



Airborne pollen and suicide mortality in Tokyo, 2001–2011

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ABSTRACT

Prior research has indicated that pollen might be linked to suicide mortality although the few studies that have been undertaken to date have produced conflicting findings and been limited to Western settings. This study examined the association between the level of airborne pollen and suicide mortality in Tokyo, Japan in the period from 2001 to 2011. The daily number of suicide deaths was obtained from the Japanese Ministry of Health, Labour and Welfare, with pollen data being obtained from the Tokyo Metropolitan Institute of Public Health. A time-stratified case-crossover study was performed to examine the association between different levels of pollen concentration and suicide mortality. During the study period there were 5185 male and 2332 female suicides in the pollen season (February to April). For men there was no association between airborne pollen and suicide mortality. For women, compared to when there was no airborne pollen, the same-day (lag 0) pollen level of 30 to < 100 grains per cm² was associated with an approximately 50% increase in the odds for suicide (e.g. 30 to < 50 grains per cm²: odds ratio 1.574, 95% confidence interval 1.076–2.303, $p=0.020$). The estimates remained fairly stable after adjusting for air pollutants and after varying the cut-points that defined the pollen levels. Our results indicate that pollen is associated with female suicide mortality in Tokyo.

1. Introduction

One of the consequences of climate change may be an increase in the levels of airborne pollen (Todea et al., 2013), with research undertaken in Europe and the United States in the past two decades indicating that pollen levels are rising (Frei, 1998; Spiessma et al., 1995; Ziello et al., 2012). High concentrations of pollen may have serious implications for health and well-being given the close association between pollen and asthma and allergic diseases (Caillaud et al., 2015; de Weger et al., 2013; Gonzalez-Barcala et al., 2013; Sun et al., 2016). It is possible that the effects of increased levels of pollen might also be important for other non-allergic diseases (de Weger et al., 2013). For example, studies have linked higher levels of airborne pollen to hospital admission for non-allergic respiratory diseases [e.g. COPD] (Hanigan and Johnston, 2007), stroke (Low et al., 2006), and emergency room visits for myocardial infarction (Weichenthal et al., 2016). An earlier study from the Netherlands also found an association

between the concentration of airborne pollen and deaths from cardiovascular and respiratory disease (Brunekreef et al., 2000).

There is some evidence that pollen may also be linked to suicide. An early ecological study from the continental United States that used tree and ragweed pollen data for the period from 1995 to 1998 found that during the tree allergy season younger and older women (< 65 and ≥ 65) had a higher relative risk for nonviolent suicide in the ‘peak-pollen’ and ‘postpollen’ periods, respectively, compared to in the ‘prepollen’ period (Postolache et al., 2005). This result was not replicated however, in a follow-up study by the same authors when using data for the period 1999–2002 and controlling for possible between-county confounders such as location (urban vs. rural), median income and the number of local psychiatrists (Woo et al., 2012). A more recent ecological time-series study from Denmark that used data for the period from 1982 to 2006 also reported that higher levels of pollen were associated with an increased suicide risk among both women and men, in all age groups and for those with and without mood disorders (Qin et al., 2013).

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Although it is uncertain what underlies these conflicting results and whether they are due to methodological differences or other factors (Qin et al., 2013; Woo et al., 2012), further research on the relationship between airborne pollen and suicide mortality is warranted as pollen might be associated with suicide via several mechanisms. For example, higher levels of pollen may exacerbate allergies or result in a greater incidence of allergic disease/disorders (Shea et al., 2008), while there is some evidence that allergic disease may be linked to suicide/suicidal behavior (Kölves et al., 2015; Messias et al., 2010; Postolache et al., 2008). To date, the few studies that have been undertaken have occurred in Western settings even though the pollen mix/exposure (Smith et al., 2014) and the level of suicide can both vary greatly across countries (World Health Organization, 2014). Given that over 800,000 suicide deaths occur worldwide annually (World Health Organization, 2014), determining the nature of this association more precisely may have potentially important public health implications.

