Impact of Meteorological Parameters on Suicide Mortality Rates: a case-crossover analysis in Southern Germany (1990 – 2006)

Alexandra Schneider[a], Regina Hampel[a], Karl-Heinz Ladwig[a,b], Jens Baumert[a], Karoline Lukaschek[a], Annette Peters[a,c], Susanne Breitner[a,c]

[a]Institute of Epidemiology, Helmholtz Zentrum München - German Research Center for Environmental Health (GmbH), Ingolstädter Landstraße 1, 85764 Neuherberg, Germany

[b]Department for Psychosomatic Medicine and Psychotherapy, Klinikum rechts der Isar, Munich, Germany

[c]Chair of Epidemiology, Institute for Medical Information Processing, Biometry and Epidemiology, Ludwig-Maximilians-Universität München, München, Germany

Corresponding author:

Susanne Breitner

Helmholtz Zentrum München, German Research Center for Environmental Health (GmbH)

Ingolstädter Landstraße 1

85764 Neuherberg, Germany

Tel.: +49 89 3187 4481

Fax: + 49 89 3187 3380

Email: susanne.breitner@helmholtz-muenchen.de

Abstract

Background. There is evidence for a seasonal pattern of suicides with peaks in spring and early summer; however, only a limited number of studies has investigated whether daily changes in meteorological variables may trigger suicides.

Methods. Daily fatal suicide (N=10,595) and meteorological data were available for four Bavarian cities and ten counties (Germany) for 1990-2006. City/county-specific immediate, delayed and cumulative effects of air temperature, sunshine duration, and cloud cover on suicides were analyzed using a time-stratified case-crossover approach; city/county-specific effects were then combined using random effects meta-analysis. Potential effect modifiers were specific weather conditions, personal or regional characteristics, and season.

Results. A 5°C increase in air temperature on the day before a suicide compared to the control days was associated with a 5.7% (95% confidence interval (CI): 0.6; 11.0) higher suicide risk. Further, the suicide risk was 6.5% (95% CI: 0.2; 13.3) higher on days with low/medium cloud cover (0-6 oktas) compared to days with high cloud cover (7-8 oktas). While daily changes in temperature were not associated with suicides in spring, we found a higher suicide risk in summer, autumn, and winter in association with temperature increases. The effects of cloud cover were strongest in summer and autumn and on days with temperature above the median (>8.8°C). Sunshine duration was not associated with suicides.

Conclusion. We found a higher risk for suicides in association with short-term increases in air temperature on the day before the event compared to the control days and on days with low to medium cloud cover. This may highlight times when people are more likely to commit suicide.

Abstract word count: 248

Keywords: suicides, air temperature, sunshine duration, cloud cover, case-crossover

1. Introduction

Suicides are considered as a “public health problem of global importance” (Turecki and Brent 2016). Although suicide rates in Germany decreased during the last decades, suicide is still among the leading causes of unnatural deaths (Lukaschek et al. 2012; Robert Koch Institut 2015): 10,078 people committed suicide in 2015 reflecting 12.3 suicides per 100,000 inhabitants and 1.2% of all deaths. In comparison, only 3,459 people died in traffic accidents (4.2 deaths per 100,000 inhabitants) (www.destatis.de).

There are several well-known risk factors for suicidal behavior, including psychiatric disorders (Crump et al. 2014; Hawton and van Heeringen 2009), male sex (Moller-Leimkuhler 2003) and older age (>60 years) (Fassberg et al. 2012). Other health-related factors associated with suicide are comorbid medical conditions (Qin et al. 2014), chronic pain (Tang and Crane 2006) and sleeping impairments (McCall and Black 2013; Nadorff et al. 2013). Lifestyle and socio-demographic factors have also been linked to an increased suicide risk: negative life events (O'Connor and Nock 2014), social isolation (Turecki and Brent 2016), living alone (Schneider et al. 2014), poverty (Whitley et al. 1999), unemployment (DeFina and Hannon 2015), job-strain (Baumert et al. 2014), family history of suicide (O'Connor and Nock 2014) as well as behavioral risk factors such as excessive smoking and alcohol consumption (Schneider et al. 2011; Tanskanen et al. 2000). Beside these classic risk factors, a seasonal pattern of suicides with peaks in late spring and early summer and a modest second peak in autumn have been observed (Ajdacic-Gross et al. 2010; Christodoulou et al. 2012; Erazo et al. 2004). One potential explanation for this observation could be an association between climate factors such as air temperature or sunlight duration and suicide. However, since season or month of the year are only rough markers of meteorological conditions, investigating seasonal patterns of suicidal behavior can give only an idea of the association between weather conditions and suicides. Studies investigating the effects of daily variations in air temperature on the risk of committing suicide overall found a positive association (Dixon and Kalkstein 2018; Gao et al. 2019; Kim et al. 2016; Kim et al. 2019;

