# Temporal Association Between Nonfatal Self-Directed Violence and Tree and Grass Pollen Counts

Haekyung Jeon-Slaughter, PhD[a]; Cynthia A. Claassen, PhD[b]; David A. Khan, MD[c]; Perry Mihalakos, BS[a]; Kevin B. Lee, MD[a]; and E. Sherwood Brown, MD, PhD[a,*]

## ABSTRACT

***Objectives:*** Prior research suggests a possible association between pollen and suicide. No studies have examined the relationship between pollen and attempted suicide. This study examines the temporal association between airborne pollen counts and nonfatal suicidal and nonsuicidal self-directed violence (SDV) requiring an emergency department visit.

***Methods:*** Data on daily emergency department visits due to nonfatal SDV as identified by *ICD-9* diagnosis criteria were extracted from emergency department medical records of Parkland Memorial Hospital in Dallas, Texas, between January 2000 and December 2003. Concurrent daily airborne tree, grass, and ragweed pollen data from the city of Dallas were extracted from the National Allergy Bureau online database. The data were analyzed using the time series method of generalized autoregressive conditional heteroskedasticity.

***Results:*** There were statistically significant and positive temporal associations between tree pollen counts and the number of nonfatal SDV events among women ($P = .04$) and between grass pollen counts and number of nonfatal SDV events among both men ($P = .03$) and women ($P < .0001$). There was no significant temporal association found between ragweed pollen counts and number of nonfatal SDV events.

***Conclusions:*** The study findings suggest that an increase in nonfatal SDV is associated with changes in tree and grass pollen counts. This is the first study that has examined an association between seasonal variation in tree and grass pollen levels and nonfatal SDV event data. The study also used a narrowly defined geographic area and temporal window. The findings suggest that pollen count may be a factor influencing seasonal patterns in suicidal behavior.

*J Clin Psychiatry 2016;77(9):1160–1167*
*dx.doi.org/10.4088/JCP.15m09864*


[a]Department of Psychiatry, The University of Texas Southwestern Medical Center, Dallas
[b]Department of Psychiatry, The University of North Texas Health Science Center, Fort Worth
[c]Division of Allergy and Immunology in the Department of Internal Medicine, The University of Texas Southwestern Medical Center, Dallas
*Corresponding author: E. Sherwood Brown, MD, PhD, Department of Psychiatry, The University of Texas Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75390-8849 (sherwood.brown@utsouthwestern.edu).

Suicide is one of the top 3 leading causes of death among age groups between 15 and 44 years and is an increasingly important cause of death among the 15- to 24-year age group.[1] In the United States, suicide was the 10th leading cause of death in 2013 according to the Centers for Disease Control and Prevention (CDC).[2] Contributors to differences in suicide rates identified by previous studies include, but are not limited to, sex,[3–5] mood disorder,[6] and seasonal affective disorder.[7] A factor that has received much attention is the seasonality of suicide, with a peak in these deaths during the spring and smaller peaks in late spring and fall.[7–9] Increases in airborne allergen counts also show that tree pollen counts peak in the spring, followed by grass pollen counts in late spring to early summer, and ragweed pollen counts in the fall. Using US county-level data, Postolache and colleagues[3] found a positive association between suicide rate and airborne tree pollen counts in cases where women completed suicide by nonviolent method. While the association was not replicated in the following study,[4] a similar result was reported by Qin et al[10] using Danish population data.

Suicides reflect only a small portion of all self-directed violence (SDV).[11] During 2008, 35,045 Americans completed suicide,[2] while an estimated 900,000 engaged in nonfatal suicide attempts.[12] Suicidal behaviors resulted in an estimated total of 678,000 emergency department visits and 500,000 hospitalizations in 2008.[12] Thus, suicide attempts are an important public health concern, and these acts frequently foreshadow a suicide. Because suicide attempts are much more common than suicides, they can be examined using smaller and more geographically defined datasets than can suicides. Additionally, focusing only on suicide may inadvertently bias results toward trends unique to violent suicidal behavior (eg, shooting, hanging, drowning, jumping) versus nonviolent suicidal behavior (eg, poisoning), as the former is more often fatal.[13] There is also a well-documented sexual dimorphism in the nature of self-directed violence.[14] This article uses *nonfatal SDV* to designate both nonfatal suicidal SDV and nonfatal, nonsuicidal SDV, following the definitions recommended by the CDC.[11]

If the propensity toward suicide is affected by temporally relevant environmental factors such as pollen, nonfatal SDV may be similarly affected. Since about a quarter of nonfatal SDV events are followed within 12 months by a suicide, a history of nonfatal SDV is one of the most identifiable risk factors for suicide.[15,16] However, to our knowledge no prior studies have examined the relationship between seasonal pollen patterns and number of nonfatal SDV events.

This study uses a time series method[17,18] to examine the temporal association between nonfatal SDV and airborne pollen counts.

## METHODS

### Data

This study used data on daily emergency department presentations for nonfatal SDV. These episodes of care were identified from a