The current study will examine the association between the level of airborne pollen and suicide mortality in Tokyo, Japan. This may be an apt setting to explore this relation for several reasons. There is some indication for example, that airborne counts of the two forms of pollen that will be the focus of this study – cedar and cypress pollen – have either increased significantly in recent decades (cedar pollen) (Yamada et al., 2014) or are expected to increase in the near future (cypress pollen) (Okano et al., 2012). This is important not only because both forms of pollen have been linked with allergic disease (Yoshida et al., 2013), but also because of the high prevalence of allergic disease that already exists in the country with some research indicating that between one-quarter and one-third of the population may be currently suffering from allergic disease (Japanese cedar pollinosis [JCP]) (Nakae and Baba, 2010; Sakashita et al., 2010). Moreover, as an earlier study has suggested that sensitization rates to (Japanese cedar) pollen might be higher in large metropolitan areas such as Tokyo compared to in rural areas (Kaneko et al., 2005), it is possible that pollen might be having an especially detrimental effect on health in this setting. In addition, suicide has been a major public health problem in Japan in recent years with the suicide rate continuing to be high in comparative terms (World Health Organization, 2014). In Tokyo, as in the rest of the country, there was a sharp increase in the suicide rate in 1998 with rates remaining at a high level throughout our study period so that by 2011 the suicide rate was over 50% higher than it had been in 1990 (22.7 vs. 14.5 per 100,000) with large increases observed across the same period for both men (30.1 vs. 18.0) and women (15.4 vs. 10.9) (Kubota et al., 2013). Given this, the aims of the current study were: (1) to determine if higher levels of pollen were associated with suicide mortality in Tokyo; (2) to explore if any associations varied between population subgroups (by sex and/or age).

2. Methods

2.1. Suicide data

Data on daily suicide deaths were obtained from the Japanese Ministry of Health, Labour and Welfare. All completed suicide cases (International Classification of Diseases, 10th Revision, ICD-10 codes X60–X84) that occurred in Tokyo between 2001 and 2011 were extracted. For each case, information was obtained on the sex and date of the suicide. The age at death was determined by calculating the difference between the date of birth and the date of suicide. As the aim of this study was to examine the association between pollen and suicide the analysis was limited to the main Japanese cedar and cypress pollen dispersion period in Japan i.e. from February to April in each year (Nakae and Baba, 2010; Yamamoto et al., 2015; Yonekura et al., 2012) (see supplementary Fig. S1). We excluded the non-Japanese suicides (1.5%) whose residence information (e.g. length of stay in the country) was unknown. During the study period there were 7517 suicide deaths.

2.2. Pollen data

Daily data on the level of airborne pollen were obtained from the Tokyo Metropolitan Institute of Public Health. This data came from 9 monitoring points located across Tokyo. Information was obtained on the pollen density of two tree species – the Japanese cedar (*Cryptomeria japonica* [sugi in Japanese]) and the Japanese cypress (*Chamaecyparis obtusa* [hinoki in Japanese]). This was measured using the Durham method where a vaseline-coated glass slide fixed inside a Durham sampler was used to capture airborne pollen grains. The number of pollen grains per cm² on the glass slide for each 24-h period constitutes the airborne pollen concentration (Konishi et al., 2014). Research suggests that there is a high correlation ($r > 0.90$) between pollen counts collected when using the Durham method and those obtained using the more commonly used Burkard volumetric sampling method (Kishikawa et al., 2009). In the current study, the vaseline-coated glass slides were retrieved each day from the samplers except for at weekends where the accumulated pollen count for Friday, Saturday and Sunday was calculated as a 3-day average. Two monitoring stations had missing data on 3 days each, which was 0.31% of the total study period of 981 days. Pollen measurements from the nine monitoring stations were highly correlated (Spearman's ρ 0.88–0.96) and were therefore averaged to obtain a daily mean pollen count.

2.3. Air pollutant and weather data

As there is some evidence that air particulate matter may exacerbate the detrimental effects of pollen on health (Konishi et al., 2014), and that specific air pollutants may be linked to a higher risk of suicide (Kim et al., 2015; Ng et al., 2016; Yang et al., 2011), we examined the effects of these air pollutants in the analysis. Data on fine particulate matter (PM_{2.5}), sulphur dioxide (SO₂), nitrogen dioxide (NO₂) and ozone (O₃) were obtained from the National Institute for Environmental Studies in Japan. The gaseous pollutants were measured in parts per billion (ppb) while particles were in µg/m³. For each air pollutant, we computed the daily averages from the hourly values available from multiple monitoring facilities provided there were no more than 4 missing hourly values. After excluding the monitoring stations with more than 30 missing daily values per year, the daily averages from the individual monitoring stations (a total of 10 sites) were subsequently averaged to calculate a citywide daily average concentration.

