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Air pollution associated with non-suicidal self-injury in Chinese adolescent students: a cross-sectional study

Weina Liu[1], **Hong Sun**[1,*], **Xin Zhang**[2], **Qi Chen**[1], **Yan Xu**[1], **Xi Chen**[3], and **Zhen Ding**[1,*]

[1]Jiangsu provincial center for disease control and prevention, Jiangsu road 172, 210009, Nanjing, China

[2]School of Statistics, Beijing Normal University, 19 XinJieKouWai Street, 100875, Beijing, China

[3]Department of Health Policy and Management, Department of Economics, Yale University, 60 College St., New Haven, CT, 06520, USA

Abstract

Background—Non-suicidal self-injury (NSSI) is a frequent phenomenon in adolescents and is closely related to eventual suicide. Although the effect of air pollution on various diseases has been extensively investigated, no studies examined its effect on NSSI in young students.

Objectives—We investigated the effect of air pollution on NSSI in Chinese students.

Methods—We investigated the incidence of NSSI in the past 12 months in 54 923 Chinese students with an anonymous questionnaire. We assessed the air pollution exposure of each student by the air quality matched with their schools, which were calculated by the inverse distance weighting method from the environmental monitoring data. We discussed the association between ambient air pollutants and the incidence of NSSI using generalized additive mixed models.

Results—A 10 μg/m^3 increase in the annual moving average concentration of particulate matter with diameters less than 2.5 micrometers ($PM_{2.5}$) and ozone (O_3) was associated with a 13.9 percent and a 10.5 percent increase in the odds ratio (OR) of NSSI, respectively. In addition, a 0.1 mg/m^3 increase in the annual moving average concentration of carbon monoxide (CO) was associated with a 4.8 percent increase in the OR of NSSI. NO_2 and SO_2 were not related to NSSI. CO and O_3 show non-linear effects on NSSI. Male students in high school are the most s to the effects of $PM_{2.5}$ on NSSI.

Conclusions—Our study suggests that increases in $PM_{2.5}$, O_3 and CO may increase the incidence of NSSI among adolescent students.

Corresponding author: Hong Sun, njmu_sunhong@hotmail.com, Tel: 8625 83759524, Address: Jiangsu provincial center for disease control and prevention, Jiangsu road 172, 210009, Nanjing, China. Co-corresponding author: Zhen Ding, jscdc@126.com Tel: 8625 83759520.

Declarations of interest:
None.

Keywords

Non-suicidal self-injury; air pollution; young students; health effect; Ozone; $PM_{2.5}$

1. Introduction

Non-suicidal self-injury (NSSI) refers to the intentional self-inflicted destruction of body tissue without suicidal intention and for purposes not socially sanctioned (Cipriano et al. 2017). NSSI is a recurrent phenomenon in adolescents and is a major public health issue in adolescents (Di Pierro et al. 2012; Kiekens et al. 2016). NSSI is typically used to deal with distressing negative affective states, especially anger and depression, and mixed emotional states. NSSI is closely related to eventual suicide (Gulbas et al. 2015; Morgan et al. 2017). Emerging studies have reported the effects of air pollution on suicides (Casas et al. 2017; Chen and Samet 2017; Szyszkowicz et al. 2010). However, there is a lack of studies on the effects of air pollution on NSSI.

With rapid economic growth in recent decades, air pollution has been part of the most important environmental issues in China. China is experiencing deteriorating air quality because of emissions from conventional energy consumption, vehicle exhaust and industrial production. (Kan et al. 2009). Particulate matter (PM) with aerodynamic diameters < 2.5 μm ($PM_{2.5}$), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide(CO) and nitrogen dioxide (NO_2) are the principal air pollutants in China, and their annual average concentrations are potentially harmful according to World Health Organization (WHO) air quality guidelines. Exposure to relatively high concentrations of pollutants among Chinese residents may help model the potentially highly non-linear dose-response relationship, which is difficult to evaluate, using data from developed nations with much lower level of pollution.

