Environment International 106 (2017) 144–152

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

The health policy implications of individual adaptive behavior responses to smog pollution in urban China

Jie Ban[a], Lian Zhou[b], Yi Zhang[a], G. Brooke Anderson[c], Tiantian Li[a,*]

[a] National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, China, No.7 Panjiayuannanli, Chaoyang District, Beijing 100021, China
[b] Jiangsu Center for Disease Control and Prevention, Nanjing, China, No.172 Jiangsu Road, Nanjing 210019, China
[c] Department of Environmental and Radiological Health Sciences, Colorado State University, USA

ARTICLE INFO

Keywords:
Smog
Air pollution
China
Environmental adaptation
Individual behavior

ABSTRACT

Smog pollution is a serious public health issue in urban China, where it is associated with public health through a range of respiratory and cardiovascular illnesses. Despite the negative health impacts of smog pollution, individual adaptive behaviors are poorly understood. This knowledge gap hinders the development of effective public policy to support and encourage the adoption of individual adaptive and mitigating behaviors to smog pollution. A questionnaire survey of 1141 randomly sampled individuals in a typical $PM_{2.5}$-polluted Chinese city was designed to establish smog concerns and behavior changes during smog events. The results demonstrate a variety of behavior responses associated with risk perception, experience of smog, age, and gender of respondents. An understanding of these variations is critical to the development of effective public policy and ultimately to the improvement of public health in cities affected by smog.

1. Introduction

China has one of the highest levels of air pollution in the world (Liu and Diamond, 2005). The prevalence of poor-quality air and its proven links to ill health (Lim et al., 2012; Zhou et al., 2016) are major concerns. In 2010, it was estimated that ambient fine particle matter ($PM_{2.5}$) contributes to > 1.2 million deaths in China annually and to the loss of 24 million healthy years (Lim et al., 2012). In 2013, $PM_{2.5}$ pollution ranked fifth among all contributors to the health burden of the population of China (Zhou et al., 2016). The frequent, large-scale smog pollution caused by $PM_{2.5}$ in urban China has led to social unrest and prompted increasing public demand for regulation to reduce smog and protect public health (Liao et al., 2015; Liu et al., 2016; Zhang et al., 2014). In response, in 2016 the Chinese central government announced its "Ten Measure Air Pollution Control Action Plan" which set a series of strict targets for emissions control, and promoted actions on developing cleaner industrial infrastructure, introducing clean energy practices, and establishing air pollution early warning systems and emergency response plans for smog events. While waiting for controls to take effect to improve ambient air quality (Tanaka, 2015; Wang et al., 2014), urban Chinese citizens have undertaken small-scale personal protective behaviors to reduce the risks of adverse health effects from air pollution (Giles et al., 2011; Laumbach et al., 2015; Rajagopalan and Brook, 2015). The need for policies to facilitate and encourage individual rapid behavioral responses to ambient air pollution has recently become more apparent (Pui et al., 2014).

In light of the importance of encouraging individuals to successfully reduce exposure to air pollution and minimize the related health impacts, this research first addresses the shortcomings in our understanding of individual behavioral responses to air pollution in China and the factors behind different behavioral responses. It then presents the results of a field questionnaire survey conducted during a period of poor air quality in Nanjing. The capital city of Jiangsu Province, Nanjing has a population of over 8 million and is an important center within the highly developed and diversified economy of the Yangtze River Delta region. Due to intensive emissions from industrial and traffic sources, as well as frequent windless atmospheric conditions, in 2013 Nanjing experienced 163 days when the $PM_{2.5}$ concentration was higher than the national air quality standard (75 μg/m^3) (Nanjing Environmental Protection Agency, 2014). Concentration data from national air pollution monitoring sites No. 1154A and No. 1157A revealed that the average concentration during the survey period (142 μg/m^3) was more than twice the annual average concentration from January 2013 to December 2014 (69 μg/m^3).

