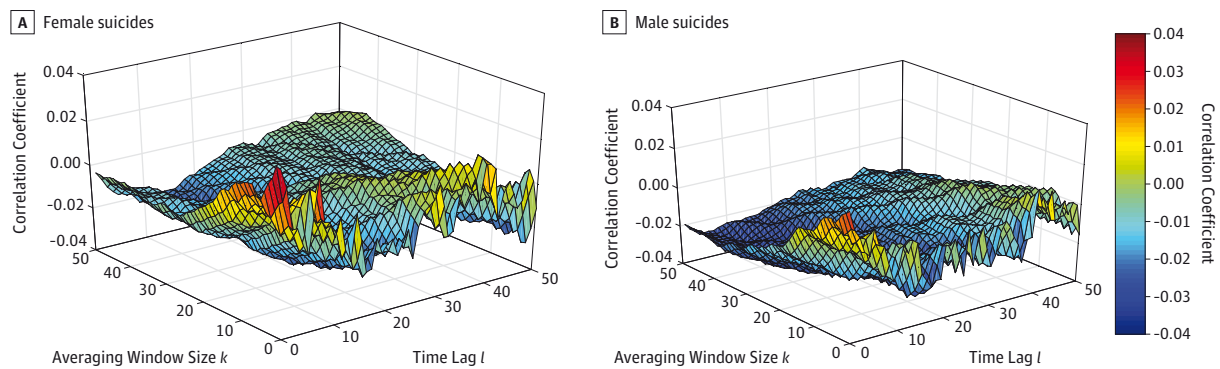
Figure 3. Correlation Coefficients for Nonviolent and Violent Suicides



Correlation coefficients for nonviolent (A) and violent (B) suicides, depending on the averaging window  $k$  and a lag of 0 days and 1 day.

<sup>a</sup> Statistically significant coefficient ( $P < .05$ ).

Figure 4. Correlation Coefficients for Duration of Sunshine and Female and Male Suicides



Correlation coefficients for duration of sunshine and female (A) and male (B) suicides depending on  $k$  (window size in days [period of  $k$  days for which sunshine duration was averaged]) and  $l$  (time lag in days between the averaged sunshine duration and day of suicide) during the entire ranges from 1 to 50 days and 0 to 50 days.

ones for the 14 days to 60 days prior to the suicide ( $r_{\text{minimum}} = -0.0346$ ;  $P < .001$ ). For all other correlations,  $P > .001$ .

## Discussion

The main goal of this study was to investigate the relationship between daily suicides, in total 69 462 in 40 years, and daily sunshine after mathematically removing seasonal variation in sunshine duration and suicide numbers. In line with our hypothesis, we were able to show that sunshine has an effect on suicides independent of seasonal rhythms. Two main results emerged from our data. First, sunshine on the day of suicide and up to 10 days prior to suicide seems to facilitate suicide, as we found a positive correlation between the duration of sunshine and suicide numbers in this period. This effect was present in all suicides, all violent suicides, and all female suicides. Second, to our knowledge, this study is the first to show that sunshine, after removal of seasonal variance in suicide numbers and sunshine duration, may also have a protective effect against suicide.

Calculated on an aggregate level (mean numbers of suicides and mean duration of sunshine on each day of the year), duration of sunshine explained a substantial proportion of the daily variation in suicide numbers in our sample ( $R^2 = 0.24$ ). However, averaging measures of sunshine duration over many years generates a curve that becomes very similar to the basic astronomical sine curve of day length and solar angle, which are the common root of all other seasonal changes. An aggregate analysis is thus not suitable to provide information on whether sunshine itself contributes to seasonal changes in suicide numbers. Previous studies analyzing the effects of solar radiation and other related climatic variables on suicide frequency based on daily data have found a positive relationship between solar radiation and suicides on the day of the suicide event and up to 4 days before.<sup>27,30</sup> In contrast to our current approach, these studies did not mathematically remove the overall effects of season on sunshine and suicide numbers.

As expected, correlation coefficients in our data set, calculated after differencing for overall effects of season, were much smaller (highest value,  $r = 0.0370$ ) than those calcu-

lated on an aggregate level. However, it needs to be considered that differencing suicide and sunshine data removed large parts of the overall seasonal variance in the data set (Figure 1). It is thus a direct consequence of the mathematical procedure that correlation coefficients are small. The fact that there are significant correlations after differencing strongly suggests that sunshine may have a more immediate effect on suicide frequency beyond known seasonal rhythms.

Given the rather low absolute values of Pearson correlation coefficients, all observed patterns need to be interpreted with particular care. First, it should be noted that with a significance level at  $P < .001$ , among 2500 correlations in Figure 2, on average only 2 or 3 significant coefficients are a result of type I error. Thus, the fact that many more values are significant in most of the graphs allows rejection of the null hypothesis that there are no correlations at all. Nevertheless, the observed correlations can still be rooted in data properties other than the relationship between sunshine and suicides. To rule out such a possibility, we performed an analysis similar to the one illustrated in Figure 2 but after random permutation of the sunshine time series. All significant correlations disappeared in that case, lending support to the hypothesis that the correlations observed in the other graphs are indeed rooted in subtle relationships between the 2 time series.

Previous studies have shown that the link between sunshine and suicide is mainly found in violent suicides.<sup>2,3,23,31,32</sup> This finding also holds true in our data before and after differencing for seasonal variation.

