# Altitude, Gun Ownership, Rural Areas, and Suicide

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**Objective.** The authors recently observed a correlation between state altitude and suicide rate in the United States, which could be explained by higher rates of gun ownership and lower population density in the intermountain West. The present study evaluated the relationship between mean county and state altitude in the United States and total age-adjusted suicide rates, firearm-related suicide rates, and non-firearm-related suicide rates. The authors hypothesized that altitude would be significantly associated with suicide rate.

**Method.** Elevation data were calculated with an approximate spatial resolution of 0.5 km, using zonal statistics on data sets compiled from the National Geospatial-Intelligence Agency and the National Aeronautics and Space Administration. Suicide and population density data were obtained through the Centers for Disease Control and Prevention (CDC) WONDER database. Gun ownership data were obtained through the CDC's Behavioral Risk Factor Surveillance System.

**Results.** A significant positive correlation was observed between age-adjusted suicide rate and county elevation (r=0.51). Firearm (r=0.41) and non-firearm suicide rates (r=0.32) were also positively correlated with mean county elevation.

**Conclusions.** When altitude, gun ownership, and population density are considered as predictor variables for suicide rates on a state basis, altitude appears to be a significant independent risk factor. This association may be related to the effects of metabolic stress associated with mild hypoxia in individuals with mood disorders.

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Suicide rates in the United States have shown consistent regional variations and have generally been higher in western states (1). One possible explanation for this relationship is an adverse effect of altitude-related hypoxia in persons with mood disorders. The peak altitudes within each state as well as the altitude of each state capital have been shown to be strongly associated with state suicide rates (2). However, alternative explanations for the significant association between suicide and altitude include relatively higher rates of gun ownership in the western United States (3, 4) and the low population density (5), which is exemplified by the rural nature of the intermountain West (6).

Mood disorders have been strongly associated with suicide in the developed world (7). While the etiology of mood disorders is still being studied, both major depression and bipolar disorder have been associated with mitochondrial dysfunction (8–10). Likewise, individuals with mitochondrial disorders often have an elevated incidence of depressive symptoms (11, 12). Life at higher altitudes provides a mild hypoxic challenge, and exposure to hypobaric hypoxia has been associated with worsening mood (13) that can persist for up to 90 days (14).

Over time, a number of compensatory changes follow moving to a higher altitude (15, 16). However, we propose that some individuals with mood disorders may not have the same capacity to adapt to the metabolic stress of high altitude. For example, lymphocytes from patients with bipolar disorder exposed to low glucose media ???were not able to up-regulate electron transport gene expression in the same manner as??? lymphocytes from individuals without bipolar disorder (17). Changes seen following reduced glucose may parallel those seen following hypoxia. Animals exposed to hypoxia have demonstrated rapid increases in brain mitochondrial number and protein (18).

In this study, we assessed the relationship of county and state altitude in the United States with total age-adjusted suicide rates, firearm-related suicide rates, and non-firearm-related suicide rates. To the extent that altitude of residence was an independent risk factor for suicide, we hypothesized that both firearm and non-firearm-related suicide rates would be correlated with county and state altitude. In addition, with state-level data, we performed a multiple regression analysis of suicide rates with mean altitude, gun ownership rates, and population densities. We hypothesized that altitude would be significantly associated with suicide rate.

## Method

### *Suicide Data*

The Centers for Disease Control and Prevention (CDC) WONDER database (19) was used to extract data sets related to suicide rates in the continental United States collected over a 20-year period (1979–1998). All data sets were age-adjusted, reported as deaths per 100,000, and included only persons at least 5 years of age. The data sets abstracted data on total suicide rate, firearm



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suicide rate, and population. Each data set was abstracted on the county level as well as the state level.

The county-level abstraction (overall suicide rate, firearm suicide rate, and population) included data sets of suicide rates from each county in the continental United States for which elevation data were available (N=3,108 counties for each data set; four counties were excluded for lack of elevation data). The overall suicide data set included all recorded suicides by county regardless of mechanism of suicide. The CDC identified 490 counties as having unreliable total suicide rates, defined as counties with 20 or fewer cumulative suicide deaths.