Individual behavior modification in response to serious air pollution could help reduce individual exposure and protect health (Giles et al.,

* Corresponding author.
E-mail addresses: Brooke.anderson@colostate.edu (G. Brooke Anderson), tiantianli@gmail.com (T. Li).

http://dx.doi.org/10.1016/j.envint.2017.06.010
Received 18 September 2016; Received in revised form 9 June 2017; Accepted 11 June 2017
Available online 23 June 2017

2011). Currently, Chinese government officials at both the central and local levels address individual behavioral modifications only during actual smog episodes. The guidelines broadcast during smog episodes, including changing the timing, location, intensity, and duration of outdoor activities, aim to encourage residents to reduce short-term exposure to poor-quality air. However, the content of these guidelines is vague and overly general and mostly addresses outdoor behavior modification. In addition, there is currently a lack of detailed guidelines for behavioral adaptations to improve indoor air quality and to lower transport emissions to reduce the production of further air pollution.

Despite recent descriptive research into government interest in specific behavioral adaptations, such as reducing outdoor activities (Giles et al., 2011), enhancing indoor protection (Semenza et al., 2008), or changing travel behavior (Elias and Shiftan, 2012), there is limited research describing the full range of individual adaptations to air pollution in China. Importantly, to form the basis for the design and delivery of effective adaptation policies, it is essential to understand the driving factors underlying different behavioral responses. Although previous studies have tried to estimate how individual-level response to smog episodes is affected by various factors, including psychosocial perceptions of air pollution (Elias and Shiftan, 2012; Liobikienė and Juknys, 2016; Semenza et al., 2008), environmental concerns (Garvill et al., 2003), and knowledge of air pollution (Rajagopalan and Brook, 2015), the effects of the interactions among multiple factors have not been formally studied. More importantly, little is known about factors driving changes to individual behavior in response to air pollution specifically within China, where urban residents are frequently exposed to intense air pollution. To provide more substantial evidence to inform effective behavioral intervention and policy-making strategies for appropriate response and mitigation, it is critical to improve understanding of the overall mechanisms that influence individual behavior.

2. Methods

2.1. Questionnaire survey

The aim of the questionnaire survey was to examine changes in individual behavior coping with smog pollution episodes. A smog pollution episode is defined here as a day categorized by the national daily weather forecasts as “smog day” or “heavy pollution”. This is a common way for urban residents to recognize smog and, therefore, for respondents to understand questions regarding behavior changes during smog episodes.

The face-to-face questionnaire survey was performed on a random sample of 1200 individuals in Nanjing during a heavily polluted period between December 2013 and January 2014. The average $PM_{2.5}$ concentration exceeded the standard limitation concentration on 52 of the 62 survey days (a rate of 83.8%), indicating frequent, serious pollution conditions in Nanjing throughout the period (Fig. A.1, Appendix 1). Thus, the timing of the survey may provide a suitable opportunity to measure more real individual perceptions and accurate recollections of behavioral changes in reaction to smog episodes, as the survey covered an entire severe pollution period, under which respondents' feelings and experiences about smog pollution were current and ongoing.

Where population information was available for a given urban area, a three-step sampling method was adopted (see Appendix 2). Inclusion criteria included those aged 16 years and over and resident in Nanjing for at least one year. Structured and anonymous interviews were conducted with each individual participant, all of whom provided written informed consent. Researchers and research-trained staff from Nanjing Disease Control and Prevention Center (CDC) conducted the field survey.

After exclusion of incomplete questionnaires and those with missing values and logical errors, valid responses were ultimately obtained from 1141 respondents, an effective response rate of 95.1% (1141/1200). The sample structure is shown in Table 1, with a comparison to the city population structure in parentheses (local income information was unavailable due to data limitation). The sample matched the local population structure closely with respect to gender and age, while respondents' education levels were higher than the average level of the city population. This pattern was also observed by Huang et al. (Huang et al., 2013) in their study of risk perception. This educational bias might be attributed to less well-educated residents experiencing greater difficulty in understanding survey questions and, therefore, returning incomplete questionnaires (Huang et al., 2013).

Table 1
Sample description.

Basic information	Groups	Percentage
Gender	Male	50.0% (51.7%)
	Female	50.0% (48.3%)
Age (years old)	16–34	39.3% (39.9%)
	35–44	23.0% (17.5%)
	45–59	25.2% (20.8%)
	≥ 60	12.5% (13.7%)
Education (years)	≤ 6	11.2% (19.2%)
	6–9	12.1% (29.6%)
	9–12	27.2% (20.8%)
	> 12	49.5% (26.1%)
Income (CNY/month)	0–700	2.3%
	700–1400	6.2%
	1400–5000	67.6%
	5000–10,000	21.3%
	> 10,000	2.6%

The questionnaire was made up of three parts. The first part, consisting of nine questions, addressed individual perceptions of smog pollution and its related health effects, and was designed based on the psychometric paradigm method (Slovic, 1987), which uses scaled questions to measure individual preferences with respect to different risks (Siegrist et al., 2005; Slovic, 1987; Tam and McDaniels, 2013). Each question measured perception levels by asking respondents to provide a score ranging from 1 to 7 for each question (see Table A.1, Appendix 3).