Plausible etiologic factors for NSSI may be divided into two major categories: individual factors (e.g., emotional dysregulation, psychiatric disorders) and environmental factors (e.g., childhood maltreatment, attachment disruption). Some research focused on early childhood traumatic experience found that childhood maltreatment emerged as a predictor of NSSI among adolescents and college students (Auerbach et al. 2014; Wan et al. 2015). A large number of studies have reported the association between air pollution and mental disorders, including depression and suicide (Kim et al. 2010; Szyszkowicz 2007). The effects of air pollution on these disorders might share some similar mechanism for NSSI. Research with experimental animals has provided evidence of neuropathological effects of exposure to polluted air. Ultrafine particles can reach into the brain (Chen and Samet 2017) and cause further change in the hormone production of mice (Yokota et al. 2016). Another possible mechanism of air pollution was related to peripheral and central inflammation (Chen and Samet 2017).

Our study was based on a priori hypothesis that air pollution may affect the incidence of NSSI in youth. Therefore, we surveyed the incidence of NSSI in Chinese adolescent students in 2013, matched with air pollution data, and then analyzed the correlation between long-term air pollution and the incidence of NSSI. The purpose of this study was to identify and assess the effects of air pollution on NSSI.

2. Materials and methods

2.1 Analytical Sample and NSSI information

This study evaluated data from 54 923 participants through the 2013 National Youth Health Risk Behaviors investigation (NYHRBI) in Jiangsu Province, located in eastern China, with 80 million residents. Systematic randomized cluster sampling was used to enroll students, and students anonymously completed the National Youth Health Risk Behaviors Questionnaire online. Details of the NYHRBI have been described previously (Liu et al. 2017). All surveys were completed between September 1, 2013 and November 30, 2013. All participation was voluntary, and students provided informed consent prior to completing the anonymous surveys. The dataset was relatively bulky, containing 18 871 middle school students, 23 905 high school students and 12 147 college students. The overall qualification rate for the questionnaire was 84%. NSSI incidence among the participants over the previous 12 months before the survey were assessed by the Function of Self Mutilation (FASM) measure within the questionnaire, which is widely used in clinical interviews and community samples of adolescents with acceptable psychometric properties (Nock and Prinstein 2005; Tang et al. 2016). This study design was approved by the institutional review board of the Jiangsu Provincial CDC.

2.2 Environment data

Air pollution measures were collected from the hourly air quality report published by the Ministry of Environmental Protection of China (MEP). The report covers 97 monitoring stations in Jiangsu province, including longitude and altitude information for each station. Five pollutants, including $PM_{2.5}$, CO, NO_2, O_3 and SO_2, were used in our analysis. The geocoded addresses of 268 schools were linked to daily average air pollution concentrations between September 2012 and December 2013. To merge the survey data with the air pollution readings, we calculated the weighted average values of all the monitoring stations within 40km of the school, where the weights were equal to the inverse of distance between stations and the schools. Air pollution exposure of each student was matched to the data of their school location. Following the Chinese education policy, most of the middle or high school students lived around their schools, no more than 5 kilometers, and most of the college school students lived in their campuses. Therefore, air pollutants data matched with schools could reflect the outdoor exposure of students.

2.3 Statistical analyses

We performed multivariate analysis to estimate the effects of air pollution on NSSI, using the generalized additive mixed models (GAMM) with link function of *logit* and with random effect of school. We expressed the estimated effects of a 10 $\mu g/m^3$ or 0.1 mg/m^3 (for CO) increase in the concentration of each individual air pollutant as the percent change in the odds ratios for NSSI. In all models, we included factors that we hypothesized a priori could potentially confound the relationship between air pollution and NSSI. Matching the incidence of NSSI in the past 12 months, we calculated the moving annual average value of five air pollutants, including $PM_{2.5}$, O_3, CO, NO_2 and SO_2.

We established adjusted models, and the fixed variables were gender, household per capita income, mother's education, maltreatment, pocket money and school level. All factors were significant in the models. In order to adjust the non-linear effect of other pollutants, we added smooth parameters in the model, including all the other four pollutants when performing specific analysis for one pollutant. School was treated as random effect in GAMM models. Heterogeneous effects of air pollution were analyzed for three principal class variables, including school level, gender, mother's education and maltreatment. The covariates and fixed effects are the same throughout the analysis. The analyses and exposure-response curves were produced by the GAM function of the *mgcv* package in R software (Wood et al. 2016).