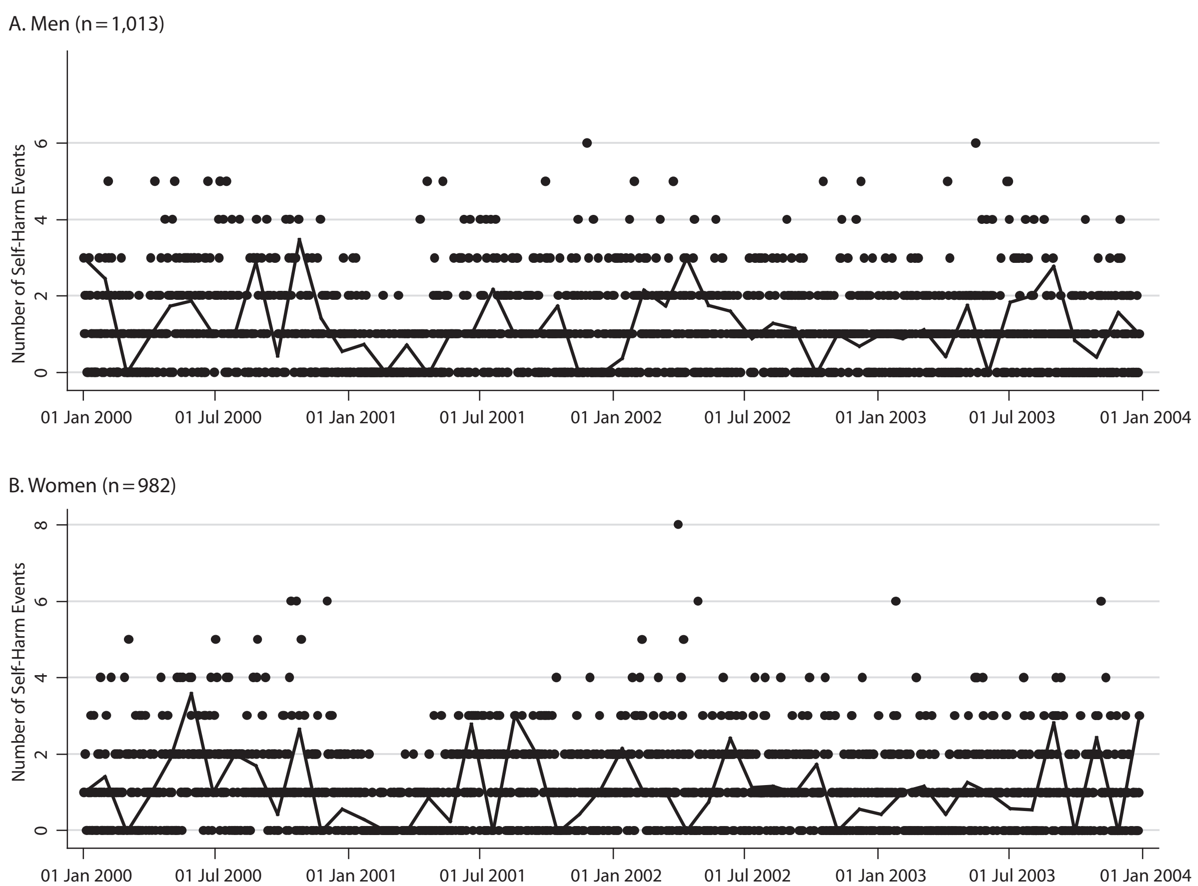
Clinical Points

- Prior research suggested a link between pollen levels and suicide, but prior studies had not examined the relationship between pollen and the more common and broader category of suicidal and nonsuicidal behaviors termed *self-directed violence.*
- The risk of suicide as well as self-directed violence may be influenced, in part, by pollen levels.
- The relationship between pollen and suicide/self-directed violence may help researchers identify new biomarkers and mechanisms related to suicide risk.

structured review of medical records and/or via *International Classification of Diseases* (*ICD-9*) External Cause of Injury Codes (E-codes) E950–E958. Episodes of care attached to the E-code E959—late effects of self-harm—were eliminated from these analyses because the actual date of injury was relatively more uncertain for these events than for those represented by E-codes E950–E958, which are acute events. While the *ICD-9* diagnosis of intentional self-injury includes nonsuicidal self-harm and suicide attempts,[19] a 2002 CDC study[20] found that 60%–70% of all emergency department events were actual suicide attempts. The nonfatal SDV data were extracted from emergency department medical records of Parkland Memorial Hospital in Dallas, Texas, from January 2, 2000, through December 28, 2003 (1,457 days). Parkland Hospital is one of the largest public hospitals in the country, and at the time of this study was the only Level I trauma center in Dallas County and the "gateway" into public mental health services for the county. As such, the majority of the county's help-seeking, nonfatal SDV patients would have been treated in that facility during those years. Daily emergency department visits were defined as the number of visits occurring between 00:00 and 24:00 in a single day. Daily airborne pollen count data in the Dallas area during the same period were extracted from the online database of the American Academy of Allergy, Asthma, & Immunology's National Allergy Bureau (http://www.aaaai.org/global/nab-pollen-counts.aspx).

To examine relationships between pollen counts and emergency department visits for SDV, we examined both an overlapping period ($t$) whereby pollen was collected between −16 hours and +8 hours from the beginning of emergency department data collection, as well as a period of pollen collection 1 day prior ($t-1$) between −40 hours and −16 hours prior to the beginning of collection of emergency department data (Figure 1). Thus, same-day correlations between number of SDV presentations and pollen counts were interpreted as 1-day lag correlations between the number of today's presentations and yesterday's pollen

**Figure 1. Number of Nonfatal Self-Directed Violence Events by Sex[a,b]**




[a]Extracted from emergency department records dated January 2, 2000–December 28, 2003.
[b]Solid lines represent kernel smoothing (bandwidth = 3 and degree = 7), and dots represent data points.

counts. The classes of airborne pollens considered in the study were tree, grass, and ragweed. Types of trees included in the study were elm, cedar, sycamore, ash, mulberry, hackberry, willow, pecan, walnut, hickory, mountain cedar, oak, cottonwood, juniper, and maple, which were common in the Dallas area at the time of the study. All the different types of tree pollen counts were aggregated into a single variable as a tree pollen count. There were missing data on pollen counts during the weekends; therefore, weekend pollen levels were imputed by last observation carried forward using Stata v.13 (StataCorp, College Station, Texas).

## Model

This study used the following model to examine a temporal correlation between daily numbers of emergency department presentations for nonfatal SDV and air pollen counts, stratified by sex:

$$[1]\quad Y^k_t = \alpha_0 \text{Pollen count}^k_t + \alpha_1 \text{Pollen count}^k_{t-1} + \text{Residual}^k_t$$

where $Y_t$ = daily number of emergency department visits due to nonfatal SDV at day $t$; $k$ = type of pollen (tree, grass, and ragweed); $t$ = day $t$; $t-1$ = 1 day before day $t$; Residual = the difference of the observed and predicted emergency department visits. Equation [1] was run separately per pollen type $k$. Conditional autoregressive heteroskedasticity (ARCH) error was defined as follows:

$$[2]\quad \sigma^2_t = \gamma_0 + \text{ARCH}(1)\text{Residual}^2_{t-1} + \text{ARCH}(2)\text{Residual}^2_{t-2} + \text{GARCH}(1)E(\text{Residual}^2_{t-1})$$

where $\sigma^2_t = E_{t-1}(\text{Residual}^2_t)$ where $E_{t-1}$ = the conditional expectation when conditioning set is composed of past values ($t$−1), and $\text{Residual}_t = \sigma_t \times \varepsilon_t$ where $\sigma_t$ = time dependent standard deviation and $\varepsilon_t$ = Gaussian white noise with a unit variance. Equation [2] describes a nonlinear model structure of error over time, a generalized ARCH (GARCH) model.