Thompson et al. 2018). Studies exploring the effects of other meteorological variables such as sunshine duration or cloud cover show less consistent results. While studies in different European countries reported a positive correlation/association between sunshine duration and suicide mortality (Papadopoulos et al. 2005; Vissoky et al. 2014), Kim et al. (2016) found no association in East Asian countries.

So far, there are only few studies examining the relation between suicide and weather-conditions in Central Europe. Therefore, we aimed to investigate the association between short-term changes of air temperature, sunshine duration or cloud cover and fatal suicides in Bavaria, Germany, for the period 1990-2006. We further explored potential effect modifications by specific weather conditions, personal or regional characteristics, and season.

2. Materials and Methods

2.1 Suicide data

Mortality data were obtained from the Bavarian State Office for Statistics and Data Processing for four Bavarian cities (München, Nürnberg, Augsburg, and Rosenheim) as well as for eleven Bavarian counties (München, Fürstenfeldbruck, Garmisch-Partenkirchen, Weilheim-Schongau, Bad Tölz-Wolfratshausen, Miesbach, Rosenheim, Berchtesgadener Land, Traunstein, Augsburg, and Aichach-Friedberg) from 1990 to 2006 (Supplemental Figure 1). We used International Classification of Diseases 9th version (ICD-9: E950-E958) codes for the period 1990–1997 and International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10: X60-X84) codes for the years 1998–2006. We did not distinguish between violent (e.g. hanging, firearms) and non-violent (e.g. poisoning) cases in our analyses, as nonviolent suicides were quite rare during our study period (2,057 cases in 17 years).

2.2 Meteorological data

We obtained meteorological data from the German Weather Service (DWD) and included daily measurements of mean air temperature, mean relative humidity, mean cloud cover, sum of sunshine duration, and sum of precipitation. Cloud cover was the only categorical variable coded in oktas (0 - no clouds to 8 - completely overcast). Continuous measurements of meteorological data throughout the whole study period were available for seven stations, which were located in seven different cities and counties (Supplemental Figure 1). If no sufficient meteorological data were available for a county, data from an adjacent county was assigned to the respective county. Suicide data from Weilheim-Schongau had to be excluded because no meteorological data were available for this county and data from adjacent counties could not be appropriately used due to the large distance. Hence, data of ten Bavarian counties and four cities were included in all further analyses. Barometric pressure was only measured at four of the seven selected stations and, therefore, not considered for analyses.

We additionally calculated dew point temperature based on air temperature and relative humidity (Kalkstein and Valimont 1986). For a more detailed description see the Supplemental Table 1.

2.3 Statistical analyses

2.3.1 Effects of meteorological variables

City/county-specific associations between meteorological variables and suicides were analyzed using a time-stratified case-crossover approach and conditional logistic regression models (Levy et al. 2001; Maclure 1991). This approach is generally recommended when studying short-term exposures that cause a transient change in risk of a rare event. For each suicide (case day), we selected control days which were falling on the same day of the week within the same month and year as the case day. Because case days and their matched control days are derived from the same person, and a conditional analysis was conducted, non-time-varying confounders (such as underlying medical conditions), time trends, and season, are controlled by design.

Meteorological variables may have a non-linear association with suicides. Therefore, each continuous variable was included linearly or as penalized spline (P-Spline) in the model for each outcome separately. Deviation from linearity was assessed based on likelihood ratio tests. All variables showed linear associations with suicides (see, for example, the exposure-response-relationship for air temperature and suicides in Supplemental Figure 2); therefore, they were included linearly in all models described below.