In addition, we obtained continuous data on ambient temperature (°C), and relative humidity (%), measured at a district observatory located in central Tokyo from the Japan Meteorological Agency for inclusion in the analysis. Daily 24-h means were computed for the study period. The inclusion of these weather variables as potential confounders was supported by a previous study in Japan that linked the occurrence of suicide to daily temperature (Likhvar et al., 2011), and by our own preliminary analyses which indicated an association with daily pollen concentrations when examined separately in a regression model. Data on daily average wind speed (m/s) and total rainfall (mm) were also obtained for an additional sensitivity analysis. We also additionally controlled for public holidays which have been previously linked to the occurrence of suicide (Barker et al., 2014).

2.4. Statistical analysis

To examine the association between pollen concentration and the occurrence of suicide we performed a time-stratified case-crossover analysis. In this study design only cases are sampled and each case acts as its own control (i.e. cases are self-matched). For each case a time (exposure) period either before or after the 'event' (or both) are chosen to serve as the matched 'control' periods. In the current study the time stratum was defined as the month of a suicide event. For each event, we selected the same days of the week within the same month as the

matching control periods. The distribution of exposure to pollen during the control periods pre- or post-suicide (or both) was then compared to the exposure on the day of the event. This method, which has recently been used to study the association between levels of air pollution and the occurrence of suicide in the United States (Bakian et al., 2015) has several advantages when compared with other analytical methods: it is possible to control for confounders that remain constant across time such as educational level, and by using control periods both before and after a death (or both), it is possible to control for time trends in the exposure if they exist.

Conditional logistic regression analysis was then used to examine the within-subject comparisons for the pollen exposure on the day of the suicide with that on control days. Daily pollen concentration was stratified into 5 categories that ran from 0 to ≥ 50 grains per cm^2 , as per the reporting guideline in Japan (Ministry of the Environment, 2014). The analysis was stratified by sex. To determine if the estimated association between pollen and suicide was robust to the inclusion of air pollutants, the initial pollen-only model was subsequently adjusted for $\text{PM}_{2.5}$, SO_2 , NO_2 and O_3 (a moving average of lag 0–3). As these air pollutants are highly correlated, each was adjusted for in a separate analysis. Besides this categorical variable, we also modeled airborne pollen as a smoothed continuous variable by using a natural cubic spline with 5 degrees of freedom to examine the concentration-response relationship. To examine if age was an important modifier, we performed further analyses stratified by age (< 30 years old, 30–60 years old, and > 60 years old).

To consider the possible delayed effect of pollen, we examined the lag terms of pollen concentration up to the three days preceding the suicide death (i.e. lag 0 to lag 3) in a single-lag model (i.e. one lag at a time). In addition, we repeated the analysis with different pollen-level cut-off points to examine if the association was affected by the way pollen exposure was categorized (see Supplementary Material Table S2). The results are presented as adjusted odds ratios (OR) with 95% confidence intervals (CI). All statistical analyses were performed with R (version 3.0.3; R Project for Statistical Computing, Vienna, Austria).

3. Results

During the study period that ran from 1 February to 30 April in each year between 2001 and 2011 there were over twice as many male than female suicides (men: 5185 [69%]; women: 2332 [31%]) (Table 1 and Fig. 1). For both men (55.0%) and women (48.1%), most deaths occurred among working-age adults (aged 30–60 years old). When suicides were stratified by the level of pollen there was little difference in the number of suicides cases per day that occurred on days with different pollen levels, with the number varying between 7.2 and 8.2 across all cut-offs (see supplementary Table S1).

Table 1
Characteristics of suicide cases in Tokyo, February – April 2001–2011.

Characteristic	Male (n =5185)		Female (n =2332)	
	No.	%	No.	%
Age (years)				
< 30	750	14.5	402	17.2
30 to 60	2854	55.0	1121	48.1
> 60	1581	30.5	809	34.7
Pollen level ^a (grains/ cm^2)				
0	136	2.6	46	2.0
> 0 to < 10	2170	41.9	1015	43.5
10 to < 30	897	17.3	374	16.0
30 to < 50	378	7.3	195	8.4
≥ 50	1604	30.9	702	30.1

^a Based on the Environmental Health Manual for Pollinosis 2014, Ministry of the Environment, Japan.