We used the following strategy for the statistical analysis: First, we selected a data period of January 2, 2000 through December 28, 2003, which followed calendar years. Second, we used a nonconstant GARCH model. The nonconstant GARCH model imposed an initial condition of no pollen and no nonfatal SDV event in examining a temporal relation between pollen counts and number of events during the study period. The beginning of our data was set to be a day during the winter period when no pollen counts were expected and, on average, zero suicide attempts were recorded. Third, we then computed various permutations of the order of autocorrelation (AR) to select lagged periods and examined stationarity (constant autocorrelation over time) and heteroskedasticity (a regular variation in uncertainty over time). ARCH effect in Residual was tested through Stata ARCHLM test (Table 1).

Goodness-of-fit was tested by likelihood ratio (LR) statistics with a null hypothesis of all coefficients $\alpha_s = 0$, where $s$ = lags, 0 = the same day, and 1 = one day prior ($t-1$). In selecting orders of GARCH model, we tested lags of up to 6 days. A *P* value less than .05 suggested statistical significance and was used for goodness-of-fit statistics.

**Table 1. ARCH(1) and ARCH(2) Model Fit Test by Sex[a] for Nonfatal Self-Directed Violence Events[b]**

| Pollen Type | Men (n = 1,013) $\chi^2$ | Men $P>\chi^2$ | Women (n = 982) $\chi^2$ | Women $P>\chi^2$ |
|---|---|---|---|---|
| Tree | | | | |
| ARCH(1)[c] | 6.53 | **.01** | 4.703 | **.03** |
| ARCH(2)[d] | 9.35 | **.01** | 6.302 | **.04** |
| Grass | | | | |
| ARCH(1)[c] | 7.05 | **.01** | 4.738 | **.03** |
| ARCH(2)[d] | 8.35 | **.01** | 5.070 | .08 |
| Ragweed | | | | |
| ARCH(1)[c] | 4.22 | **.04** | 5.791 | **.02** |
| ARCH(2)[d] | 6.23 | **.04** | 5.821 | **.05** |

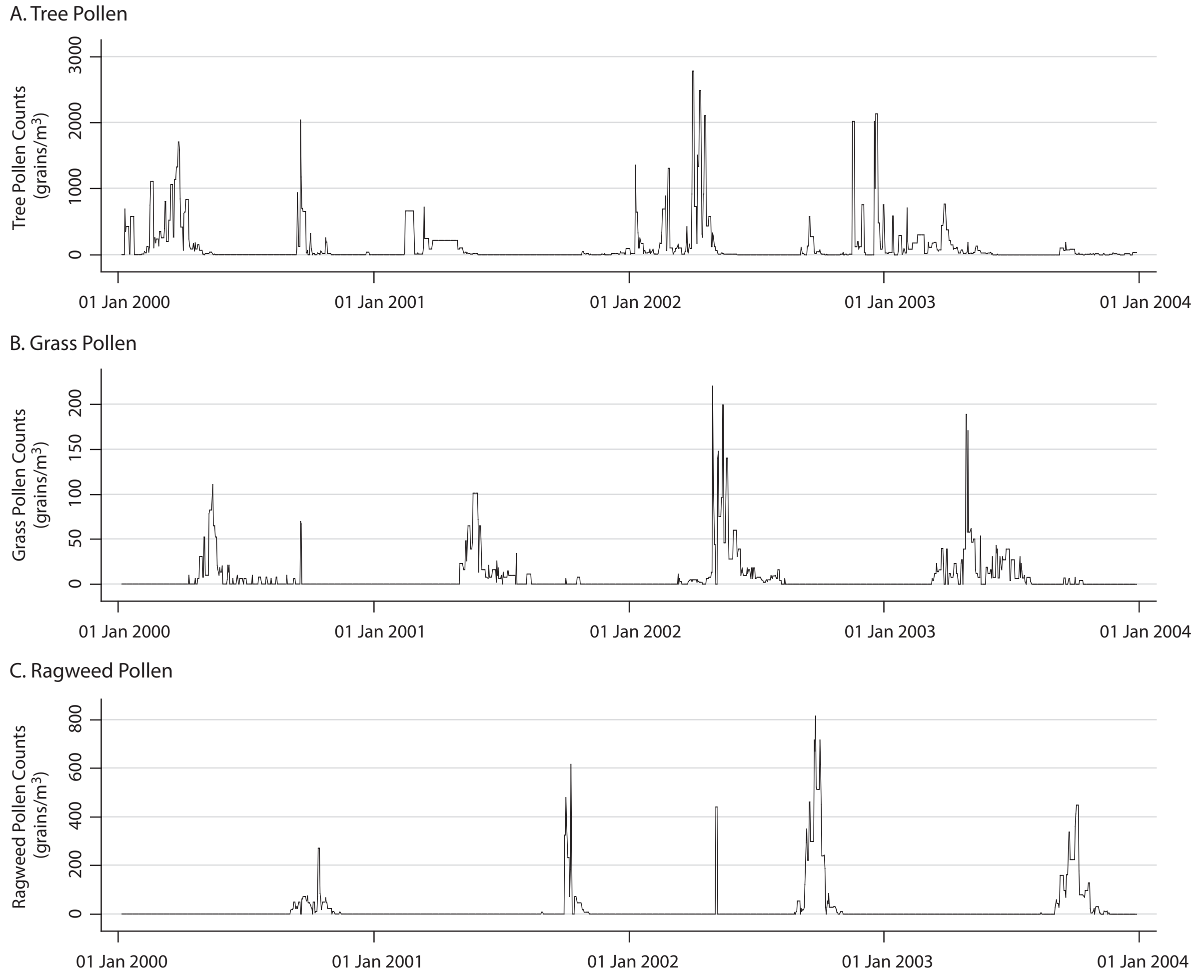
[a] $H_0$: no ARCH effects versus $H_1$: ARCH(*p*) disturbance.
[b] Bold = rejecting $H_0$.
[c] ARCH(1) is the first lag of the squared residuals from regression of daily self-directed violence events on pollen. The *df* for ARCH(1) = 1.
[d] ARCH(2) is the second lag; *df* = 2.
Abbreviations: ARCH = autoregressive conditional heteroskedasticity, ARCH(*p*) = ARCH process [eg, ARCH(1) is modeling the first lag, whereas ARCH(2) is modeling the second], *df* = degree of freedom, $H_0$ = null hypothesis, $H_1$ = alternative/predicted hypothesis.