3. Results

3.1. Descriptive statistics

The descriptive statistics on the rate of NSSI, ambient air pollution, and sociodemographic characteristics of the study population (n = 54 923) were shown in Table 1. There were 268 schools took part in this investigation. The rate of NSSI ranged from 5.04% (for colleges) to 11.05% (for high school), with an average of 9.27%, which was similar to the rate of NSSI in middle school (9.74%). There was a similar proportion of males and females (48.08% VS 51.92%). The moving annual average of $PM_{2.5}$ and O_3 was 51.67 μg/m^3 and 61.73 μg/m^3, separately. The average monthly household per capita income was approximately 2 500 Chinese yuan ($400). A total of 13.2% mothers of investigated subjects received a college education.

3.2 Effects of air pollution on NSSI of students

Five pollutants were analyzed for their association with NSSI, including $PM_{2.5}$, Ozone, SO_2, NO_2, and CO. We assessed the annual moving average for each pollutant on the investigated day. When we assessed one of the five pollutants, the other four pollutants were smoothed in the GAMM model. As showed in Table 2, six significant confounding factors were controlled in the model: gender, household per capita income, mother's education, monthly pocket money, school level and maltreatment. $PM_{2.5}$, O_3 and CO were positively correlated with the incidence of NSSI, while SO_2 and NO_2 were not significantly correlated with NSSI. An increase of 10 μg/m^3 $PM_{2.5}$ and O_3 was associated with 13.9% and 10.5% higher odds for NSSI. A 0.1 mg/m^3 increase of CO was associated with 5.1% higher odds for NSSI.

3.3 Heterogeneous effects of air pollution on NSSI

Table 3 showed the stratified results for different gender, grade, mother's education and maltreatment. For $PM_{2.5}$, those male high school students with relatively low mother's education were the most susceptible to NSSI. O_3 and CO were significantly associated with NSSI in all of the middle school students and high school students, regardless of gender, mother's education and maltreatment. We defined statistically meaningful subgroups of the four variables in Table 3 as a high-risk population. The high-risk population for $PM_{2.5}$ was male high school students with lower mother's education. The high-risk population for O_3 and CO was middle school and high school students (Table 3).

3.4 The exposure-response relationship between air pollution and NSSI

Fig. 1 summarized the exposure-response relationship between $PM_{2.5}$, O_3, and CO based on the total subjects and high-risk population identified from Table 3. After adjusting for confounder, $PM_{2.5}$ was linearly correlated with the risks of NSSI, while the O_3 and CO were not linearly correlated with the risks of NSSI in these models. For the high-risk population, the ORs for NSSI were increasing with the increase of the three pollutants (Fig.1).

Fig. 2 shows the relationship between air pollutants ($PM_{2.5,}$ O_3, CO) quartiles and OR for NSSI in high-risk students identified from Table 3. The OR for NSSI in the highest $PM_{2.5}$ quartile was 1.98-fold (95%CI: 1.54-2.54) higher than the OR for NSSI in the lowest $PM_{2.5}$ quartile. For O_3, the highest OR appeared at the third quartile, with a value of 1.23 (95%CI: 1.06-1.42). CO showed a similar trend as $PM_{2.5}$; the highest OR was 1.43 (95%CI: 1.28-1.61), and it was observed in the highest CO quartile.

4. Discussion

This is the first report of the effects of air pollution on NSSI, and we have identified long-term exposure of $PM_{2.5}$, O_3 and CO as possible risk factors for NSSI. In addition, the related exposure-effects relationship has been characterized.

The prevalence of NSSI in Japanese college students was 10% (31/313) in a previous report (Tresno et al. 2013). In another Chinese report that examined 1 288 middle school students, 22.67% had a history of NSSI (Yan et al. 2012). In Italian adolescents, at least one act of self-injury was reported by 18.4% (49/267) of the sample (Di Pierro et al. 2012). Studies from Germany report prevalence rates between 15% and 26% in adolescents (Plener et al. 2009). In the USA, the prevalence was as higher as 37.2% in a cross-sectional sample of 9^{th}-12^{th} graders (n = 1 036, 51.9% girls) (Yates et al. 2008). In the present study, the prevalence was 9.27%, which was the lowest value. However, considering the huge population of China, the problem of NSSI in students remains a very important issue to be addressed. Finding environmental risk factors associated with NSSI will help in the prevention of NSSI.