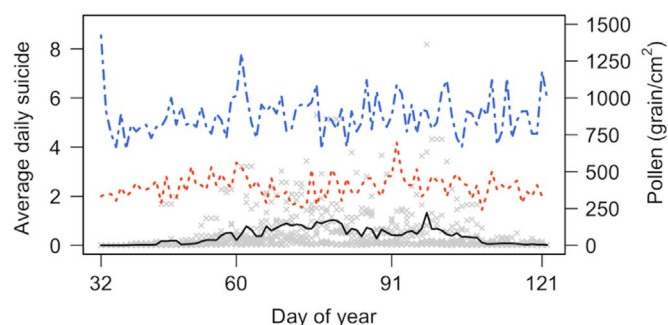


Fig. 1. Daily average number of suicides and air pollen level from February to April 2001–2011. The red dotted line represents female suicides, the blue dotted dashed line represents male suicides, and the black solid line represents the daily air pollen level averaged for the study period. The marks on the x-axis denote the first day of a month in a non-leap year.

In the regression analysis that examined the association between the level of pollen and suicide mortality there was a noticeable difference between men and women. While there was no association between pollen and suicide among men, for women, higher levels of pollen (≥ 30 grains/ cm^2) were associated with a 48–57% statistically significant increase in the odds for suicide compared to the no-pollen category, while at a low level of pollen (> 0 to < 10 grains/ cm^2), the evidence for an association was weaker (OR: 1.349, 95%CI: 0.962–1.891, $p < 0.10$) (Table 2). The non-significant results for men were also observed in the analyses that adjusted for the individual air pollutants. For women, the results remained stable when SO_2 , NO_2 and O_3 were included in the analysis. The effect estimates however increased marginally when $\text{PM}_{2.5}$ was adjusted for with all levels of pollen being significantly associated with suicide. Additional adjustment for wind speed and total rainfall did not change the results notably (data not shown). Age did not modify the association between the level of pollen and suicide as in the age-stratified analysis there was no association for either women or men (Table 3).

When the effects of earlier pollen concentration were examined by including lag terms for each of the 3 days preceding the suicide death, only the same-day pollen levels (lag 0) were associated with suicide among women (Table 4). When different cut-off points were used to categorize daily pollen concentration, for men, no level of pollen was associated with increased odds for suicide. Among women, pollen in the range of 20 to < 100 grains/ cm^2 was associated with the greatest risk for suicide although the level of 100 to < 300 was of borderline statistical significance (see supplementary Table S2). This association for females was also discernible in the concentration-response curve (Fig. S2).

4. Discussion

This study examined the association between airborne pollen and suicide mortality in Tokyo in February to April (the pollen season) 2001–2011. Analyzing data for over 7500 suicide deaths showed that although there was no association between pollen exposure and suicide among men, for women being exposed to a medium level of pollen (20 to < 100 grains/ cm^2 per day) was associated with an approximately 50% increase in the odds of suicide. Moreover, the immediate effects of pollen exposure appear to be more associated with suicide risk in the sense that only same-day exposure but not exposure during the preceding days increased the risk for suicide mortality.

Three earlier studies that examined the association between airborne pollen and suicide mortality produced conflicting findings (Postolache et al., 2005; Qin et al., 2013; Woo et al., 2012). However, our results concur with those which showed that pollen exposure was associated with an increased risk for suicide. It is uncertain what underlies this association although several mechanisms

Table 2

Adjusted odds of suicide associated with the level of airborne pollen stratified by sex.

Adjustment for air pollutant ^a	Pollen level ^b	Male (n =5185)		Female (n =2332)	
		OR	95%CI	OR	95%CI
None	0	1		1	
	> 0 to < 10	0.874	0.709, 1.077	1.349 ^d	0.962, 1.891
	10 to < 30	0.920	0.733, 1.115	1.318	0.917, 1.894
	30 to < 50	0.948	0.743, 1.209	1.574 ^c	1.076, 2.303
	≥ 50	0.911	0.721, 1.151	1.477 ^c	1.020, 2.139
PM _{2.5}	0	1		1	
	> 0 to < 10	0.875	0.696, 1.099	1.465 ^c	1.017, 2.112
	10 to < 30	0.930	0.727, 1.189	1.488 ^c	1.007, 2.199
	30 to < 50	0.945	0.726, 1.230	1.805 ^c	1.197, 2.722
	≥ 50	0.914	0.709, 1.177	1.616 ^c	1.085, 2.405
SO ₂	0	1		1	
	> 0 to < 10	0.874	0.709, 1.077	1.347 ^d	0.961, 1.889
	10 to < 30	0.920	0.733, 1.155	1.315	0.915, 1.891
	30 to < 50	0.949	0.743, 1.210	1.563 ^c	1.068, 2.288
	≥ 50	0.911	0.721, 1.151	1.477 ^c	1.020, 2.139
NO ₂	0	1		1	
	> 0 to < 10	0.870	0.706, 1.073	1.352 ^d	0.964, 1.896
	10 to < 30	0.913	0.727, 1.146	1.324	0.920, 1.904
	30 to < 50	0.945	0.741, 1.206	1.576 ^c	1.077, 2.305
	≥ 50	0.897	0.709, 1.136	1.492 ^c	1.028, 2.164
O ₃	0	1		1	
	> 0 to < 10	0.876	0.711, 1.079	1.348 ^d	0.962, 1.890
	10 to < 30	0.923	0.735, 1.158	1.316	0.915, 1.892
	30 to < 50	0.944	0.740, 1.204	1.577 ^c	1.077, 2.307
	≥ 50	0.904	0.716, 1.143	1.481 ^c	1.022, 2.145