## RESULTS

During the study period, the total number of patients evaluated in the Parkland emergency department for nonfatal SDV was 1,995 and of these, 51% (n = 1,013) were men and 49% (n = 982) were women. On average, about 1.21 male and 1.16 female SDV patients were admitted to the Parkland emergency department daily during the study period. Figure 2 depicts the number of events per day by sex, with smoothing lines indicating seasonal fluctuations of emergency department visits for treatment of SDV. Figure 3 shows daily pollen counts in the Dallas area collected during the same study period, with tree pollen counts higher than grass and ragweed pollen counts. Figure 3 also shows a seasonal pattern in pollen counts for each type of pollen in the Dallas area. Tree pollens were prevalent except during summer, grass pollen reached its peak during spring, and ragweed pollen peaked in early fall (September to October). The year 2002 showed the largest increase in numbers of emergency department visits by women for nonfatal SDV compared to the years before and after, and it also was the highest year in tree pollen counts during the study period. There was a consistent and clear seasonal pattern in the grass pollen counts during the study period with increases in counts in 2002 and 2003.

Table 2 shows time series estimates of the number of emergency-department–treated, nonfatal SDV events predicted by pollen counts. There was a statistically significant positive correlation between numbers of SDV presentations by women at $t$ and same-day ($t$) or prior-day ($t-1$) tree pollen counts. As tree pollen counts increase by 1,000 at $t$, the estimated number of the same-day, nonfatal

**Figure 2. Pollen Counts by Type[a]**




[a]Extracted from records for the Dallas area dated January 2, 2000–December 28, 2003.

SDV presentations by women increased by 56%, and the following-day nonfatal SDV presentations by women increased by 57%. Numbers of nonfatal SDV presentations by men were not significantly correlated with tree pollen counts.

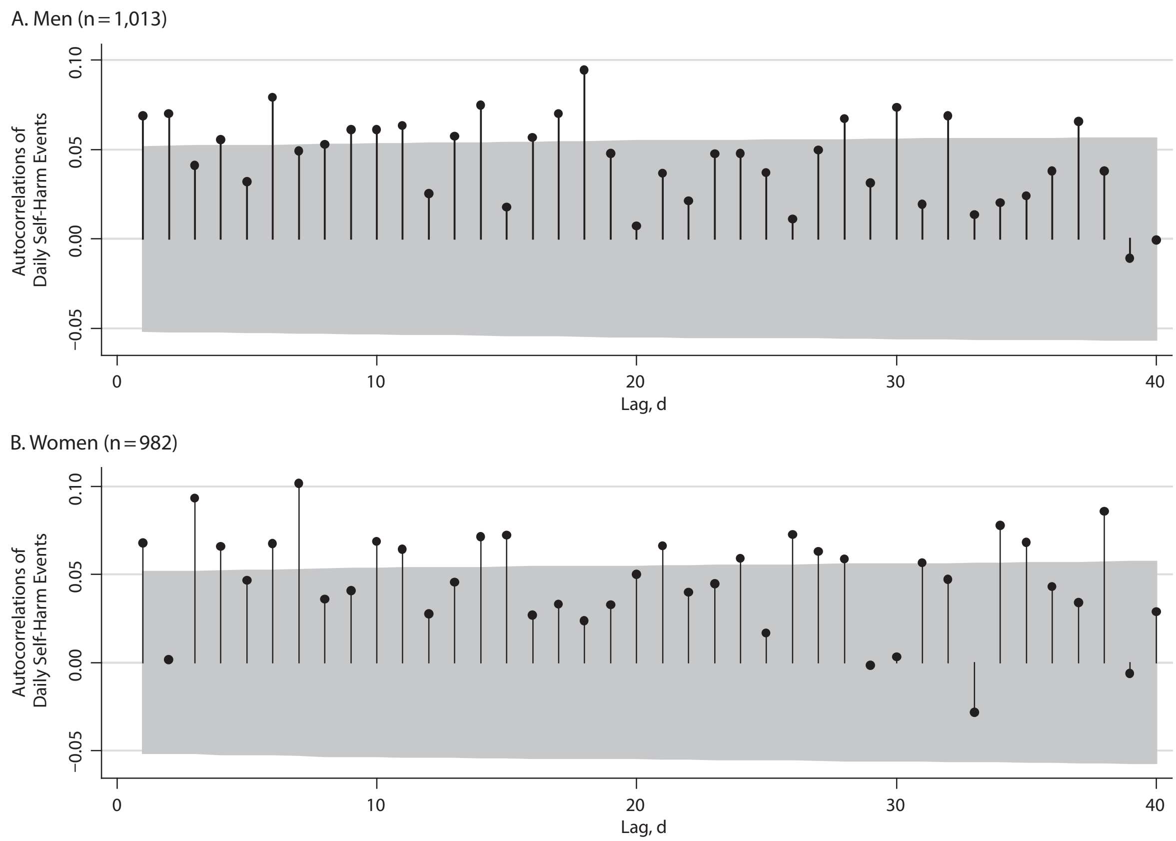
However, for both sexes, the number of daily emergency department presentations for nonfatal SDV at *t* was predicted by grass pollen counts at *t* (the same-day or prior-day counts). As grass counts increase by 100 at *t*, the estimated same-day numbers of nonfatal SDV events at *t* by women and men increased by 124% and 95%, respectively. No statistically significant correlation was found for either sex between number of events and ragweed pollen counts.

Daily numbers of emergency department presentations for nonfatal SDV were serially correlated [positive signs of ARCH(1), ARCH(2), and GARCH(1)] in Table 2. For all 3 types of pollens, the sum of coefficients of ARCH(1), ARCH(2), and GARCH(1) was less than 1 (Table 2). This implies that the unusual spikes in the numbers of nonfatal SDV presentations were stabilized within a short period; the increased number of nonfatal SDV presentations started declining with an average estimated rate of 95% at $t+1$ [GARCH(1), Table 2]. The lower the sum of coefficients, the shorter the period of unusual spikes of number of events.