Previous studies have showed associations between air pollution and mental health, even criminal activity (Herrnstadt and Muehlegger 2015). A recent study showed that air pollution reduces hedonic happiness and increases the rate of depressive symptoms (Zhang et al. 2017). Time series studies of acute events have linked higher air pollution levels with increases in suicides (Kim et al. 2010) and depression-related admissions (Szyszkowicz 2007). A one year follow-up study reported that depression mediated the relationship between distress tolerance and NSSI among adolescents (Lin et al. 2017). Additional studies reported that youth with high levels of depressive symptoms had the greatest frequency of NSSI (Boone and Brausch 2016). All of these studies showed that depression may mediate the association between air pollution and the incidence of NSSI in adolescents. Thus, the association between air pollution and NSSI is plausible.

The 3-day moving average concentrations of O_3 and PM_{10} have been reported to be associated with emotional symptoms in elderly people (Y-H Lim et al. 2012). Szyszkowicz et al. (Szyszkowicz 2007; Szyszkowicz et al. 2010) reported that air pollution was associated with depressive disorders and suicide attempts. In the present study, we identified that annual moving average concentrations of O_3, $PM_{2.5}$ and CO are associated with high incidence of NSSI in students. Our results further indicated that long-term air pollution is a possible risk factor associated with NSSI. In contrast with previous study results, we found that NO_2 and SO_2 are not significantly associated with NSSI. For example, Lim *et.al* (Y Lim et al. 2012) reported that NO_2 was positively associated with depressive symptoms measured repeatedly among an elderly population in Korea. Szyszkowicz (2007) reported that SO_2 and NO_2, were positively associated with increased emergency department visits due to depression in warm seasons. The difference in results might be explained by the lower concentrations of SO_2 and NO_2 in our report.

A recent study showed that PM_{10} and O_3 could trigger suicide, particularly during warm periods, even at low concentrations of PM_{10} (29±15.2 μg/m^3) and O_3 (61.8±30.3 μg/m^3) (Casas et al. 2017). Our study provided a much wider concentration range of $PM_{2.5}$, with annual moving average concentration as high as 51.7 μg/m^3. In addition, quantitative results showed that a 10 μg/m^3 increase in annual average concentration of $PM_{2.5}$ might increase the incidence of NSSI in high school students to as high as 17.4% (Table 3). Notably, male high school students were identified as the most susceptible population for the effect of $PM_{2.5}$ on NSSI. This finding might be explained by the high exposure to PM2.5 among these students (e.g., more sport; basal higher metabolic rate) or the basal high stress situation. It has been reported that ultrafine particles can reach the brain, either by traveling from the nose along the olfactory nerve or by the systemic circulation following translocation across the alveolar-capillary layer in the lung (Chen and Samet 2017). In animal models, exposure to diesel exhaust particles during pregnancy increases testosterone and dopamine levels, and decreases serotonin in mice, which may lead to aggressive and depressive behaviors (Yokota et al. 2016), which might be the mechanism of the effect of $PM_{2.5}$ on NSSI. Despite available epidemiologic evidence does not provide a strong support for this association, the emerging neurotoxicologically data still suggested that ambient air pollution might contribute to the psychopathological state (e.g., loss of cognitive control; emotional dysregulation) leading to suicidal behaviors in children and adolescents. Two cross-sectional studies examined early-life exposure to PM and impulsivity in school-aged children and adolescents, and reported significant associations (Chiu et al. 2013; Yorifuji et al. 2016). These observations support the possibility that ambient air pollution may be a determinant of diathesis, and thus, future studies need to prospectively assess whether air pollution exposure leads to acute exacerbations of psychopathologies that trigger suicidal behaviors in adolescent students.