^a Selective adjustment for PM_{2.5}, SO₂, NO₂, and O₃. All models were adjusted for public holidays, temperature, and relative humidity.^b In grains per cm².^c P-value < 0.05.^d P-value < 0.10.**Table 3**

Adjusted odds of suicide associated with the level of airborne pollen stratified by age group.

Gender and pollen level ^a	< 30 years old (n =1152)		30 to 60 years old (n =3975)		> 60 years old (n =2390)	
	OR	95%CI	OR	95%CI	OR	95%CI
Male						
0	1		1		1	
> 0 to < 10	0.908	0.549, 1.502	0.897	0.673, 1.196	0.810	0.551, 1.190
10 to < 30	0.965	0.552, 1.685	0.946	0.693, 1.292	0.855	0.563, 1.298
30 to < 50	0.771	0.421, 1.411	1.011	0.725, 1.410	0.925	0.592, 1.446
≥ 50	0.950	0.536, 1.684	0.915	0.664, 1.260	0.889	0.579, 1.366
Female						
0	1		1		1	
> 0 to < 10	1.445	0.639, 3.268	1.401	0.824, 2.381	1.265	0.750, 2.136
10 to < 30	1.265	0.524, 3.054	1.502	0.856, 2.635	1.131	0.638, 2.006
30 to < 50	1.892	0.754, 4.749	1.648 ^b	0.915, 2.967	1.359	0.745, 2.481
≥ 50	2.042	0.831, 5.017	1.562	0.880, 2.770	1.191	0.665, 2.133

^a In grains per cm². All models were adjusted for public holidays, temperature, and relative humidity.^b P-value < 0.10.

have been proposed. Postolache and colleagues have suggested for example, that among individuals who are vulnerable to suicide, mood disorders and allergies (i.e. have allergen-specific IgE), cytokines produced as part of the immune response to allergen exposure (e.g. pollen) might have a role in the development of suicidal behavior (Postolache et al., 2008; Qin et al., 2013). Support for this supposition comes from two meta-analyses which have suggested that cytokines might be linked to suicidal behavior (Black and Miller, 2015; Ducasse et al., 2015) while a more recent review has highlighted the heterogeneity of findings across studies (Ganança et al., 2016). Given that the neurobiology of suicidal behavior is still poorly specified (Brundin et al., 2015), the exact role of cytokines in the emergence of suicidal behavior is unclear, although it has been suggested that they might affect monoaminergic neurotransmission, which has previously been linked to suicidal behavior (Ganança et al., 2016). Clinical research has also indicated that peripheral cytokines are associated with aggression and hopelessness, both of which may be important factors in suicidal behavior (Brundin et al., 2015).

Another factor that might link cytokines and suicidal behavior is depression, which has been estimated to be an underlying factor in more than half of all suicides (Hawton and van Heeringen, 2009). Specifically, evidence suggests that proinflammatory cytokines might be important in the development of depression in some individuals (Raison et al., 2006) and that the inflammatory response in atopic disorders might be one source of such cytokines (Berk et al., 2013). This might help explain why an earlier study in Japan linked pollinosis with depression (Hashimoto et al., 2007) and why research from elsewhere has shown an association between allergic rhinitis and depression/depressive mood (Cuffel et al., 1999; Kim et al., 2016).

Higher pollen levels have been found to aggravate allergic symptoms (Annesi-Maesano et al., 2012), while more severe allergy (as

Table 4

Adjusted odds of suicide associated with the level of airborne pollen on different lag days, stratified by sex.