The firearm suicide data set included only suicides completed by firearms. This data set enabled us to calculate the non-firearm suicides for each county. Forty-one percent of reported suicides in the CDC data were non-firearm suicides. Of the 3,108 counties, 740 were identified as having unreliable data because they had 20 or fewer firearm suicide deaths.

The state-level CDC WONDER abstraction also included overall suicide and suicide by firearms data sets (the 48 contiguous states plus the District of Columbia). All firearm suicide data abstracted from the CDC WONDER database were identified as reliable by the CDC—that is, each state had more than 20 suicide deaths over the observed period.

### *Gun Ownership Data*

Gun ownership rates for each state were taken from the CDC's Behavioral Risk Factor Surveillance System, which included survey data from 201,881 respondents nationwide (20). For gun ownership, data were available only on a state level.

### *Population Density Data*

Population density for each county was calculated from county populations provided by the CDC WONDER database, as reported in the 2000 census) (19), and the area in square miles of each county from the Shuttle Radar Topography Mission (SRTM) data set. Since some counties with a high mean altitude may have a low population, we also evaluated the relationship between adjusted suicide rates and the altitude of the most populous county in each state.

### *Average Elevation*

The SRTM elevation data set, developed by the National Geospatial-Intelligence Agency and the National Aeronautics and Space Administration, was used to calculate the average elevation of each county. SRTM is a global data set created in February 2000 with a spatial resolution of approximately 0.1 km. The spatial extent for this data set covered only the contiguous United States. Four counties were not included in this data set: one county each in Montana and Georgia and two counties in Virginia. These counties were removed from the analysis, which resulted in a total of 3,108 counties. The average elevation of each of the counties was evaluated using zonal statistics in an ArcGIS/ArcInfo 9.3 environment (ESRI, Redlands, Calif.). ArcGIS/ArcInfo is geographical information system software used to calculate data related to mapping and querying geographical databases. The data from the SRTM provided mean elevation calculations for each square kilometer in each county. County outlines provided by ArcGIS/ArcInfo were then overlaid on the mean spatial data to obtain mean county elevation for each county. Data inputs for this analysis used a 1:500,000-scale U.S. counties vector data set and a mosaiced digital elevation model of ~0.5 km spatial resolution derived from the SRTM data set. State elevations were calculated by taking the mean of the county elevations for each state.

### *Data Analysis*

Pearson correlation coefficients were computed to investigate the association between elevation and suicide rate. In addition, a two-tailed multiple regression analysis was performed to analyze the dependent variable, age-adjusted suicide rate. This regression was run with the independent variables defined as the average state elevation, the county population density, and the state gun ownership rate.

The following equation describes our model of the multiple regression analysis of state elevation, population density, and gun ownership with respect to suicide rate:

$$Y_{suicide\_rate} = \beta_1 X_{elevation} + \beta_2 X_{population\_density} + \beta_3 X_{gun\_ownership} + c,$$

where $\beta_1$, $\beta_2$, and $\beta_3$ are regression coefficients and c is a constant. Statistical significance was defined at an alpha level of 0.05 and two-tailed. R version 2.10 (http://www.R-project.org) was used for the computation.