When investigating the effects of air temperature, we adjusted the models for long-term time trend, precipitation and cloud cover; models assessing sunshine duration or cloud cover were adjusted for long-term time trend, air temperature and precipitation. Because of the low frequencies of lower categories and to simplify the statistical analyses, we grouped cloud cover into three categories (0-3, 4-6, and 7-8 oktas).

For each meteorological variable immediate (lag 0), lagged (1 to 4 days before the event) and cumulative effects (5-day average of lag 0 to lag 4) on suicides were analyzed separately. For cloud cover, we did not consider the 5-day average for analysis, as an average of a categorical variable cannot be meaningfully calculated. Each exposure variable and the other meteorological variables were always included with the same lag.

In a second stage, we combined city- and county-specific effects estimates using random effects meta-analysis; city- and county-specific exposure-response functions were combined through a multivariate meta-analysis framework as proposed by Gasparrini and colleagues (Gasparrini et al. 2012).

Effects are shown as percent risk increase for an increase of 5°C in temperature, and 60min in sunshine duration. Highest cloud cover (7-8 oktas) was chosen as reference category when presenting the associations between cloud cover and suicides.

2.3.2 Effect modifications

In further analyses, we explored the following potential effect modifications: i) age (<65 years or ≥ 65 years); ii) sex (male or female); iii) place of residence (urban or rural), iv) season (spring: March-May, summer: June-August, autumn: September-November, or winter: December-February); or v) specific meteorological conditions (temperature<median value or ≥median value; relative humidity<median value or ≥median value) modified the associations between meteorological variables and suicides. Effect modifications were analyzed by including interaction terms as well as the main effects of these two variables in the models.

2.3.3 Sensitivity analyses

In order to check the robustness of our results we performed several sensitivity analyses: i) We included trend as a P-Spline; ii) all models were only adjusted for time trend; iii) instead of adjusting for cloud cover, the models were adjusted for sunshine duration; iv) we investigated the effects of dew point temperature as this parameter combines air temperature and relative humidity and might be a better marker for the perceived temperature than air temperature alone; v) we calculated polynomial distributed lag (PDL) models, which include all temperature lags simultaneously. In order to avoid multicollinearity, we used an Almon distributed lag model (Almon 1965) which forces estimates to a polynomial shape. The sum of the lagged temperature effects resulting from a PDL model were compared with the effect of the 5-day temperature average; and vi) we analyzed the association of meteorological variables on suicides and undetermined cases (ICD-9: E980-E989, ICD-10: Y10-Y34, Y89) combined as it is assumed that most of the undetermined deaths are probably suicides (Ohberg and Lonnqvist 1998).

All analyses were performed using SAS V9.3 (SAS Institute Inc) and R Statistical Software version 3.1.1 (R Development Core Team 2008).

3. Results

3.1 Suicide data and meteorological data

During the study period (1990-2006), a total of 10,595 fatal suicides were documented. This is equivalent to 1.71 cases per day (see Table 1). 69% of the suicides were committed by men, and almost 74% of suicide cases were younger than 65 years.

Overall, the number of suicides per 100,000 inhabitants decreased during the study period from a maximum 19.1 cases per 100,000 inhabitants in 1992 to 14.6 cases per 100,000 inhabitants in 2006 (Figure 1). Looking at the monthly distributions, we found the highest number of cases per 100,000 inhabitants from March to July (range: 1.45-1.55) and decreasing numbers from August to December. Table 1 shows a description of the meteorological variables combining the data of the seven selected measurement stations (each 6,209 days). A description of the variables for each station separately can be found in the Supplemental Material (Supplemental Table 2). For all measurement stations, no or a very low percentage (<0.2%) of days with missing values were observed. Only cloud cover was not measured at one station (Garmisch-Partenkirchen). These missing values were replaced by the rounded average of two measurement stations within the same county. Low (0-3 oktas), medium (4-6 oktas), and high cloud cover (7-8 oktas) was observed for 26%, 34%, and 40% of the measurements, respectively.