Lag term and pollen level ^a		Male (n =5185)		Female (n =2332)	
		OR ^b	95%CI	OR ^b	95%CI
Lag 0	0	1		1	
	> 0 to < 10	0.874	0.709, 1.077	1.349 ^d	0.962, 1.891
	10 to < 30	0.920	0.733, 1.115	1.318	0.917, 1.894
	30 to < 50	0.948	0.743, 1.209	1.574 ^c	1.076, 2.303
	≥ 50	0.911	0.721, 1.151	1.477 ^c	1.020, 2.139
Lag 1	0	1		1	
	> 0 to < 10	0.830	0.672, 1.024	1.154	0.829, 1.608
	10 to < 30	0.841	0.669, 1.056	1.071	0.750, 1.529
	30 to < 50	0.838	0.656, 1.070	1.284	0.883, 1.867
	≥ 50	0.851	0.675, 1.074	1.172	0.815, 1.685
Lag 2	0	1		1	
	> 0 to < 10	1.065	0.862, 1.316	1.197	0.874, 1.639
	10 to < 30	1.019	0.810, 1.284	1.176	0.836, 1.654
	30 to < 50	1.167	0.913, 1.491	1.222	0.847, 1.761
	≥ 50	1.077	0.853, 1.359	1.199	0.847, 1.696
Lag 3	0	1		1	
	> 0 to < 10	0.943	0.788, 1.130	0.960	0.725, 1.271
	10 to < 30	0.885	0.725, 1.081	0.935	0.688, 1.271
	30 to < 50	1.037	0.832, 1.291	1.035	0.741, 1.445
	≥ 50	0.973	0.794, 1.193	0.955	0.697, 1.307

^a Lag 0 denotes the day of suicide death; lags 1, 2, and 3 denote the specific day prior to a suicide. Spearman's rank order correlation coefficients for the lags ranged from 0.82 to 0.91. Pollen is measured in grains per cm².

^b All models were adjusted for public holidays, temperature, and relative humidity.

^c P-value < 0.05.

^d P-value < 0.10.

measured by a history of inpatient vs. outpatient hospital treatment status) has been associated with an increased risk for suicide (Qin et al., 2011). One mechanism that may connect pollen, symptom severity and suicide is a deteriorating quality of life (QOL), as research has indicated that (allergic rhinitis) symptom severity is associated with worse QOL (Jaruvongvanich et al., 2016; Stuck et al., 2004) while there is some evidence that poorer QOL and health-related quality of life (HRQL) may be important for suicidal behavior (Goldney et al., 2001; Kumar and George, 2013). The use and adverse effects of allergy medications might also be a factor in the association between allergic disorders and suicidal behavior (Kölves et al., 2015). As yet, however, there has been little research on this potential relation although an earlier ecological study from the United States indicated that the effects of different allergy medications might vary, as the county-level volume of non-sedating antihistamine prescriptions was associated with increased suicide rates whereas those for intranasal corticosteroids were linked to lower suicide rates (Woo et al., 2011).

The finding of an association between pollen and suicide only among women concurs with the result of an earlier study from the United States (Postolache et al., 2005) but not with a more recent study from Denmark where pollen was linked to suicide mortality among both men and women, although the effect was stronger in the latter when there were middle levels of pollen (i.e. 30–100 grains/m³ air) (Qin et al., 2013). Several factors might be important in this context. Earlier cohort research from Finland that used skin-prick tests for allergens which included birch and timothy grass and information on the participants' self-reported history of allergic disease found that women, but not men with atopic diseases had higher odds for developing depression (Timonen et al., 2002). Hormonal factors might also play a role (Postolache et al., 2008). Specifically, it has been suggested that androgens may be immunosuppressive while estrogens are proinflammatory (Chen et al., 2008) with this possibly contributing to the worse clinical situation among women with allergic disease

(allergic asthma) (Lee et al., 2006) and hence, possibly an increased risk for suicide. It can be speculated that this sex difference might even be explained by differential exposure. Earlier research has indicated that the level of indoor pollen in Tokyo might be low compared to the level outdoors (Ishibashi et al., 2008). Thus, if there was a difference in time spent indoors/outdoors between the sexes it is possible that it might have also been important for the observed association.

The effects of pollen on suicide were seen immediately (lag 0) but did not stretch back to the days before the suicide. This suggests that higher levels of pollen may have an immediate detrimental effect on health – a finding which concurs with the result from a recent study of pollinosis symptoms undertaken in Tokyo (Bando et al., 2015).