## DISCUSSION

This study found a statistically significant positive temporal association between tree pollen counts and emergency department presentations for treatment of nonfatal SDV among women. The finding is consistent with previous studies that found a positive association between tree pollen level and suicide rate during the nonwinter season in the United States[3] and Denmark.[21] Numbers of nonfatal SDV presentations by women in a given day were predicted by tree pollen counts on the same day and up to 2 days before, and they were also predicted by grass pollen counts on the same day and up to 1 day before. Residuals of pollen predicted daily nonfatal SDV presentations and were serially correlated. The effect of same-day pollen counts on nonfatal SDV was carried into the subsequent day, a day of unusually high numbers of nonfatal SDV presentations followed by another day high in number of events. However, the unusual

**Figure 3. Autocorrelation Plots of Nonfatal Self-Directed Violence Events by Sex[a,b]**




[a]Horizontal axis represents lag ($q$), which is the difference in time (d) by which 1 observation lags behind (or is later than) another. Vertical axis represents autocorrelation calculated by Bartlett formula $\sqrt{\frac{1+\sum_{i=1}^{q-1} r_i^2}{N}}$ where $N$ = sample size, $r$ = Pearson correlation, $i$ = the number of autocorrelations (ie, the autocorrelation factors), and $q$ = lag.
[b]The gray area is 95% confidence area. Data points outside of the gray area indicate significant autocorrelations between 2 time points with $q$ difference; $q$ = 1 indicates adjacent periods.

spikes of nonfatal SDV presentations observed in a given day subsided the following day. In addition, this study found a statistically significant temporal association between grass pollen counts and the number of presentations by men and women for treatment of nonfatal SDV.

Using US county-level data, Postolache and colleagues[3] found a positive association between suicide rate and airborne tree pollen counts in nonviolent suicides completed by women. Qin and colleagues,[10] using Danish population data, also demonstrated a positive association between suicide rates and tree pollen counts.[10]

The current study extends the existing literature, which has focused on suicides, by suggesting that emergency department presentations for treatment of nonfatal SDV are also associated with pollen counts. Not only did this study confirm a temporal association between tree pollen counts and nonfatal SDV presentations by women, but also linked grass pollen counts to the number of emergency department presentations for treatment of nonfatal SDV in both sexes. Previously, Woo and colleagues[4] examined the association of grass pollen with suicide rates using US county-level data and found evidence of a temporal association between grass pollen level and suicide rates between counties. However, this positive and statistically significant association disappeared after controlling in the model for county variance, and they concluded that it might be due to county-specific, unmeasured confounding factors such as socioeconomic and health care infrastructure variation by county. Possible reasons for the differences in findings between the current study and the study by Woo and colleagues[4] include the assessment of emergency department presentations for nonfatal SDV (vs counts of suicide) and the use of data from Dallas County, a county with very high spring pollen counts (vs multiple-county data). Because presentations in the emergency department for treatment of nonfatal SDV are much more common than suicides, this finding may facilitate further research by allowing for prospective studies of survivors of intentionally self-inflicted injuries or overdoses.

This study is also, to our knowledge, the first in this research area that used data from a more southern geographical area of the northern hemisphere, where seasonal variation in daylight is much less than in more northern latitudes. This

**Table 2. Non-Constant ARCH(1), ARCH(2), and GARCH(1)[a] Estimates of Number of Nonfatal Self-Directed Violence Events by Sex[b]**

| | | Men (n = 1,013) | | | Women (n = 982) | | |
|---|---|---|---|---|---|---|---|
| Pollen Type | | Estimate | OPG Standard Error | $P > z$[c] | Estimate | OPG Standard Error | $P > z$[c] |
| Tree[d] (1,000 counts) | $\alpha_0$ | 0.31 | 0.24 | .19 | 0.57 | 0.28 | .04 |
| | $\alpha_1$ | 0.42 | 0.23 | .07 | 0.56 | 0.28 | .04 |
| | ARCH(1) | 0.05 | 0.03 | .08 | 0.06 | 0.03 | .05 |
| | ARCH(2) | −0.02 | 0.03 | .57 | −0.02 | 0.03 | .53 |
| | GARCH(1) | 0.94 | 0.02 | < .0001 | 0.95 | 0.01 | < .0001 |
| | $\gamma_0$ | 0.05 | 0.02 | .03 | 0.02 | 0.01 | .01 |
| Grass[e] (100 counts) | $\alpha_0$ | 0.95 | 0.43 | .03 | 1.24 | 0.35 | < .0001 |
| | $\alpha_1$ | 0.77 | 0.44 | .08 | 0.61 | 0.35 | .08 |
| | ARCH(1)[c] | 0.07 | 0.03 | .03 | 0.07 | 0.03 | .03 |
| | ARCH(2)[c] | −0.04 | 0.03 | .19 | −0.03 | 0.03 | .29 |
| | GARCH(1)[c] | 0.95 | 0.01 | < .0001 | 0.96 | 0.01 | < .0001 |
| | $\gamma_0$ | 0.04 | 0.02 | .02 | 0.03 | 0.01 | .029 |
| Ragweed[f] (100 counts) | $\alpha_0$ | 0.16 | 0.14 | .26 | 0.29 | 0.16 | .079 |
| | $\alpha_1$ | 0.11 | 0.14 | .42 | 0.08 | 0.16 | .62 |
| | ARCH(1) | 0.04 | 0.03 | .16 | 0.06 | 0.29 | .02 |
| | ARCH(2) | −0.003 | 0.03 | .89 | −0.03 | 0.03 | .30 |
| | GARCH(1) | 0.94 | 0.02 | < .0001 | 0.96 | 0.01 | < .0001 |
| | $\gamma_0$ | 0.05 | 0.02 | .01 | 0.02 | 0.01 | .02 |