3.2 Meteorological variables and suicides

An increase in daily air temperature by 5°C on the day before a suicide compared to the control days was associated with a percent change in suicide risk of 5.7% (95%-CI: 0.6; 11.0) (Figure 2). We found a similar association for the 5-day average of temperature (percent change of 5.2% (95%-CI: -1.1; 11.9)), although the effect was not significant.

As the effects of low (0-3 oktas) and medium cloud cover (4-6 oktas) were very similar we combined these two categories. On days with cloud cover between 0-6 oktas (lag 0) the suicide risk was 6.5% (95%-CI: 0.2; 13.3) higher compared to days with high cloud cover (7-8 oktas) (Figure 2).

City- or county-specific estimates for air temperature with a lag of one day are shown in Figure 3. While we found a moderate heterogeneity (percentage of variation between effect estimates due to heterogeneity rather than chance, I^2=54.18%) between the city-/county-specific temperature effects, the effects of cloud cover did not differ significantly between the study regions.

3.3 Effect modifications

To reduce the number of performed interaction analyses, we only inspected the lag of each meteorological variable with the strongest significant main effect on suicides. We observed a stronger association between temperature (lag 1) and suicide risk in individuals ≥65 years (percent change of 9.0% (95%-CI: 3.4; 15.0), Figure 4) compared to younger individuals (3.5% (95%-CI: -1.4; 8.7)). The temperature effect was also slightly more pronounced in men (5.9% (95%-CI: 1.5; 10.5)); however, the association did not significantly differ from the effect for women (3.6% (95%-CI: -3.3; 10.9)). While temperature increases in spring were not associated with suicides, we found positive associations in summer (6.7% (95%-CI: 0.3; 13.6)), autumn (4.4% (95%-CI: -1.9; 11.2)), and winter (11.7% (95%-CI: 3.5; 20.5)).

Low/medium cloud cover (lag 0) was associated with a 12.9% (95%-CI: 1.9; 25.0) and 9.8% (95%-CI: 0.0; 20.5) higher suicide risk in summer and autumn, respectively; no effects of cloud cover were found in winter and spring. Moreover, the association between cloud cover and suicides was stronger on days with temperature ≥8.8°C (8.9% (95%-CI: 1.6; 16.7)). Stronger effects of low cloud cover on warmer days probably reflect our finding of stronger effects in summer and autumn.

3.4 Sensitivity analyses

Changing the adjustment of our models did not lead to substantial changes of the associations between meteorological variables and suicides. The immediate effect of cloud cover became insignificant when adjusting for sunshine duration. However, this is probably due to the close relation of these two variables. Because of the very high correlation between air temperature and dew point temperature (Spearman correlation coefficient of 0.95), the temperature variables showed very similar associations with suicides. The sum of the lagged temperature effects (5.6% (95%-CI: 0.5; 11.0)) resulting from PDL analyses were comparable to the effects of the 5-day temperature average on total suicides. There were no essential differences observed when comparing the effects of meteorological variables on suicides or the sum of suicides and undetermined cases because of the very low number of undetermined cases.

4. Discussion

4.1 Summary

This is one of the first studies investigating the associations between daily changes in meteorological variables and fatal suicides in Central Europe. We found a rather immediate increase in suicides associated with increases in air temperature on the day before the event compared to the control days and with low to medium cloud cover. While temperature was not associated with suicides in spring, we found positive associations in summer, autumn, and winter. Temperature effects were more pronounced in the elderly. The effects of cloud cover were strongest in summer and autumn and on days with temperature above median (>8.8°C).