The second part, consisting of ten questions, measured individual behavioral changes during smog pollution episodes. Behavioral change was described using a four-point scale, where 4 represented an increase in behavior, 3 represented no change in behavior, 2 represented reduced behavior, and 1 represented behavior in which the participant never engaged regardless of air pollution levels (“I never do it”). The questions in this section dealt with four behavior categories: (1) concern behaviors, including interest in weather forecasts, causes of smog, and health protection guidelines; (2) normal daily activities, including changes in duration and intensity of outdoor activity and indoor ventilation; (3) additional protective behavior, i.e., wearing professional anti-pollution masks and the use of household air purifiers; and (4) transport patterns, particularly concerning car use.

The third part of the questionnaire, consisting of seven questions, surveyed demographic information and individual self-reported experiences of suffering from air pollution (0 = never experienced, 1 = experienced), as well as health status on the day of the survey (0 = not comfortable, 1 = comfortable).

2.2. Statistical models

Descriptive statistical data are presented here to show general patterns in changes in individual behavior in response to smog pollution episodes. To examine the effects on behavioral responses to smog pollution at the individual level from demographic, perception, self-reported experience and health status variables, we constructed an ordinal logistical regression model. The model used each behavior change status as a dependent variable. In the model, we excluded the samples that selected "I never do it" for a particular behavior to remove the confounding effects on the model results. Perceptions, negative experiences, and health status were treated as potential impact variables for each behavioral change. Moreover, to explore the factors driving individuals to initiate additional protective behaviors during smog episodes, a binary logistic regression model, in which each behavior was converted into a dichotomous variable, was adopted. In this model, wearing a mask or using an air purifier ("I do it" including "increase," "remain unchanged," and "reduce") was defined as "1," and not wearing a mask or using an air purifier ("I never do it") was defined as "0". An explanation of all the model parameters is listed in Table A.2, Appendix 4. P values were used to indicate the significance of effects, and $P < 0.05$ was chosen to indicate statistical significance. Odds ratio was adopted to describe the influence of independent variables on the shift from "0" to "1". All data analysis was conducted using SPSS18.0.

3. Results

Of the 1141 Nanjing respondents surveyed effectively, 50% were female and over 35% were aged over 45 years (Table 1). Overall, the demographics of this sample were representative of the city population in gender and age as referenced from the 2010 census. However, there was a noticeable sampling bias towards respondents with higher education (49.5%) than the general population of Nanjing. Because of this bias, we examined correlations between education level and public perceptions as well as behavioral changes. We found a significantly positive correlation between education level and public perceived concern ($r = 0.187$, $P < 0.0001$), knowledge ($r = 0.209$, $P < 0.0001$), severity ($r = 0.151$, $P < 0.0001$) and acceptance factors ($r = -0.142$, $P < 0.0001$), consistent with previous studies reporting positive associations between education and perception. However, education bias did not show any significant correlation with behavioral change (except for the correlation with concern behaviors ($P < 0.0001$)). Therefore, the higher education bias may influence the perception rating and indicate a higher level of risk perception of local air pollution, and may also lead to a higher proportion of increasing concern behaviors.

3.1. Behavioral responses to hazardous air pollution

Behavioral responses, presented in Table 2, were first separated into two general responses: "I never do it" and "I do it." The latter status included the further subcategories of "my behavior increased," "my behavior remained unchanged," and "my behavior was reduced." During smog episodes, most individuals performed behaviors that demonstrated their increased interest in air pollution ("concern behaviors"), including taking an increased interest in the weather forecast or reading health guidelines: 77.8% of respondents were more concerned with the weather forecast during smog pollution episodes and 83.5% paid more attention to the causes of smog pollution and consulted health protection guidelines during periods of poor air quality.