[a]ARCH(1) and ARCH(2) are the first lag of the squared residuals from regression of daily self-directed violence events on pollen and the second lag, respectively. GARCH(1) is the first lag of the conditional variance.
[b]Dependent variable is number of daily self-directed violence events. Pollen counts are measured in grains/m$^3$. Convergence achieved within 11 iterations.
[c]$z$ = estimate divided by standard error. Bold $P$ values indicate statistically significant estimates.
[d]LR = −2,751.77, Wald $\chi^2_2$ = 83.88, $P < .0001$ for men; LR = −2,701.18, Wald $\chi^2_2$ = 84.51, $P < .0001$ for women.
[e]LR = −2,732.76, Wald $\chi^2_2$ = 119.35, $P < .0001$ for men; LR = −2,694.06, Wald $\chi^2_2$ = 159.83, $P < .0001$ for women.
[f]LR = −2,761.41, Wald $\chi^2_2$ = 29.84, $P < .0001$ for men; LR = −2,712.32, Wald $\chi^2_2(2)$ = 44.71, $P < .0001$ for women.
Abbreviations: $\alpha_0$ = the intercept of the ARCH model (ie, estimated emergency department visits when pollen count is 0), $\alpha_1$ = the slope of the ARCH model (ie, change in estimated emergency department visits over time), ARCH = autoregressive conditional heteroscedasticity, $\gamma_0$ = the intercept of the GARCH model (ie, overall average variance), GARCH = generalized autoregressive conditional heteroskedasticity, LR = likelihood ratio, OPG = outer product of the gradient.

lower latitude could have implications for the findings as well, given the well-established negative effects of ground-level ozone on air quality, which may increase the impact of pollen on inflammatory markers.[22,23] The nonsignificant relationship between ragweed pollen counts and nonfatal SDV may be due to lack of ragweed pollen count variation contributed by a much shorter period of ragweed production than of other pollens.

Seasonality has been studied in relation to suicide and suicidal ideation[24] and by subgroups with specific medical conditions, such as atopic disorder[25] and seasonal allergies.[21] The findings from the current study, along with earlier reports on pollen's association with suicides, provide a possible link between cyclic variation in environmental factors (seasonality) and suicidal patterns. Environmental factors such as temperature, sunshine, humidity, and wind can impact density of pollen counts and content of aeroallergens.[26] However, this study used unadjusted pollen counts because adjusted pollen counts for these environmental factors might increase type II error, failing to reject a null hypothesis when there is a true positive correlation between pollen and SDV.

The mechanism linking pollen with SDV is not known. Potential mechanisms include inflammatory and immune responses to the pollen. Vulnerability can be identified in terms of inflammation biomarkers such as elevated levels of interleukin-6 among depressed patients[27,28] and significantly lower levels of interleukin-8 and cerebrospinal fluid vascular endothelial growth factor[29] among those presenting with acts of SDV. One underlying mechanism accounting for the temporal association between airborne pollen and suicides is inflammatory cytokines attributed to major depressive disorder (MDD).[30] Allergen-specific T Helper 2 (Th2) cytokines cells have been identified in affected tissues of allergic patients, which underscores that allergen-specific T cells play a role in atopic allergies.[31] In addition, pollen itself can induce oxidative stress in airways and can activate innate immune cells such as dendritic cells to produce proinflammatory cytokines.[32,33] Inflammation may also play a role in the pathophysiology of nonfatal SDV for those who were vulnerable to proinflammatory cytokine–induced depression. Cytokine immunotherapy is associated with worsening depressive symptoms for individuals with risk factors for MDD prior to the immunotherapy.[34] Murine studies illustrate that exposure to allergens in sensitized animals can induce avoidance behavior and activation of limbic brain regions.[35–37] Other rodent models have shown that sensitization and challenge with allergens (including tree pollens) induced anxiety in rodents paralleled by an increase in Th2 cytokines in the prefrontal cortex.[38] In addition, human data support these animal studies with evidence of increased expression of the Th2 cytokines interleukin-4 and interleukin-13 in the orbitofrontal cortex of suicide victims.[39] Finally, use of intranasal corticosteroids, typically for the treatment of allergic rhinitis, has been associated with a lower risk of suicide.[40]

A number of studies report regional differences in the seasonality of suicide, with the highest association in countries with more pronounced seasonal variation in sunshine irradiance followed by those with temperate climate zones; no association was found in tropical regions, attributing this effect to increased exposure to sunshine.[9,41] This alternate suggested mechanism of action does not involve inflammatory pathways but is instead analogous to effects observed with pharmacologic interventions on serotonergic neurotransmission, namely the correlation between increased agitation and suicides with use of selective serotonin reuptake inhibitors.[42] Currently, there is conflicting evidence for this theory as some studies report rapid improvements in mood associated with light therapy,[43,44] while other studies question antidepressant-induced suicidality.[45] As hours of sunshine do correlate with pollen levels, the pollen-induced inflammatory pathway toward increased suicidality is a grounded underlying mechanism for the seasonality of SDV.

Methodological approaches used in prior studies have varied in the size of the geographic region studied, the time period examined, and model selection. However, all of these studies aggregated daily pollen data to weekly or quarterly data to make pollen data comparable to available suicide rate data. While aggregation of pollen data is necessary to examine rare events like counts of suicide, it cannot capture day-to-day variation in airborne pollen counts, and particularly not during peak season. Thus, analyzing daily data using a time series model, GARCH, provides a more sensitive metric for determining a temporal relationship between suicides/nonfatal SDV and pollen counts when pollen counts and suicides fluctuate daily.