4.2 Weather and suicides

So far, the number of studies investigating the association between daily meteorological changes and daily suicide counts is still limited, especially in Central Europe. Although adjusting for seasonality, most studies found a higher suicide risk in association with increases in air temperature from day to day (Dixon and Kalkstein 2018; Gao et al. 2019; Hiltunen et al. 2014; Kim et al. 2016; Kim et al., 2019; Thompson et al. 2018). A recent systematic review and meta-analysis reported a 1% increase in the incidence of suicide (Incidence Rate Radio (IRR) = 1.01; 95%-CI: 1.00–1.02; $p < 0.05$) per each 1°C increase in temperature (Gao et al. 2019), which is comparable to our findings. This temperature-suicide association was mainly driven by studies using daily temperatures (Gao et al. 2019). In accordance with our findings, a recent study conducted in three East Asian countries found the strongest temperature effects with a delay of one day also using a time-stratified case-crossover method (Kim et al. 2016). Moreover, we found an increased suicide risk on days with low to medium cloud cover (0 – 6 oktas) compared to days with high cloud cover (7 or 8 oktas), but no associations with sunshine duration. Studies on sunshine duration are inconsistent (Kim et al. 2016; Likhvar et al. 2011; Salib 1997; Vissoky et al. 2014). Some studies (Jee et al. 2017; Müller et al. 2011; Papadopoulos et al. 2005) also found a positive association between solar radiation and suicides which might be a surrogate for sunshine duration or cloud cover. We can only speculate why we did not find an association between sunshine duration and suicides but with cloud cover although these two meteorological variables are closely related. A reason might be the measurement accuracy of sunshine duration in our study; another reason might be that cloud cover might act as a surrogate for a different (unmeasured) variable.

4.3 Susceptible subgroups and season

In our study, temperature effects were more pronounced in individuals older than 65 years and were slightly stronger in men. Similar findings were also observed in a study conducted in South Korea (Kim et al. 2011). A further study using data of 15 East Asian cities (Kim et al. 2016) found stronger effects in men but could not find a consistent effect modification by age. It is assumed that the elderly are more susceptible to heat (Hansen et al. 2011) and it has been shown that they commit suicide at a higher rate than any other age group (Stanley et al. 2016).

Kim et al. (2011) hypothesized that men more often have outdoor jobs than women and therefore can less avoid stress due to temperature. It has also been reported that women are more able to control their skin temperature than men (Violani and Lombardo 2003). Therefore, our finding of (slightly) stronger temperature effects in men might be reasonable. Moreover, women more frequently attempt suicides rather than actually commit it, whereas men are more likely to complete suicides and choose more violent suicide methods (Mergl et al. 2015). In our study, only 31% of the suicides were committed by women. Therefore, the absence of significant temperature effects in women might only be due to a lack of power.

In our study, temperature effects were positive in summer, autumn and winter. We did not find temperature effects in spring although suicide rates were comparably high, which is contrary to previous studies (Hiltunen et al. 2014; Holopainen et al. 2013). These studies hypothesized that increasing thermal stress on warm days after cold nights during spring may over-activate brown adipose tissue and impair heat tolerance. This impairment then may lead to a change in neural activity in the brain areas receiving projections from brown adipose tissue and thereby may increase the risk of suicide (Holopainen et al. 2013). We can only speculate that changes in temperature did not add much to the per se higher suicide risk in spring. Our results also show that not only increases in daily air temperature during summer might be associated with suicides but also short-term increases in temperature during colder time periods (winter). However, for cloud cover we found increased suicide risks in spring, summer, as well as autumn and on days with an average temperature above the median (8.8°C) but no significant effects in winter.

4.4 Potential mechanisms

Several mechanisms linking air temperature and sunshine to suicides have been discussed so far, including neurobiological, sociological and cultural pathways.

Among neurobiological mechanisms, the serotonergic system has been shown to have a major role in suicidal behavior (Sadkowski et al. 2013). Among others, abnormalities in serotonin transportation and in serotonin levels in key brain areas have all been linked with suicide (Mann 2013). Studies have observed that ambient temperature can modulate serotonin function. For example, a recent study from Finland showed that higher ambient air temperature is associated with changes in serotonin transporter density that, in turn, increases impulsivity and irritability (Tiihonen et al. 2017). Moreover, it has been shown that low as well as high levels of melatonin are associated with suicidal ideas and depressive disorders. It is assumed that low melatonin levels in depressives are correlated with low serotonin levels in the brain (Srinivasan et al. 2006). This leads to the paradox that sunshine can ameliorate depression but might also be a trigger for suicides (Papadopoulos et al. 2005). At first, sunshine improves the motivation and the usual lack of energy is withdrawn. This extra energy can potentially motivate a depressive person to carry out suicide. An improvement in mood and a protection against suicidal thoughts is expected only on a long-term basis. This hypothesis was supported by Page et al. (2007) who found no seasonal association in a large dataset of suicides in England and Wales but very clear immediate effects of increased temperatures.