During smog episodes, more than three quarters of respondents altered their normal daily activities: 85.9% reduced ventilation when indoors (for example, by keeping windows closed), and most also reduced the intensity (85.2%) and strength (85.8%) of outdoor activities. Most respondents (76.4%) increased their use of anti-particulate matter pollutant (anti-PM) masks to block out ambient pollution when outdoors during smog events. However, 84.8% (962 respondents) indicated they have never used air purifiers in the home. In addition, 52.5% of respondents do not change their private vehicle use habits and 30.6% drive more than usual during smog episodes.

3.2. Factors driving behavioral changes

Understanding the driving factors will assist policy makers in identifying how people react to air pollution and in effectively implementing intervention strategies. By category, concern behaviors appear to be influenced by risk perception during smog episodes (Table 3). The possibility of performing concern behaviors increased significantly in individuals with higher perceived concern, including increasing interest in the weather forecast (coefficient = 0.364, $P < 0.001$) and in causes of air pollution (coefficient = 0.241, $P = 0.014$). Respondents with higher income levels (coefficient = 0.448, $P = 0.01$) and female respondents (coefficient = 0.434, $P = 0.02$) showed a higher probability of concern for health protection guidelines.

Changes to normal daily activities were strongly influenced by self-reported experiences of suffering the effects of smog pollution. Respondents who had previously experienced serious air pollution or suffered from its effects were more likely to reduce the duration (coefficient = −0.446, $P = 0.026$) and intensity (coefficient = −0.789, $P < 0.001$) of outdoor activities and to reduce indoor ventilation (coefficient = −0.682, $P = 0.002$). Self-reported negative experiences of air pollution also led to significant increases in the use of both anti-PM masks (coefficient = 0.193, $P = 0.020$) and air purifiers (coefficient = 0.939, $P = 0.014$). During smog episodes, younger residents were more likely than older residents to increase their amount of car use. This was found to be significant in both the 16–34 year age group (coefficient = 0.622, $P = 0.024$) and the 35–44 year age group (coefficient = 0.850, $P = 0.004$).

A binary logistic regression model was used to examine the factors associated with the shift in individual choice from "never take action"

Table 2
Percentages of different behavioral changes.

Behavior category		I never do it	I do it	Behavior status (Percentage)		
		(n)	(n)	Increase (%)	Remain unchanged (%)	Reduce (%)
Concern behaviors	Caring about the weather forecast	38	1099	77.3	22.6	0.1
	Caring about the causes of air pollution	46	1089	83.9	16.1	0
	Caring about health protection guidelines	40	1095	84.5	15.4	0.1
Daily normal behaviors	Changing duration of outdoor activity	71	1069	0.6	14.2	85.2
	Changing intensity of outdoor activity	102	1038	0.4	13.8	85.8
	Changing ventilation in living space	134	1007	3.8	10.3	85.9
Additional protective behaviors	Anti-PM mask use	308	829	76.4	22.7	0.9
	Air purifier use	962	173	61.3	36.4	2.3
Transportation behaviors	Car use	225	891	30.6	52.5	16.8

Table 3
Effects of multi-angle driven factors on behavioral changes analyzed by an ordinal logistic regression model[a].

		Concern		Daily normal behaviors			Additional protective behaviors		Transport pattern
	Weather forecast	Reason for air pollution occurrence	Health protection guidelines	Duration of outdoor activity	Intensity of outdoor activity	Ventilation	Air purifier use	Anti-PM mask use	Car
Perception factors									
Concern	0.364**	0.241*	0.173	− 0.014	− 0.193	0.067	0.052	0.012	0.051
Knowledge	0.299*	0.546**	0.153	0.129	0.173	− 0.122	− 0.044	− 0.125	− 0.005
Familiarity	− 0.057	− 0.025	0.030	− 0.083	0.020	− 0.264	− 0.134	− 0.136	− 0.166
Dread	0.272*	0.181	0.193	0.038	0.139	− 0.118	0.063	0.282*	− 0.208*
Severity of air pollution	− 0.062	0.276	0.059	0.049	− 0.108	− 0.034	− 0.103	0.019	0.069
Severity of health effects	0.198*	0.023	0.098	− 0.262*	− 0.282*	0.013	0.552	0.063	0.168
Controllability	− 0.114	− 0.079	− 0.190	0.105	0.215*	0.180	0.332*	0.107	− 0.060
Acceptance of air pollution	− 0.109	− 0.128	− 0.248*	0.502**	0.442**	0.447**	0.300	− 0.372**	− 0.292*
Acceptance of health effects	− 0.201	− 0.396**	− 0.089	− 0.162	− 0.128	0.076	− 0.132	0.208	0.211
Gender_1(female)	0.073	0.039	0.434*	− 0.074	− 0.398*	− 0.250	0.193	0.303	− 0.044
Age_1 (16–34 years old)	− 0.478	− 0.729	− 0.466	− 0.214	− 0.014	0.451	− 1.519	1.083*	0.622*
Age_2 (35–44 years old)	− 0.336	− 0.669	− 0.319	0.053	0.070	− 0.275	− 0.797	0.471	0.850**
Age_3 (45–59 years old)	− 0.104	− 0.714	− 0.537	0.007	0.097	0.201	− 1.440	0.384	0.617*
Education	0.104	0.053	0.094	− 0.102	− 0.151	− 0.057	0.143	0.055	− 0.043
Income	0.331*	0.392**	0.448**	− 0.112	− 0.184	0.049	− 0.038	0.083	0.117
Health status	− 0.021	0.035	0.092	− 0.250	− 0.177	− 0.168	0.128	0.296**	0.225**
Self-reported experience of smog_1[b]	0.417	0.233	0.030	− 0.446*	− 0.798**	− 0.682**	0.936*	0.193*	0.227