### *Complementary Studies*

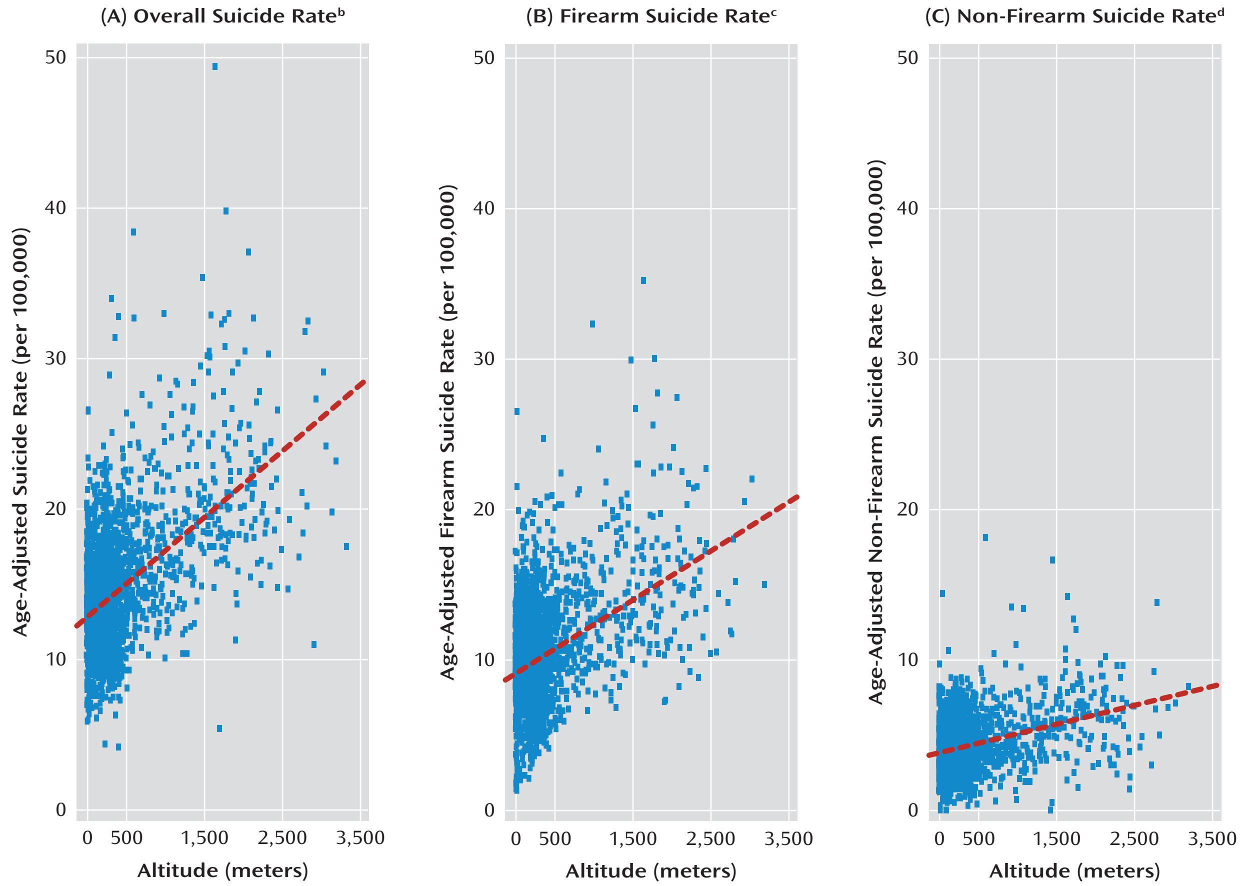
To increase our confidence in the results we present here, we conducted two additional analyses. First, we looked at the relationship between suicide and altitude in the context of a number of possible covariates. We analyzed the following county-level variables: altitude; total number of child psychiatrists; total number of psychiatrists; number of psychiatric, patient care, and hospital full-time staff; percentage of persons in poverty; unemployment rate for persons age 16 and older; per capita income; percentage of persons age 25 or older with less than 9 years of school; percentage of persons age 25 or older with at least high school diploma; percentage of persons age 25 or older with 4 years or more of college; population density; male population ratio; white male population ratio; white female population ratio; and divorced female population ratio. These data were obtained from the Area Resource File 2008 (US Department of Health and Human Services, Health Resources and Services Administration, Bureau of Health Professions, Rockville, Md., 2009) and analyzed using a normalized regression method.

Second, in order to address possible cultural factors, we analyzed suicide rates by county, as a function of elevation, in South Korea. South Korea was selected not only because it is culturally quite different from the United States, but also because it has both a variable geography with many mountainous areas and a relatively high suicide rate (N. Kim and P. Renshaw, unpublished 2010 data). Elevation data were extracted from SRTM (21). County boundary data were obtained from the Korean National Geographic Information Institute (21). Suicide data for a 4-year period (2005–2008) were obtained from Statistics Korea (22). A total of 233 counties were included in this analysis.