Regarding sociological factors, one possible mechanism is the use of excess alcohol on hot days (Page et al. 2007); alcohol can exert effects on health through depression of the central nervous system, and by causing diuresis and dehydration (Keatinge 2003). Unfortunately, information on population alcohol consumption was not available for our study, so we cannot comment further on this potential mechanism. Cultural pathways include increased stress from the upcoming school year, or - in areas that are more rural - stress from the approaching harvest season or an increased accessibility to potentially harmful resources (Dixon and Kalkstein 2018).

4.5 Strengths and limitations

A main strength of our study is the availability of daily suicide and meteorological data allowing the application of sophisticated statistical models. So far, only a few short-term studies used modern time-series approaches with the possibility to appropriately adjust for other meteorological variables and long-term time trend (Kim et al. 2011; Kim et al. 2016; Likhvar et al. 2011; Page et al. 2007). Information on sex and age allowed us to investigate potential effect modifications.

Complete meteorological data were only available for seven counties. By assigning meteorological data from other counties to a county with no or only incomplete data, we cannot rule out exposure misclassification. However, meteorological variables showed a very high correlation between the different measurement stations. When investigating short-term effects of exposure variables on a health outcome the correct specification of the day-to-day variability is of greater importance than correct absolute exposure levels. Therefore, we assume that exposure misclassification is a rather small problem in our study.

Data were only available for a small part of Germany. Therefore, the generalizability of our results is questionable. However, despite the small study area we were able to include a large number of suicide cases (>10,000) during a long study period (17 years) in our analyses and the results indicated no or only a moderate heterogeneity between the city/county-specific effects of meteorological variables. Therefore, we assume that similar associations could be observed for whole Germany.

Certain individuals may be genetically predisposed to chemical imbalances or challenging situation such as remaining in debt traps; therefore, we cannot rule out the induction of chemical imbalances over time. If this would be the case, the model assumptions used in this paper might ignore autocorrelated errors that changing financial/economic conditions in Bavaria may have induced over years (perhaps resulting in declining suicide rates).

5. Conclusion

We found a higher risk for suicides in association with short-term increases in air temperature on the day before the event compared to the control days and on days with low to medium cloud cover. This may highlight time periods when people are more likely to commit suicide. Gaining knowledge about triggers or predictive factors of these tragic events is important to help clinicians and therapists to advise potential victims as well as friends and relatives in order to improve suicide prevention.

Funding

This study has been funded by the German Research Foundation (DFG grant number BR 3944/2-1). The sponsor was not involved in the planning of the study design, data collection, analysis and interpretation of the date, in the writing of the manuscript and in the decision to submit the article for publication.

Research was further supported within the Munich Center of Health Sciences (MC-Health), Ludwig-Maximilians-Universität, as part of LMU innovative.

Declarations of interest

none

References

Ajdacic-Gross V, Bopp M, Ring M, Gutzwiller F, Rossler W. 2010. Seasonality in suicide--a review and search of new concepts for explaining the heterogeneous phenomena. Soc Sci Med 71:657-666.

Almon S. 1965. The distributed lag between capital appropriations and expenditures. Econometrica 33:178-196.

Baumert J, Schneider B, Lukaschek K, Emeny RT, Meisinger C, Erazo N, et al. 2014. Adverse conditions at the workplace are associated with increased suicide risk. J Psychiat Res 57:90-95.

Christodoulou C, Douzenis A, Papadopoulos FC, Papadopoulou A, Bouras G, Gournellis R, et al. 2012. Suicide and seasonality. Acta Psychiat Scand 125:127-146.

Crump C, Sundquist K, Sundquist J, Winkleby MA. 2014. Sociodemographic, psychiatric and somatic risk factors for suicide: A Swedish national cohort study. Psychol Med 44:279-289.

DeFina R, Hannon L. 2015. The changing relationship between unemployment and suicide. Suicide Life-Threat 45:217-229.

Dixon PG, Kalkstein AJ. 2018. Where are weather-suicide associations valid? An examination of nine US counties with varying seasonality. Int J Biometeorol 62:685-697.