When splitting the time series into males and females, it appears that the positive correlations between daily sunshine hours and suicide rates are predominantly seen among females, while the negative correlations are mainly found among males. This finding is in line with a previous study by Papadopoulos et al,<sup>27</sup> who found that among females a shorter sunshine exposure is needed to trigger suicide. Women not only more frequently have mood disorders but also show higher rates of suicide attempts; however, an explanation for the increased vulnerability in women regarding a short-term increase in daily sunshine is still missing.<sup>33,34</sup>

Owing to the correlative nature of the data, it is impossible to directly attribute the increase in suicide to sunshine during



the 10 days prior to the suicide event. Several astronomical and climatic factors (temperature, humidity, air pressure, etc) covary with sunshine to a certain degree. Some climatic factors may possibly covary with sunshine even after differencing for season. In this study, we did not account for these factors. However, several lines of evidence suggest that light plays an important role in regulating neurobiological systems that have also been linked to suicide and impulsivity. Suicidal behavior is closely related to mood disorders, which are known to be associated with serotonin dysfunction and are highly sensitive to seasonal changes, predominantly to sunshine.<sup>10,11,14</sup> The serotonin transporter is in a hyperfunctional state during depression in seasonal affective disorders and normalizes after light therapy and in natural summer remission.<sup>8</sup> Low levels of the serotonin metabolite 5-hydroxyindoleacetic acid in cerebrospinal fluid,<sup>35-38</sup> reduced serotonin transporter binding in brain and blood platelets,<sup>39-45</sup> and several other serotonergic measures<sup>46-48</sup> have repeatedly been associated with suicidal ideation, impulsivity, and suicide. Studies performed in higher-latitude geographical regions have also repeatedly shown that these measures clearly vary with seasons and correlate with sunshine.<sup>8-10,12,49</sup> Serotonin neurotransmission is thus a plausible candidate pathway for mediating the effects of sunshine on suicidal behavior. Much less is known about short-term effects of light on human neurobiology. However, recent work in rodents showed that light affects brain monoamine signaling within days or even hours,<sup>19,20</sup> and a study in humans showed that changes in sunshine intensity affect brain serotonin 1A receptor binding within less than a week.<sup>11</sup>

It has been proposed that the effects of sunshine on mood and motivation in depressed patients are similar to those of antidepressants, by improving motivation and, only later, mood.<sup>23,50</sup> Susceptible persons may become agitated and impulsive while still having depressed mood, which could lead to an increased suicide risk. Suicide attempts, although relatively rare, have also been described in patients with seasonal depression during the early stage of bright light therapy.<sup>51</sup> In the long term, however, sunshine, similar to antidepressants, improves mood and thereby may contribute to decreased suicide. In sum, data indicate that due to interaction with the serotonergic system, sunshine influences mood, impulsiveness, and aggression, which are known to play a key role in suicidal behavior.<sup>15-17</sup>

For performing similar analyses about the relationship between sunshine and suicides, Tsai and Cho<sup>52</sup> used autoregressive integrated moving average models. Their main purpose

was to forecast future values of a time series based on the past, which was not our primary concern in this study. However, we note that the integration part of an autoregressive integrated moving average model is akin to differencing the time series (in our case with a lag of 365 days). Calculating correlation coefficients between past values of the time series and present values of another time series is related to the autoregressive part of an autoregressive integrated moving average model. The only component on which our analysis does not touch is the moving average part of the model, which, through its attempt to forecast future time series values based on random shocks, is usually considered difficult to interpret and thus not fruitful in our endeavor to find explicit relationships in the data.

Daily sunshine 14 to 60 days before index days was associated with reduced suicide in our data and thus seems to be protective against suicide. However, we cannot exclude that this finding is in part owing to suicidal individuals who committed suicide already after a short-term increase in environmental light and thus no longer enter statistics after longer periods of sunshine. A study of the effects of an earthquake on the number of cardiovascular events found an increase in cardiac deaths among people with preexisting cardiovascular disease immediately after the earthquake and a subsequent decrease in cardiovascular deaths below baseline values in the weeks thereafter, indicating that those most at risk were “picked off” from statistics by the stressful experience.<sup>53</sup>

Furthermore, we could not include data on multiple internal and external factors related to suicide such as genetic variables, mental health, lifetime substance abuse, family characteristics, social factors, and community characteristics. Finally, misclassification of cause of death<sup>54</sup> could have introduced a bias regarding the absolute number of suicides.

## Conclusions

Our data suggest that the duration of sunshine influences suicide rates independent of seasonal rhythms. Moreover, they show that sunshine has a bimodal effect on suicidal behavior as an increase in suicide was found in short time scales, while after longer periods more sunshine was associated with decreased suicide. Further research is warranted to determine which patients with severe episodes of depression are most susceptible to the suicide-triggering effects of sunshine.

### ARTICLE INFORMATION

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**Study concept and design:** Vyssoki, Kapusta, Praschak-Rieder, Willeit.

**Acquisition, analysis, or interpretation of data:** All authors.

**Drafting of the manuscript:** All authors.

**Critical revision of the manuscript for important intellectual content:** All authors.

**Statistical analysis:** Dorffner.

**Administrative, technical, or material support:** Vyssoki, Kapusta.

**Study supervision:** Praschak-Rieder, Willeit.

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