For O_3, we reported annual average concentration of 61.73 μg/m^3, which was much similar with Casas's reports on O_3 and suicide (Casas et al. 2017). In Casas's reports among adolescents, a 10 μg/m^3 increase in O_3 was associated with 8% higher odds for suicide; the corresponding increase odds for NSSI in the present study was 10.5%. There are currently no other published data showing adverse O_3 effects on depressive symptoms, mood disorders, or other psychiatric diseases in youth (Chen and Samet 2017). There are no epidemiologic data on the possible link between O_3 exposure and increased diathesis for suicidal behaviors. However, accumulating evidence indicated that both peripheral and central inflammation contributed to the pathophysiology of suicidality, while exposures to airborne particles and O_3 are known to cause widespread inflammatory responses in humans and animal models (Chen and Samet 2017). For CO, every 0.1 mg/m^3 increase was associated with 5.1% higher odds for NSSI. The results were consistent with Szyszkowicz's reports about increased emergency department visits due to depression in warm seasons (Szyszkowicz 2007). This result showed a possible correlation between ambient CO and the incidents of NSSI for youth students, even at the current low concentrations.

This study has some strength. First, we used a larger sample, investigating data of 54 923 randomly sampled students from 268 schools, including middle school, high school and colleges. No NSSI related selection bias exists during the investigation procedure. Second, this study estimated the effects of air pollution based on multi-pollutant models. The principal co-pollutant was adjusted as smooth parameters in the GAMM model, and the incidence of NSSI was analyzed for stratified populations. The confounding factors were controlled during the analysis as much as possible.

This study also has some limits. First, as a retrospective survey, the incidence of NSSI in the past 12 months was self-reported, while the exposure of air pollution used the annual average ambient air quality data of the schools. Regardless of the fact that the time span matched, the precedence relationship between air pollution exposure and NSSI was no better than in a cohort study. Thus, it was difficult to make a causal inference. Second, the occurrence of NSSI was a profound procedure, there still some other confounders could not be controlled in the regression models. However, individual analysis and quartile analysis both showed comparable results. Then we were in a position to assume that the results were robust.

In conclusion, this is the first report to investigate the relationship between NSSI and long-term air pollution. Increasing concentrations of $PM_{2.5}$, O_3, and CO were significantly associated with the incidence of NSSI among the adolescent student population in China, suggesting the possible associations between air pollution and NSSI. In addition, male students in high school were identified as the most susceptible population. Additional studies should verify the possible causal relationship and mechanisms between air pollution and NSSI, to reduce the impending suicide.

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Highlight

1. $PM_{2.5}$, ozone, and CO are positively associated with a high incidence of non-suicidal self-injury (NSSI) in Chinese adolescent students.
2. O_3 and CO showed a non-linear association with NSSI.
3. Male students in high school were the most susceptible to the effects of $PM_{2.5}$ on NSSI.