Erazo N, Baumert J, Ladwig KH. 2004. Sex-specific time patterns of suicidal acts on the German railway system. An analysis of 4003 cases. J Affect Disord 83:1-9.

Fassberg MM, van Orden KA, Duberstein P, Erlangsen A, Lapierre S, Bodner E, et al. 2012. A systematic review of social factors and suicidal behavior in older adulthood. Int J Environ Res Public Health 9:722-745.

Gao J, Cheng Q, Duan J, Xu Z, Bai L, Zhang Y, et al. 2019. Ambient temperature, sunlight duration, and suicide: A systematic review and meta-analysis. Sci Total Environ 646:1021-1029.

Gasparrini A, Armstrong B, Kenward MG. 2012. Multivariate meta-analysis for non-linear and other multi-parameter associations. Stat Med 31:3821-3839.

Hansen A, Bi P, Nitschke M, Pisaniello D, Newbury J, Kitson A. 2011. Older persons and heat-susceptibility: The role of health promotion in a changing climate. Health Promot J Aust 22 Spec No:S17-20.

Hawton K, van Heeringen K. 2009. Suicide. Lancet 373:1372-1381.

Hiltunen L, Haukka J, Ruuhela R, Suominen K, Partonen T. 2014. Local daily temperatures, thermal seasons, and suicide rates in Finland from 1974 to 2010. Environ Health Prev Med 19:286-294.

Holopainen J, Helama S, Bjorkenstam C, Partonen T. 2013. Variation and seasonal patterns of suicide mortality in Finland and Sweden since the 1750s. Environ Health Prev Med 18:494-501.

Jee HJ, Cho CH, Lee YJ, Choi N, An H, Lee HJ. 2017. Solar radiation increases suicide rate after adjusting for other climate factors in South Korea. Acta Psychiatr Scand 135:219-227.

Kalkstein LS, Valimont KM. 1986. An evaluation of summer discomfort in the United States using a relative climatological index. American Meteorological Society 67:842-848.

Keatinge WR. 2003. Death in heat waves. BMJ 327:512-513.

Kim Y, Kim H, Kim DS. 2011. Association between daily environmental temperature and suicide mortality in Korea (2001-2005). Psychiatry Res 186:390-396.

Kim Y, Kim H, Honda Y, Guo YL, Chen BY, Woo JM, et al. 2016. Suicide and ambient temperature in East Asian countries: A time-stratified case-crossover analysis. Environ Health Perspect 124:75-80.

Kim Y, Kim H, Gasparrini A, Armstrong B, Honda Y, Chung Y, et al. 2019. Suicide and Ambient Temperature: A Multi-Country Multi-City Study. Environ Health Perspect 127(11):117007.

Levy D, Lumley T, Sheppard L, Kaufman J, Checkoway H. 2001. Referent selection in case-crossover analyses of acute health effects of air pollution. Epidemiology 12:186-192.

Likhvar V, Honda Y, Ono M. 2011. Relation between temperature and suicide mortality in Japan in the presence of other confounding factors using time-series analysis with a semiparametric approach. Environ Health Prev Med 16:36-43.

Lukaschek K, Erazo N, Baumert J, Ladwig KH. 2012. Suicide mortality in comparison to traffic accidents and homicides as causes of unnatural death. An analysis of 14,441 cases in Germany in the year 2010. Int J Env Res Pub He 9:924-931.

Maclure M. 1991. The case-crossover design: A method for studying transient effects on the risk of acute events. Am J Epidemiol 133:144-153.

Mann JJ. 2013. The serotonergic system in mood disorders and suicidal behaviour. Philos Trans R Soc Lond B Biol Sci 368:20120537.

McCall WV, Black CG. 2013. The link between suicide and insomnia: Theoretical mechanisms. Curr Psychiat Rep 15:389.

Mergl R, Koburger N, Heinrichs K, Szekely A, Toth MD, Coyne J, et al. 2015. What are reasons for the large gender differences in the lethality of suicidal acts? An epidemiological analysis in four European countries. PLoS One 10:e0129062.

Moller-Leimkuhler AM. 2003. The gender gap in suicide and premature death or: Why are men so vulnerable? Eur Arch Psy Clin N 253:1-8.