[a] $^{**}P < 0.01$, $^{*}P < 0.05$.
[b] "Self-reported experience of smog_1" represents respondents reporting they have suffered the effects of smog pollution in the last 3 months.

Table 4
Binary logistic regression analysis of driving factors among individuals adopting additional protective behaviors[a].

	Wearing mask_1	Usage of air purifier_1[b]
Perception factors		
Concern	0.103	− 0.149
Knowledge	0.064	0.450**
Familiarity	0.018	0.106
Dread	0.132	− 0.134
Severity of air pollution	0.337**	− 0.144
Severity of health effects	− 0.002	0.337**
Controllability	0.071	0.228**
Acceptance of air pollution	− 0.128	0.149
Acceptance of health effects	0.179	0.001
Gender_1 (female)	1.019**	0.190
Age_1 (16–35 years old)	1.058**	1.575**
Age_2 (35–45 years old)	0.223	1.449**
Age_3 (45–59 years old)	0.723**	1.442**
Education	− 0.087	0.010
Income	0.257	0.315*
Health status	− 0.146	0.082
Self-reported experience of smog pollution	0.548**	− 0.048

[a] $^{**}P < 0.01$, $^{*}P < 0.05$.
[b] Wearing mask_1 represents respondents who wear anti-PM mask during smog episodes; Usage of air purifier_1 represents respondents who use air purifier during smog episodes.

to "take additional protective actions" (Table 4). Higher perception levels ($P < 0.01$), females ($P < 0.01$) and younger groups ($P < 0.01$) showed significantly higher possibilities of behavioral shift.

4. Discussion

As indicated by individual self-reported perception levels (see Fig. A.2, Appendix 5), Nanjing residents believe they are very aware of the extent of air pollution and its related health impacts. This is consistent with an earlier study, which indicated that urban residents already have strong basic knowledge of air pollution due to the dissemination of information through multiple mass media platforms (China Internet Network Information Center, 2016; Liu et al., 2016). A majority of individuals were aware of a range of behavioral changes they could adopt to cope with smog pollution. However, there were clear differences among individual preferences for adopting different categories of behavioral response. Concern behaviors were more easily realized and increased relative to other categories of behavior. This was especially true for concerns about how smog pollution formed and how to protect health. Correct behavioral responses to daily normal activities were also well known and widely performed during smog episodes. In contrast, additional protective behaviors, especially using air purifiers to control indoor air quality, were rarely understood and little performed, indicating poor behavioral response intervention. Furthermore, 83.1% of individuals maintained or even increased car use on smog pollution days, further contributing to air pollution emissions and the generation of more smog (Ellis, 2013).

Supporting the findings of previous studies (Batterman et al., 2005; Ellis, 2013), changes in concern behaviors were mostly affected by individual levels of psychological perception of smog pollution. Individuals with higher perceived concern, greater knowledge of smog pollution, and higher perceptions of health risks were more likely to view air pollution as an unacceptable risk. These individuals, in turn, were more likely to increase their concern behaviors. Effective intervention strategies for encouraging public concern behaviors must address individuals' subjective judgments regarding air pollution and its related health risks. Basic information about smog and its related health risks should be widely communicated and disseminated to increase individual awareness (Liu et al., 2016).