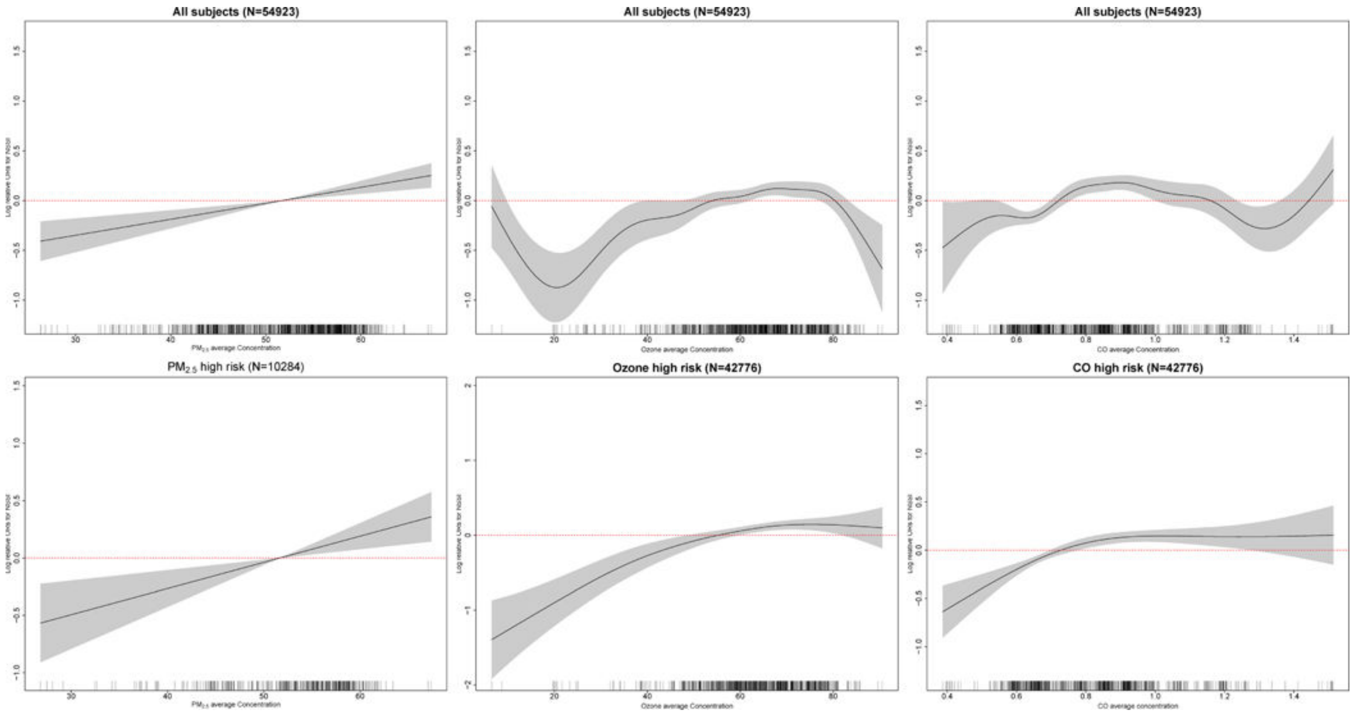

Fig.1.

The exposure-response curves of three air pollutants (annual moving average concentrations) with the odds ratio (OR) for non-suicidal self-injury(NSSI) in all subjects (upper) or in high-risk subjects (lower). Models were adjusted for five air pollutants, gender, household per capita income, mother's education, pocket money, school level and maltreatment.

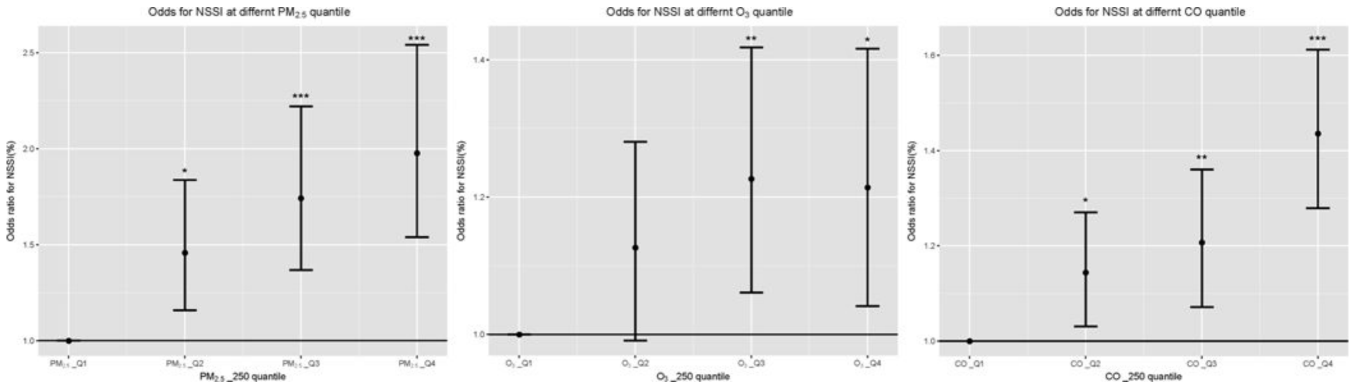

Fig.2.