## Results

As shown in Figure 1 and Table 1, there were significant positive correlations between age-adjusted suicide rate and county elevation in the United States. Both firearm suicide rate and non-firearm suicide rate were positively correlated with county altitude. All correlations were run using the CDC WONDER data set restricted to counties with reliable values as well as the complete data set. The reliable values and the complete data set correlations did not differ significantly. A correlation analysis based on state-level data showed that elevation ($r=0.79$, $df=47$, $p<0.001$) had a more significant association with age-adjusted suicide rate than did gun ownership ($r=0.49$, $df=47$, $p<0.001$). A negative correlation was observed between suicide rates and population density (population per square mile) on a state level ($r=-0.36$, $df=47$, $p=0.010$), which is consistent with results from previous studies (6).

FIGURE 1. Scatterplots of Suicide Rates and Average Elevation of Counties in the Continental United States[a]




[a] Includes the 48 contiguous states and the District of Columbia; excludes counties with fewer than 20 cumulative suicide deaths (N=490) and counties for which elevation data were not available (N=4).
Overall suicide rate by elevation (r=0.51, df=2616, p<0.001).
Suicide rate of death by firearms by elevation (r=0.40, df=2366, p<0.001).
Suicide rate of non-firearm deaths by elevation (r=0.32, df=2366, p<0.001).

TABLE 1. Correlations Between Elevation and Age-Adjusted Suicide Rates in U.S. States and Countie

| | Elevation | | | |
|---|---|---|---|---|
| | Counties | | States[a] | |
| Suicide Rate | r | p | r | p |
| Age-adjusted suicide rate[b] | 0.51 | <0.001 | 0.79 | <0.001 |
| Age-adjusted firearm suicide rate[c] | 0.41 | <0.001 | 0.64 | <0.001 |
| Age-adjusted non-firearm suicide rate[c] | 0.32 | <0.001 | 0.53 | <0.001 |

[a] Based on 48 states and the District of Columbia (excludes Alaska and Hawaii).
[b] Based on 2,618 counties (excludes Alaska and Hawaii; counties with fewer than 20 cumulative suicide deaths [N=490]; and counties for which elevation data were not available [N=4]).
[c] Based on 2,368 counties (excludes Alaska and Hawaii and counties with fewer than 20 cumulative firearm-related suicide deaths [N=740]; and counties for which elevation data were not available [N=4]).

For the most populous county in each state, there was a strong association between suicide rates and altitude (r=0.72, df=47, p<0.001). This observation suggests that the relationship between suicide rate and altitude does not derive solely from data from counties with high altitudes and low populations. For the 50 counties with the highest suicide rates, there was only a weak, nonsignificant association between suicide rate and altitude (r=0.07, df=48, p<0.626). This is most likely due to the limited range in suicide rates across this small sample. In terms of size, these counties tend to be smaller and to have a lower population density (Table 2). This underscores the importance of including population density as a covariate in these analyses. Since the CDC WONDER criteria for reliable suicide data included a minimum number of deaths per county, counties with very small populations were excluded from the analysis.

**TABLE 2. U.S. County Population and Population Density[a]**

| | Population | | Population Density (Population/Square Mile) | |
|---|---|---|---|---|
| Counties | Mean | SD | Mean | SD |
| The 50 counties with the highest suicide rate | 380,000 | 720,000 | 228 | 690 |
| The most populous county in each state (N=49) | 19,100,000 | 25,900,000 | 45,100 | 95,100 |
| All counties[b] (N=2,618) | 1,470,000 | 4,800,000 | 4,032 | 27,000 |

[a] Based on 48 states and the District of Columbia; excludes Alaska and Hawaii.
[b] Excludes counties with fewer than 20 cumulative firearm-related suicide deaths (N=740); and counties for which elevation data were not available (N=4).