Personal experience of suffering from the effects of air pollution exposure has been identified as an important factor driving individuals to positively change their normal behavioral responses to reduce harmful health effects (Semenza et al., 2008). Previous studies have noted that when people fail to be alarmed about a risk or hazard, they do not take precautions (Karagulian et al., 2015; Zhou and Jerrett, 2014). In contrast, when individuals have been adversely affected by or have suffered ill health as a result of hazardous air pollution, they become more willing to take preventative action to confront air pollution effects, rather than merely becoming more concerned about them. Due to the frequency of large-scale smog pollution events in China caused by higher levels of ambient $PM_{2.5}$, a considerable proportion of the population is exposed and may be affected by the long-term health impacts of smog (Madaniyazi et al., 2015). Increased health protection demands from individuals will trigger urgent requirements for correct, targeted, and detailed protection behavior guidelines.

There are two important policy implications: first, based on the results which show that concern behaviors can increase significantly during pollution episodes, we recommend that governments emphasize behavioral intervention by disseminating information regarding the potential impacts of pollution exposure. This will strengthen public recognition of smog pollution, including possible routes of exposure, risks to individuals with pre-existing diseases, and other vulnerable groups. Second, based on the results showing that not all residents behave effectively in response to smog exposure, we recommend the provision of detailed action guidelines, including advice regarding how to reduce outdoor and indoor exposure, and protective actions for vulnerable individuals. By integrating these two interventions, a greater proportion of individuals may more appropriately adapt their normal daily activities in preparation for and during smog events.

Furthermore, similar to other research, we found that women are more willing to adopt positive behaviors, which may be due in part to their perceived responsibility for protecting family health (Semenza et al., 2008). In our study, over 50% of female respondents indicated they have helped others to protect themselves during smog episodes by providing smog information to relatives (41%), guiding others to adopt protective measures (39%), and showing concern for the health of children and the elderly (73%). Therefore, women could play an important role in promoting family behavioral changes in response to air pollution. We suggest that behavioral interventions by government could include the targeting of information at public places frequently visited by women with caring responsibilities, such as health centers. We also recommend the development of informative literature emphasizing how one can protect children, the elderly and other vulnerable groups.

Driven by individual negative experiences of smog pollution and higher perception levels, individuals may increase their additional protective reactions during serious air pollution episodes (Table 3). However, the adoption of anti-PM masks is a simpler and easier adaptation than using air purifiers. Air purifiers have been demonstrated to be an effective way to reduce indoor exposure (Batterman et al., 2005) and lead to considerable health benefits (Chen et al., 2015). They do not require installation and are easy to operate. The price of air purifiers in China ranges from dozens to hundreds of dollars, varying according to the size of the house, function and brand, so air purifiers are feasible and affordable (Xu, 2013). However, according to our results, most surveyed residents never use household air purifiers. In addition to the non-significant influence of income (see Appendix 6), low air purifier usage may result from individuals not fully understanding their effectiveness or overlooking the necessity of controlling indoor exposure to air pollution. Because outdoor ambient pollutants can enter indoor areas (Ji and Zhao, 2015) and because urban Chinese residents spend on average over 80% of their time indoors (Wang et al., 2015), there may be considerable indoor exposure in the absence of effective indoor air quality control. Since reducing ventilation by closing doors and windows does little to reduce indoor pollution concentration (Chen et al., 2015), improving individual knowledge of indoor air pollution is critical, as is advising individuals to adopt more effective indoor protection behaviors. Therefore, we recommend the promotion of detailed indoor behavior guidelines, which especially encourage the adoption of efficient household air purifiers.

Our results suggest there is no outstanding single factor driving change in car use behavior. Results provided some evidence that younger people may increase their car use during smog pollution episodes, even though this contributes to further air pollution emissions. Vehicle-related emissions are a critical contributor to ambient air pollution at the global scale (Karagulian et al., 2015), including in Chinese megacities (Chan and Yao, 2008; Karagulian et al., 2015; Pui et al., 2014). Increased car use by individuals during pollution episodes may worsen the adverse conditions, posing a conflict between air pollution adaptation and mitigation. Interventions directed to reduce car use and increase low-emission public transport in metropolitan areas can effectively produce important health benefits (Rojas-Rueda et al., 2012; Xia et al., 2015).