The findings of this study should be considered in light of several limitations. We had no information on the medical status of those who died from suicide and hence we were unable to determine whether the association between pollen and suicide occurred among individuals who were healthy, had certain disorders/illnesses or whether a combination of conditions (comorbidity) was important in this respect. We also lacked information on other variables which might have been important. For example, Woo et al. (2012) have suggested that socio-economic variables might confound the association between the pollen level and suicide rates but we were not able to examine the effects of socioeconomic factors due to an absence of data. It will be important for future studies to incorporate such data into the analyses to better understand the association between pollen and suicide mortality so it can be determined whether an association exists, and if it does, whether it is direct or whether pollen might be acting as a proxy for some other, as yet, unidentified factor. We also assumed that readings obtained from monitoring stations correctly reflected the level of exposure to environmental elements. However, a recent study from Kanagawa prefecture, Japan found that personal pollen exposure may be more dependent on indoor rather than outdoor pollen counts, and that as people spend more time indoors, outdoor counts might be potentially inaccurate (Yamamoto et al., 2015). Given this, and that as mentioned above, the difference in time spent indoors and outdoors might also be important for our results, the fact that we were only able to examine outdoor pollen counts should also be considered a limitation. In addition, it is possible that the averaging of the pollen concentration on Friday to Sunday in the present study might also have weakened the association. Finally, this study was undertaken in just one location. As the prevalence of allergic disorders (Nakae and Baba, 2010) and the levels of airborne pollen (Sahashi, 2015) differ across Japan, this association should also be examined in other locations to determine if the results obtained in Tokyo are generalizable to the whole of the country.

5. Conclusions

To the best of our knowledge, this is the first study to examine the association between airborne pollen and suicide mortality in a non-Western setting. It showed that airborne pollen was associated with increased odds for suicide mortality in Tokyo but that this relation was restricted to women. This finding adds to the growing body of research evidence which suggests that pollen might also have an effect on non-allergic disease outcomes (de Weger et al., 2013). Given the large number of deaths from suicide each year with an estimated 20 attempted suicides occurring for each completed suicide (World Health Organization, 2014), and that climate change may lead to higher levels of some forms of pollen in the future (Hamaoui-Laguel et al., 2015), then undertaking research in other locations to determine if and how pollen affects suicidal behavior, and the role of other environmental factors in this association, should now become a priority.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2017.02.008.

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Airborne pollen and suicide mortality in Tokyo, 2001-2011

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Supplementary Material

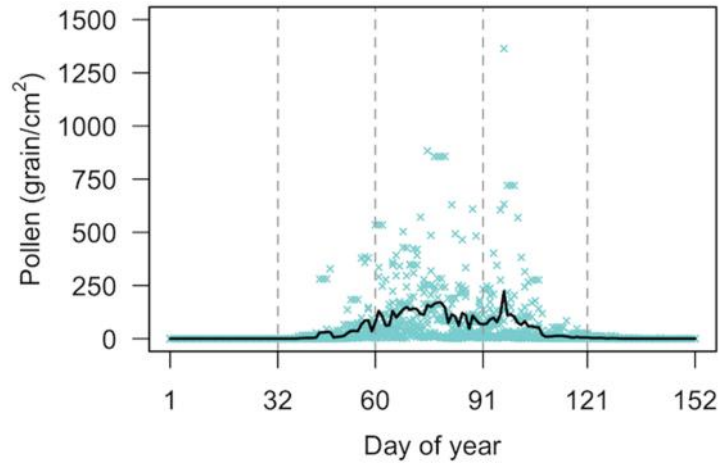


Fig. S1. Average daily level of airborne pollen from Japanese cedar and Japanese cypress trees from January to May, 2001-2011. Marks on the x-axis represent the first day of a month in a non-leap year.