Müller H, Biermann T, Renk S, Reulbach U, Ströbel A, Kornhuber J, et al. 2011. Higher environmental temperature and global radiation are correlated with increasing suicidality--a localized data analysis. Chronobiol Int 28:949-957.

Nadorff MR, Nazem S, Fiske A. 2013. Insomnia symptoms, nightmares, and suicide risk: Duration of sleep disturbance matters. Suicide Life-Threat 43:139-149.

O'Connor RC, Nock MK. 2014. The psychology of suicidal behaviour. The lancet Psychiatry 1:73-85.

Ohberg A, Lonnqvist J. 1998. Suicides hidden among undetermined deaths. Acta Psychiatr Scand 98:214-218.

Page LA, Hajat S, Kovats RS. 2007. Relationship between daily suicide counts and temperature in England and Wales. Br J Psychiatry 191:106-112.

Papadopoulos FC, Frangakis CE, Skalkidou A, Petridou E, Stevens RG, Trichopoulos D. 2005. Exploring lag and duration effect of sunshine in triggering suicide. J Affect Disord 88:287-297.

Qin P, Hawton K, Mortensen PB, Webb R. 2014. Combined effects of physical illness and comorbid psychiatric disorder on risk of suicide in a national population study. Br J Psychiatry 204:430-435.

R Development Core Team. 2008. R: A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria.

Robert Koch Institut. 2015. Gesundheit in Deutschland - Gesundheitsberichterstattung des Bundes.

Sadkowski M, Dennis B, Clayden RC, Elsheikh W, Rangarajan S, Dejesus J, et al. 2013. The role of the serotonergic system in suicidal behavior. Neuropsychiatr Dis Treat 9:1699-1716.

Salib E. 1997. Elderly suicide and weather conditions: Is there a link? Int J Geriatr Psychiatry 12:937-941.

Schneider B, Baumert J, Schneider A, Marten-Mittag B, Meisinger C, Erazo N, et al. 2011. The effect of risky alcohol use and smoking on suicide risk: Findings from the German MONICA/KORA-Augsburg cohort study. Soc Psychiatry Psychiatr Epidemiol 46:1127-1132.

Schneider B, Lukaschek K, Baumert J, Meisinger C, Erazo N, Ladwig KH. 2014. Living alone, obesity, and smoking increase risk for suicide independently of depressive mood findings from the population-based MONICA/KORA-Augsburg cohort study. J Affect Disord 152-154:416-421.

Srinivasan V, Smits M, Spence W, Lowe AD, Kayumov L, Pandi-Perumal SR, et al. 2006. Melatonin in mood disorders. World J Biol Psychiatry 7:138-151.

Stanley IH, Hom MA, Rogers ML, Hagan CR, Joiner TE, Jr. 2016. Understanding suicide among older adults: A review of psychological and sociological theories of suicide. Aging Ment Health 20:113-122.

Tang NK, Crane C. 2006. Suicidality in chronic pain: A review of the prevalence, risk factors and psychological links. Psychol Med 36:575-586.

Tanskanen A, Tuomilehto J, Viinamaki H, Vartiainen E, Lehtonen J, Puska P. 2000. Smoking and the risk of suicide. Acta Psychiatr Scand 101:243-245.

Thompson R, Hornigold R, Page L, Waite T. 2018. Associations between high ambient temperatures and heat waves with mental health outcomes: A systematic review. Public Health 161:171-191.

Tiihonen J, Halonen P, Tiihonen L, Kautiainen H, Storvik M, Callaway J. 2017. The association of ambient temperature and violent crime. Sci Rep 7:6543.

Turecki G, Brent DA. 2016. Suicide and suicidal behaviour. Lancet 387:1227-1239.

Violani C, Lombardo C. 2003. Peripheral temperature changes during rest and gender differences in thermal biofeedback. J Psychosom Res 54:391-397.

Vissoky B, Kapusta ND, Praschak-Rieder N, Dorffner G, Willeit M. 2014. Direct effect of sunshine on suicide. JAMA Psychiatry 71:6.

Whitley E, Gunnell D, Dorling D, Smith GD. 1999. Ecological study of social fragmentation, poverty, and suicide. BMJ 319:1034-1037.