**TABLE 3. Normalized Correlation Coefficients of Covariates (β Coefficients) for Suicide Rates in U.S. Counties**

| Measure | Overall Suicide Rate, 1998–2000 and 2003–2005[a] (2,631 Observations) | 3-Year Suicide Rate, 2003–2005[a] (2,781 Observations) | 3-Year Suicide Rate, 1998–2000[a] (2,770 Observations) |
|---|---|---|---|
| Adjusted $R^2$ | 0.449* | 0.305* | 0.527* |
| Altitude | 0.239* | 0.135* | 0.184* |
| Total number of child psychiatrists, 2005 | –0.087 | –0.069 | –0.047 |
| Total number of psychiatrists, 2005 | 0.034 | 0.027 | 0.024 |
| Number of psychiatry, patient care, and hospital full-time staff, 2005 | 0.073* | 0.043 | 0.046 |
| Percentage of persons in poverty[a] | 0.142* | 0.075* | 0.100* |
| Unemployment rate for persons age 16 and older[a] | –0.027 | 0.010 | –0.057* |
| Per capita income[a] | 0.117* | 0.058 | 0.057* |
| Percentage of persons age 25 or older with less than 9 years of school, 2000 | –0.228* | –0.167* | –0.107* |
| Percentage of persons age 25 or older with at least a high school diploma, 2000 | –0.135* | –0.136* | –0.066 |
| Percentage of persons age 25 or older with 4 years or more of college, 2000 | –0.139* | –0.032 | –0.128* |
| Population density[a] | –0.021 | –0.011 | –0.018 |
| Male population ratio[a] | –0.030 | 0.011 | –0.041 |
| Female population ratio[a] | –0.047 | 0.039 | –0.009 |
| White male population ratio[a] | –0.202 | 0.050 | –0.005 |
| White female population ratio[a] | 0.306* | 0.043 | 0.082 |
| Divorced female population ratio, 2000 | 0.534* | 0.492* | 0.637* |

[a] The 1998 and 1999 populations were estimated on the basis of 1990 U.S. census data. The 2003, 2004, and 2005 populations were estimated on the basis of 2000 U.S. census data.
*$p \leq 0.05$.

The multiple regression analysis using state elevation, population density, and gun ownership as independent variables showed that elevation was a significant factor when based on state-level data ($r=0.004$, $p<0.001$). Surprisingly, in this multiple regression, population density was not significant and gun ownership was barely significant ($r=0.062$, $p=0.017$). The overall model, though, had an adjusted $R^2$ value of 0.687 ($p<0.001$), suggesting that these three variables captured much of the variance in suicide rates across states.

Table 3 presents normalized correlation coefficients from a multiple regression model. In this analysis, county altitude had one of the highest normalized beta values among the variables included in the model. Notably, the number of psychiatrists per county was not a significant risk factor in this model. In addition, divorced white women appeared to be at especially high risk of suicide, as has been previously demonstrated (23). Estimates of suicide rate for this analysis were derived from relatively brief sampling periods (3–6 years), which likely explains the somewhat lower adjusted $R^2$ value for the model.

The analysis of suicide data and county altitude in South Korea showed a strong association between suicide rate and altitude ($r=0.39$, $df=231$, $p<0.001$).

## Discussion

Our results are consistent with previous reports of increased suicide rates among gun owners (4, 24, 25) and rural residents (6). In addition, the association we observed between altitude, county of residence, and overall suicide rate replicates and extends earlier observations (2). Unique to this study is an evaluation of the relationship between overall suicide rates, firearm-related suicide rates, and non-firearm-related suicide rates and their relation to altitude of residence. Data on gun ownership were not available on a county basis (4). However, when altitude, gun ownership, and population density were considered as predictor variables for suicide rates on a state basis, altitude appeared to be a significant risk factor.

Despite the very strong associations between suicide and altitude of residence, the data we present here should be interpreted cautiously. As recently reviewed by Hawton and van Heeringen (26), suicide rates are known to vary with age, sex, ethnicity, socioeconomic factors, psychiatric illness, and family history. Tondo and colleagues (27) have also emphasized the important role that health care access plays in variation in suicide rates. However, in our analyses, we found that altitude remains a significant risk factor even when additional risk factors were included in the model.

Cultural factors, too, are known to influence suicide rates (28). However, in this context, it is notable that suicide rates in South Korea also demonstrated a strong association with local altitude. Nonetheless, given these multiple risk factors, ecological studies of suicide tend to provide weak evidence for causal association. Most people who commit suicide have psychiatric disorders, especially mood and substance use disorders (29), and further research will be needed to clarify the effects of altitude on the course of mental illness.

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