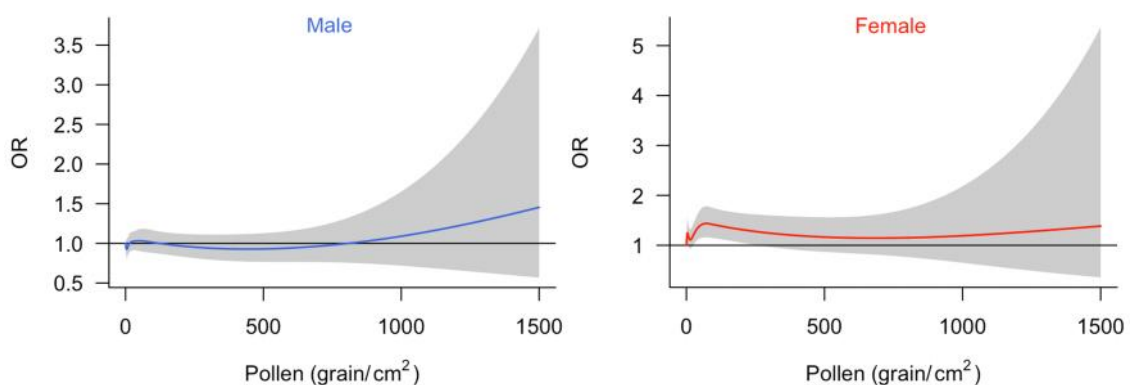


Fig. S2. Concentration-response curve for the association between airborne pollen and daily suicide deaths among males and females. Pollen was smoothed using a natural cubic spline with 5 degrees of freedom. The estimated odds ratios (ORs) were computed with zero pollen as the reference category and were adjusted for public holidays, smoothed mean temperature and relative humidity.

Table S1 Suicide cases by pollen level in Tokyo, February – April, 2001-2011.

Pollen level (grains/cm ²)	Number of days (%)	Number of suicide deaths (%)	Female (%)	Number of cases per day
0	23 (2.3)	182 (2.4)	25	7.9
> 0 to < 10	424 (43.2)	3185 (42.4)	32	7.5
10 to < 30	167 (17.0)	1271 (16.9)	29	7.6
30 to < 50	71 (7.2)	573 (7.6)	34	8.1
≥ 50	296 (30.2)	2306 (30.7)	30	7.8
0	23 (2.3)	182 (2.4)	25	7.9
> 0 to < 10	424 (43.2)	3185 (42.4)	32	7.5
10 to < 20	113 (11.5)	835 (11.1)	28	7.4
20 to < 30	54 (5.5)	436 (5.8)	32	8.1
≥ 30	367 (37.4)	2879 (38.3)	31	7.8
0	23 (2.3)	182 (2.4)	25	7.9
> 0 to < 10	424 (43.2)	3185 (42.4)	32	7.5
10 to < 50	238 (24.3)	1844 (24.5)	31	7.7
50 to < 100	112 (11.4)	913 (12.2)	31	8.2
≥ 100	184 (18.8)	1393 (18.5)	30	7.6
0	23 (2.3)	182 (2.4)	25	7.9
> 0 to < 50	662 (67.5)	5029 (66.9)	31	7.6
50 to < 100	112 (11.4)	913 (12.2)	31	8.2
100 to < 300	135 (13.8)	1041 (13.8)	30	7.7
≥ 300	49 (5.0)	352 (4.7)	30	7.2
Total	981 (100.0)	7517 (100.0)	31	7.7

Table S2

Adjusted odds of suicide associated with the level of airborne pollen defined using different cut-points.

Pollen level ^a	Male (<i>n</i> = 5185)		Female (<i>n</i> = 2332)	
	OR ^b	95%CI	OR ^b	95%CI
0	1		1	
> 0 to < 10	0.877	0.711, 1.080	1.361 ^d	0.971, 1.907
10 to < 20	0.916	0.727, 1.155	1.191	0.823, 1.724
20 to < 30	0.944	0.731, 1.220	1.791 ^c	1.194, 2.684
≥ 30	0.927	0.738, 1.165	1.567 ^c	1.091, 2.252
0	1		1	
> 0 to < 10	0.874	0.709, 1.077	1.357 ^d	0.968, 1.902
10 to < 50	0.925	0.740, 1.157	1.392 ^d	0.974, 1.988
50 to < 100	0.935	0.735, 1.190	1.527 ^c	1.044, 2.234
≥ 100	0.887	0.696, 1.129	1.438 ^d	0.982, 2.105
0	1		1	
> 0 to < 50	0.878	0.713, 1.082	1.362 ^d	0.972, 1.907
50 to < 100	0.909	0.717, 1.151	1.510 ^c	1.038, 2.197
100 to < 300	0.874	0.687, 1.111	1.449 ^d	0.991, 2.119
≥ 300	0.815	0.623, 1.066	1.331	0.871, 2.003

^a In grains per cm².

^b Estimated effects of pollen on the day of suicide. All models were adjusted for public holidays, temperature, and relative humidity.

^c *P*-value < 0.05.

^d *P*-value < 0.10.