Our pollen data are from an area with wide seasonal variability in pollen counts, and our medical records data comprise sufficient numbers of nonfatal events to support advanced modeling; together, these represent a final strength of this study. There are also several potential limitations to these findings. First, the nonconstant GARCH model predictability is highly sensitive to selection of the data period. Our analysis is based on the assumption that there was a period of time when there were virtually no airborne pollens or emergency department presentations for nonfatal SDV, and it used a time period at the beginning of each January when there was no airborne pollen and no such events. If this assumption is violated, a positive temporal association between events and pollen counts is not guaranteed, which is a well-documented limitation in a time series analysis.[46] Second, although the Parkland Hospital emergency department was by far the largest in Dallas County at the time of the study, daily event counts could have been differentially affected by numbers of events presenting to other care sites. Counts of emergency department presentations relied on structured medical record review and E-code diagnoses during a period when recording the intent of an injury episode was not required in medical records; therefore, some nonfatal SDV events were more likely not picked up by our case identification protocol. Thus, the study results may be subject to a selection bias and measurement errors. Third, although we assume that most self-inflicted injuries presented for care within minutes to hours after the act, the time period between the event and presentation for care—and thus the lag between pollen count change and emergency department presentation for care after nonfatal SDV—cannot be precisely measured with our approach. Fourth, this study used aggregated data; thus, the current model did not consider individual variance of exposure and proximity to the sources of the pollen. Variation in time spent indoors, as well as the environment and exact location in which patients lived or worked, might alter the degree and timing of exposure to the pollens studied. Finally, this study did not explore pollen count association with other climatic factors such as sunshine, temperature, and humidity, which may temporally affect the propensity toward suicide deaths.[42] Other climatic factors could be used in multiple imputation of missing weekend pollen data[47] as auxiliary information in future studies. Multiple imputations using auxiliary information has been proven to improve efficiency of regression estimation when auxiliary data (climatic factors) are moderately associated with partially observed data such as weekend pollen counts.[48]

To our knowledge, this study is the first to find a positive association between seasonal variation in tree and grass pollen levels and suicidal behavior patterns by using data on nonfatal SDV events, which are more frequent than suicides. When combined with prior literature, the findings from the current study suggest that pollen count may be a factor that influences the established seasonality of suicide. A future prospective study is needed to explore underlying neurobiological mechanisms mediating the relationship between pollen levels and nonfatal SDV.

***Submitted:*** February 5, 2015; accepted July 13, 2015.

***Online first:*** June 7, 2016.

***Potential conflicts of interest:*** **Dr Brown** has received research/grant support from Sunovion, Forest, Alkermes, the Stanley Medical Research Institute, the National Institute of Mental Health, the National Institute on Drug Abuse, the National Institute on Alcohol Abuse and Alcoholism, the National Center for Complementary and Integrative Medicine, and the National Heart, Lung, and Blood Institute, which is outside of this submitted work. **Drs Jeon-Slaughter**, **Claassen**, **Khan**, and **Lee** and **Mr Mihalakos** have no conflict of interests to disclose.

***Funding/support:*** This study was funded in part by the UT Southwestern Summer Medical Student Research Program (Dr Lee) and Summer Undergraduate Research Fellowship (SURF) (Mr Mihalakos).

***Role of the sponsor:*** The sponsor was not involved in the design, collection, and analysis of the data. Interpretation of the results was by the authors, and the decision to submit this manuscript for publication in *The Journal of Clinical Psychiatry* was made by the authors.

***Acknowledgments:*** The authors thank Claire Gardner, BA, and Cassandra Hatt, MS, of the Department of Psychiatry, The University of Texas Southwestern Medical Center, Dallas, Texas, for their assistance with copy editing, manuscript preparation, and submission. Ms Gardner and Ms Hatt have no conflicts of interest to disclose.

## REFERENCES

1. Public health action for the prevention of suicide: a framework. World Health Organization Web site. http://apps.who.int/iris/bitstream/10665/75166/1/9789241503570_eng.pdf. Updated 2012. Accessed March 10, 2016.
2. National Center for Injury Prevention and Control. *WISQARS Fatal Injuries:*