There are three possible avenues for transportation behavior intervention. First, adaptation and mitigation messages must be delivered at the same time. The simultaneous presentation of these two messages should help individuals to appropriately balance adaptive and mitigating behaviors. This may increase the likelihood that people will not only see the importance of avoiding air pollution in their daily lives but also help them develop a perception of themselves as part of the solution. Second, to encourage individuals to drive less, it is important that policymakers strengthen and encourage the use of low-emission public transport. Third, as the current study suggests no car use reduction or even increased car use during smog episodes, policy makers may need to develop a traffic control strategy to reduce car use during serious pollution events (Pui et al., 2014; Shapiro et al., 2002). In December 2015, Beijing city government declared its first ever "red alert" warning—the highest level of air pollution warning for that city (Zhang, 2015). During the red alert period, strict rules to limit car use were imposed. Based on registration plate numbers, certain cars were not allowed to travel within the city.

Consequently, the number of cars in use during that pollution episode was successfully controlled, significantly reducing daily pollutant emissions by 36% and $PM_{2.5}$ concentrations by 11–21% (Zhang, 2015; Zheng et al., 2015). In these ways, policy makers may achieve the combined benefit of controlling air quality and improving public health.

In summary, the current work suggests that individual behavior changes during smog episodes may be driven by integrated factors. Policy makers, therefore, should use a variety of methods to prompt individual action, including strengthening individual perceptions of air pollution and facilitating the adoption of practices to cope with air pollution. In China today, public awareness of behavioral change in urban areas is still not sufficient to increase protective action during pollution episodes. Therefore, adequate behavioral guidelines and targeted interventions are needed to encourage people to reduce exposure, adapt to air pollution, and mitigate further pollution.

The higher education level bias may limit this study as it may indicate higher perception ratings than actually exist among the general public. The possible influence of higher educational attainment on increasing concern behaviors may not be as broad as the survey suggests. However, this limitation seems common and acceptable considering that respondents with more education are more likely to take the survey.

5. Conclusions

The overall objective of this study was to provide a scientifically credible analysis of current behavioral responses to smog pollution and the factors driving these responses among urban Chinese residents. Our results will help policy makers better understand individual responses and adaptations to air pollution events as well as identify possible ways to achieve the implementation of effective behavioral interventions. We initially examined multiple driving factors affecting different behavioral responses, and a greater understanding of these should help decision makers both in China and elsewhere to provide appropriate public behavior interventions and reduce the health risks associated with air pollution.

Author contribution

J. B., Y. Z., and T. L. designed the survey. L. Z. performed the survey and collected the data. J. B. analyzed the data and composed the paper. All authors contributed to the interpretation of results. J. B. and L. Z. are co-first authors due to their equal contribution to this study.

Conflict of interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (Grant: 21277135, 91543111).

Appendix 1

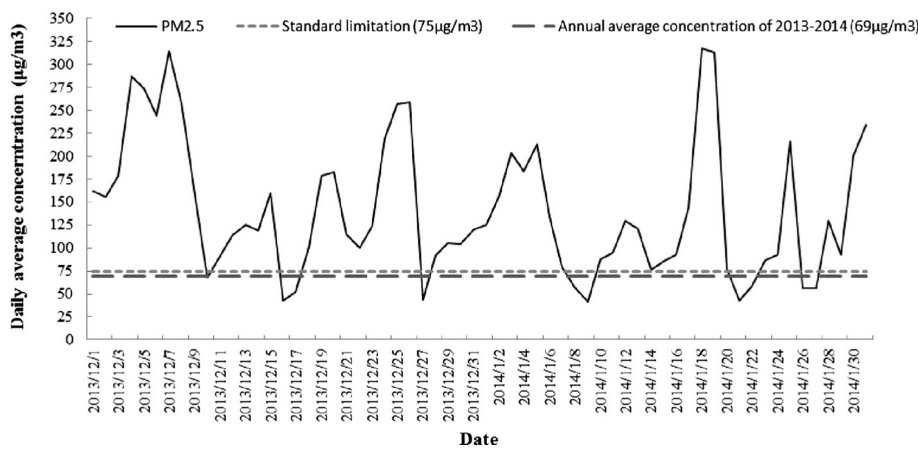

Fig. A.1. Daily average concentration of $PM_{2.5}$ in Nanjing during survey period (the short dotted line is the national standard concentration limit); the concentration exceeded the limit on 52 days, a rate of 83.8%. The long dotted line is the annual average concentration of $PM_{2.5}$ from January 2013 to December 2014 (69 μg/m^3); the average concentration during the survey period (142 μg/m^3) was more than two times the annual average concentration.