The relationship between air pollutants (annual moving average concentrations of $PM_{2.5}$, O_3 and CO) quartile and the odds ratio for NSSI in high-risk students identified in Table 3. This figure shows that the OR for NSSI increased with $PM_{2.5}$, O_3 and CO. Models were fitted for five air pollutants, gender, household per capita income, mother's education, pocket money, school level and maltreatment. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

Table 1

Summary statistics of key variables

Variable	Definition	Mean/N	Min	Max
N	Investigated subjects (N)	54 923		
Non-suicidal self-injury(NSSI)	indicator for people who have self-injured during the past 12 months (%)	9.27%		
	NSSI in Middle school students	9.74%		
	NSSI in High school students	11.05%		
	NSSI in College students	5.04%		
$PM_{2.5}$_year	Average annual particulate matter with a diameter smaller than 2.5 micrometers (μg/m^3)	51.67	26.32	67.38
CO_ year	Average annual carbon monoxide (mg/m^3)	0.82	0.39	1.51
NO_2_ year	Average annual NO_2	31.40	11.36	53.47
O_3_ year	Average annual ozone (μg/m^3)	61.73	6.48	90.58
SO_2_ year	Average annual sulfur dioxide (μg/m^3)	24.16	0.68	41.83
Gender				
Male	indicator for being male	48.08%		
Female	indicator for being female	51.92%		
Age	age	16.2	8.8	24.6
Household per capita income	Monthly household per capita income (Chinese yuan)	2 500	<200	>5 000
Pocket money	Monthly pocket money	130	0	> 1 000
Mother's education	Mother's education			
Less than college		86.8%		
College or above		13.2%		
School type	Investigated school	268		
	Primary school (N)	108		
	High school (N)	121		
	Colleges (N)	39		
Maltreatment	The rate of students received maltreatment in the past year	33.2%		

Table 2

Effects of air pollution on non-suicidal self-injury activity of students (N=54 923)

Dependent variable	**Pollutant (Odds ratio)**				
Nonsuicidal self-injury activity	**$PM_{2.5}$(÷10) (μg/m^3)**	**O_3(÷10) (μg/m^3)**	**CO (×10) (mg/m^3)**	**NO_2(÷10) (μg/m^3)**	**SO_2(÷10) (μg/m^3)**
Pollutant	1.139**	1.105***	1.051*	0.923	0.990
Female	0.756***	0.756***	0.748***	0.756***	0.756***
Household per capita income	0.914***	0.923***	0.914***	0.914***	0.914***
Mother's education	1.197***	1.221***	1.197***	1.197***	1.209***
Pocket money	1.094***	1.094***	1.094***	1.094***	1.094***
School level	0.691***	0.691***	0.684***	0.684***	0.691***
Maltreatment	3.878***	3.875***	3.872***	3.885***	3.850***
s ($PM_{2.5}$_ year)[a]	No	Yes	Yes	Yes	Yes
s (O_3_ year)	Yes	No	Yes	Yes	Yes
s (CO_ year)	Yes	Yes	No	Yes	Yes
s (NO_2_ year)	Yes	Yes	Yes	No	Yes
s (SO_2_ year)	Yes	Yes	Yes	Yes	No
Adjusted R-squared	0.050	0.050	0.050	0.051	0.050

* $p<0.05$,

** $p<0.01$,

*** $p<0.001$.

[a] s () means smooth function in GAMM model.

Table 3

Heterogeneous effects of Air pollution

Dependent variable NSSI	A. School level			B. Gender		C. Mother's education		D. Maltreatment	
	middle school	high school	college	male	female	high school or less	College or above	Yes	No
$PM_{2.5}$_year (÷10)	1.030	1.174*	1.105	1.162**	1.073	1.139**	0.990	1.202***	1.028*
O_3_year (÷10)	1.139***	1.105**	0.914	1.105**	1.116**	1.105***	1.139*	1.047*	1.090**
CO_year (×10)	1.083***	1.094***	1.116	1.041*	1.062***	1.041***	1.073**	1.055***	1.032*
Observations	18 871	23 905	12 147	26 409	28 514	47 700	7 223	18 215	36 708

* $p<0.05$,

** $p<0.01$,

*** $p<0.001$.

Note: Data were the odds ratio (OR) for NSSI. Models were fitted for five air pollutants, gender, household per capita income, mother's education, pocket money, school level and maltreatment.