*Fatal Injury Reports*. Atlanta, GA: Centers for Disease Control and Prevention; 2013.
3. Postolache TT, Stiller JW, Herrell R, et al. Tree pollen peaks are associated with increased nonviolent suicide in women. *Mol Psychiatry*. 2005;10(3):232–235.
4. Woo JM, Gibbons RD, Rogers CA, et al. Pollen counts and suicide rates: association not replicated. *Acta Psychiatr Scand*. 2012;125(2):168–175.
5. Mergl R, Havers I, Althaus D, et al. Seasonality of suicide attempts: association with gender. *Eur Arch Psychiatry Clin Neurosci*. 2010;260(5):393–400.
6. Postolache TT, Mortensen PB, Tonelli LH, et al. Seasonal spring peaks of suicide in victims with and without prior history of hospitalization for mood disorders. *J Affect Disord*. 2010;121(1–2):88–93.
7. Reutfors J, Ösby U, Ekbom A, et al. Seasonality of suicide in Sweden: relationship with psychiatric disorder. *J Affect Disord*. 2009;119(1–3):59–65.
8. Christodoulou C, Douzenis A, Papadopoulos FC, et al. Suicide and seasonality. *Acta Psychiatr Scand*. 2012;125(2):127–146.
9. Chew KSY, McCleary R. The spring peak in suicides: a cross-national analysis. *Soc Sci Med*. 1995;40(2):223–230.
10. Qin P, Waltoft BL, Mortensen PB, et al. Suicide risk in relation to air pollen counts: a study based on data from Danish registers. *BMJ Open*. 2013;3(5):e002462.
11. Crosby A, Han B, Ortega L, et al. Suicidal thoughts and behaviors among adults aged ≥ 18 years—United States, 2008–2009: surveillance summaries. Centers for Disease Control and Prevention Web site. http://www.cdc.gov/mmwr/preview/mmwrhtml/ss6013a1.htm. Updated October 21, 2011. Accessed March 10, 2016.
12. *Results from the 2008 National Survey on Drug Use and Health: National Findings*. NSDUH Series H-36, HHS Publication No. SMA 09-4434. Rockville, MD: Office of Applied Studies, Substance Abuse and Mental Health Services Administration: 2009.
13. Miller M, Azrael D, Hemenway D. The epidemiology of case fatality rates for suicide in the northeast. *Ann Emerg Med*. 2004;43(6):723–730.
14. Brådvik L. Violent and nonviolent methods of suicide: different patterns may be found in men and women with severe depression. *Arch Suicide Res*. 2007;11(3):255–264.
15. Pringle B, Colpe LJ, Heinssen RK, et al. A strategic approach for prioritizing research and action to prevent suicide. *Psychiatr Serv*. 2013;64(1):71–75.
16. Maciejewski DF, Creemers HE, Lynskey MT, et al. Overlapping genetic and environmental influences on nonsuicidal self-injury and suicidal ideation: different outcomes, same etiology? *JAMA Psychiatry*. 2014;71(6):699–705.
17. Bollerslev T. Generalized autoregressive conditional heteroskedasticity. *J Econom*. 1986;31(3):307–327.
18. Engle RF. Autoregressive conditional heteroscedasticity with estimates of variance of United Kingdom inflation. *Econometrica*. 1982;50(4):987–1008.
19. National Center for Health Statistics. *Hospital and Payer International Classification of Diseases, Clinical Modification (ICD-9-CM)*. Medicode; 1999.
20. Centers for Disease Control and Prevention (CDC). Nonfatal self-inflicted injuries treated in hospital emergency departments—United States, 2000. *MMWR Morb Mortal Wkly Rep*. 2002;51(20):436–438.
21. Qin P, Mortensen PB, Waltoft BL, et al. Allergy is associated with suicide completion with a possible mediating role of mood disorder - a population-based study. *Allergy*. 2011;66(5):658–664.
22. Gleason JA, Bielory L, Fagliano JA. Associations between ozone, PM2.5, and four pollen types on emergency department pediatric asthma events during the warm season in New Jersey: a case-crossover study. *Environ Res*. 2014;132:421–429.
23. Sheffield PE, Knowlton K, Carr JL, et al. Modeling of regional climate change effects on ground-level ozone and childhood asthma. *Am J Prev Med*. 2011;41(3):251–257, quiz A3.
24. Messias E, Clarke DE, Goodwin RD. Seasonal allergies and suicidality: results from the National Comorbidity Survey Replication. *Acta Psychiatr Scand*. 2010;122(2):139–142.
25. Timonen M, Viilo K, Hakko H, et al. Is seasonality of suicides stronger in victims with hospital-treated atopic disorders? *Psychiatry Res*. 2004;126(2):167–175.
26. Reid CE, Gamble JL. Aeroallergens, allergic disease, and climate change: impacts and adaptation. *EcoHealth*. 2009;6(3):458–470.
27. Bull SJ, Huezo-Diaz P, Binder EB, et al. Functional polymorphisms in the interleukin-6 and serotonin transporter genes, and depression and fatigue induced by interferon-alpha and ribavirin treatment. *Mol Psychiatry*. 2009;14(12):1095–1104.
28. O'Donovan A, Rush G, Hoatam G, et al. Suicidal ideation is associated with elevated inflammation in patients with major depressive disorder. *Depress Anxiety*. 2013;30(4):307–314.
29. Isung J, Aeinehband S, Mobarrez F, et al. Low vascular endothelial growth factor and interleukin-8 in cerebrospinal fluid of suicide attempters. *Transl Psychiatr*. 2012;2(11):e196.
30. Miller AH, Maletic V, Raison CL. Inflammation and its discontents: the role of cytokines in the pathophysiology of major depression. *Biol Psychiatry*. 2009;65(9):732–741.
31. Dantzer R. Cytokine, sickness behavior, and depression. *Immunol Allergy Clin North Am*. 2009;29(2):247–264.
32. Csillag A, Boldogh I, Pazmandi K, et al. Pollen-induced oxidative stress influences both innate and adaptive immune responses via altering dendritic cell functions. *J Immunol*. 2010;184(5):2377–2385.
33. Tomee JF, van Weissenbruch R, de Monchy JG, et al. Interactions between inhalant allergen extracts and airway epithelial cells: effect on cytokine production and cell detachment. *J Allergy Clin Immunol*. 1998;102(1):75–85.
34. Capuron L, Ravaud A. Prediction of the depressive effects of interferon alfa therapy by the patient's initial affective state. *N Engl J Med*. 1999;340(17):1370.
35. Costa-Pinto FA, Basso AS, Britto LR, et al. Avoidance behavior and neural correlates of allergen exposure in a murine model of asthma. *Brain Behav Immun*. 2005;19(1):52–60.
36. Costa-Pinto FA, Basso AS, De Sá-Rocha LC, et al. Neural correlates of IgE-mediated allergy. *Ann N Y Acad Sci*. 2006;1088(1):116–131.
37. Costa-Pinto FA, Basso AS, Russo M. Role of mast cell degranulation in the neural correlates of the immediate allergic reaction in a murine model of asthma. *Brain Behav Immun*. 2007;21(6):783–790.
38. Tonelli LH, Katz M, Kovacsics CE, et al. Allergic rhinitis induces anxiety-like behavior and altered social interaction in rodents. *Brain Behav Immun*. 2009;23(6):784–793.
39. Tonelli LH, Stiller J, Rujescu D, et al. Elevated cytokine expression in the orbitofrontal cortex of victims of suicide. *Acta Psychiatr Scand*. 2008;117(3):198–206.
40. Woo JM, Gibbons RD, Qin P, et al. Suicide and prescription rates of intranasal corticosteroids and nonsedating antihistamines for allergic rhinitis: an ecological study. *J Clin Psychiatry*. 2011;72(10):1423–1428.
41. Nejar KA, Benseñor IM, Lotufo PA. Sunshine and suicide at the tropic of Capricorn, São Paulo, Brazil, 1996–2004. *Rev Saude Publica*. 2007;41(6):1062–1064.
42. Vyssoki B, Kapusta ND, Praschak-Rieder N, et al. Direct effect of sunshine on suicide. *JAMA Psychiatry*. 2014;71(11):1231–1237.
43. Burgess HJ, Fogg LF, Young MA, et al. Bright light therapy for winter depression—is phase advancing beneficial? *Chronobiol Int*. 2004;21(4–5):759–775.
44. Neumeister A, Goessler R, Lucht M, et al. Bright light therapy stabilizes the antidepressant effect of partial sleep deprivation. *Biol Psychiatry*. 1996;39(1):16–21.
45. Weisberg HI, Hayden VC, Pontes VP. Selection criteria and generalizability within the counterfactual framework: explaining the paradox of antidepressant-induced suicidality? *Clin Trials*. 2009;6(2):109–118.
46. Ruppert D. *Statistics and Data Analysis for Financial Engineering*. New York, NY: Springer Science + Busines Media, LLC; 2011.
47. Little RJA, Rubin DB. *Statistical Analysis With Missing Data*. 2nd ed. New York, NY: Wiley; 2002.
48. Horton NJ, Laird NM. Maximum likelihood analysis of logistic regression models with incomplete covariate data and auxiliary information. *Biometrics*. 2001;57(1):34–42.