Appendix 2

Sampling method

Considering the total population and possible attrition bias, an investigation such as this should cover at least 1100 individuals. With an average of 3 residents per household, 400 households were required. Where population information was available in the urban areas sampled, a three-step sampling method was used. First, a district within the city was selected and all communities over 10,000 residents within this district served as the primary sample units based on probabilities proportional to population size (PPS). In the second step, one such community was randomly selected, and 400 households within this community were in turn selected using a simple random sampling method (SRS). A table containing all the household IDs was built using SRS, and then a series of random numbers were generated to select one household; the other 399 households were selected by using equal interval numbers based on the starting household ID. In the third step, from each household, residents over 16 years of age who were able to independently complete the questionnaire were asked to do so. If the selected respondent did not meet these criteria, the household was replaced with another nearby household and another person was selected using a KISH table.

Appendix 3

Table A.1
Question design and definition of risk characteristics.

Questions	Perception factor	Value
1. In your opinion, how aware are you of the risk associated with smog?	Knowledge	1–7[a]
2. In your opinion, is the risk associated with haze a familiar risk or an unfamiliar risk?	Familiarity	1–7[b]
3. In your opinion, are you concerned about the risk associated with smog?	Concern	1–7[c]
4. In your opinion, is smog serious?	Severity	1–7[d]
5. In your opinion, is the health risk associated with smog serious?	Severity	1–7[e]
6. In your opinion, how do you fear the risk associated with smog?	Dread	1–7[f]
7. In your opinion, to what degree can you avoid the risk associated with smog?	Controllability	1–7[g]
8. In your opinion, to what degree can you accept the risk caused by smog?	Acceptance	1–7[h]

[a] Scale ranges from 1 = Unknown to 7 = High level of knowledge.
[b] Scale ranges from1 = Not familiar at all to 7 = Very familiar.
[c] Scale ranges from 1 = Not concerned at all to 7 = Very concerned.
[d] Scale ranges from 1 = Not serious at all to 7 = Very serious.
[e] Scale ranges from 1 = Not serious at all to 7 = Very serious.
[f] Scale ranges from 1 = No dread at all to 7 = Complete dread.
[g] Scale ranges from 1 = Not controllable at all to 7 = Completely controllable.
[h] Scale ranges from 1 = Not acceptable at all to 7 = Very acceptable

Appendix 4

Table A2
Description of the modeling parameters.

	Models	Variables	Description
Dependent variables	For ordinal logistic regression model	Concern behaviors Daily normal behaviors Additional protective behaviors Transportation behaviors	3-point scale variable, ranging from the behavior is reduced = 1, the behavior is unchanged = 2, the behavior is increased = 3
	For binary logistic regression model	Air purifier usage	Dichotomous variable, representing whether respondent uses air purifiers during smog episodes; (Yes = 1; No = 0).
		Anti-PM mask usage	Dichotomous variable, representing whether respondent uses anti-PM masks during smog episodes; (Yes = 1; No = 0).
Independent variables	For both models	Gender	Dichotomous variable, representing the gender of respondent; (male = 1; female = 0).
		Age	Categorical variable, 16–34 years old = 1; 35–44 years old = 2; 45–59 years old = 3; over 60 years old = 4.
		Education	Continuous variable, representing the educational level of respondent (years).
		Income	Categorical variable, representing the annual income of the family (RMB/yr); (under 1400 RMB = 1; under 10,000 RMB = 2; > 10,000 RMB = 3).
		Health status	7-point scale variable, representing respondent health status on the survey day (ranging from very uncomfortable = 1 to very comfortable = 7)
		Self-reported experience of smog pollution	Dichotomous variable, representing whether respondent has experience of suffering from smog pollution in the last 3 month (Yes = 1; No = 2).
		Perception factors	Continuous variables representing self-reported perception of different aspects, including perceived concern, knowledge, familiarity, dread, severity, controllability, and acceptance of local air pollution.

Appendix 5

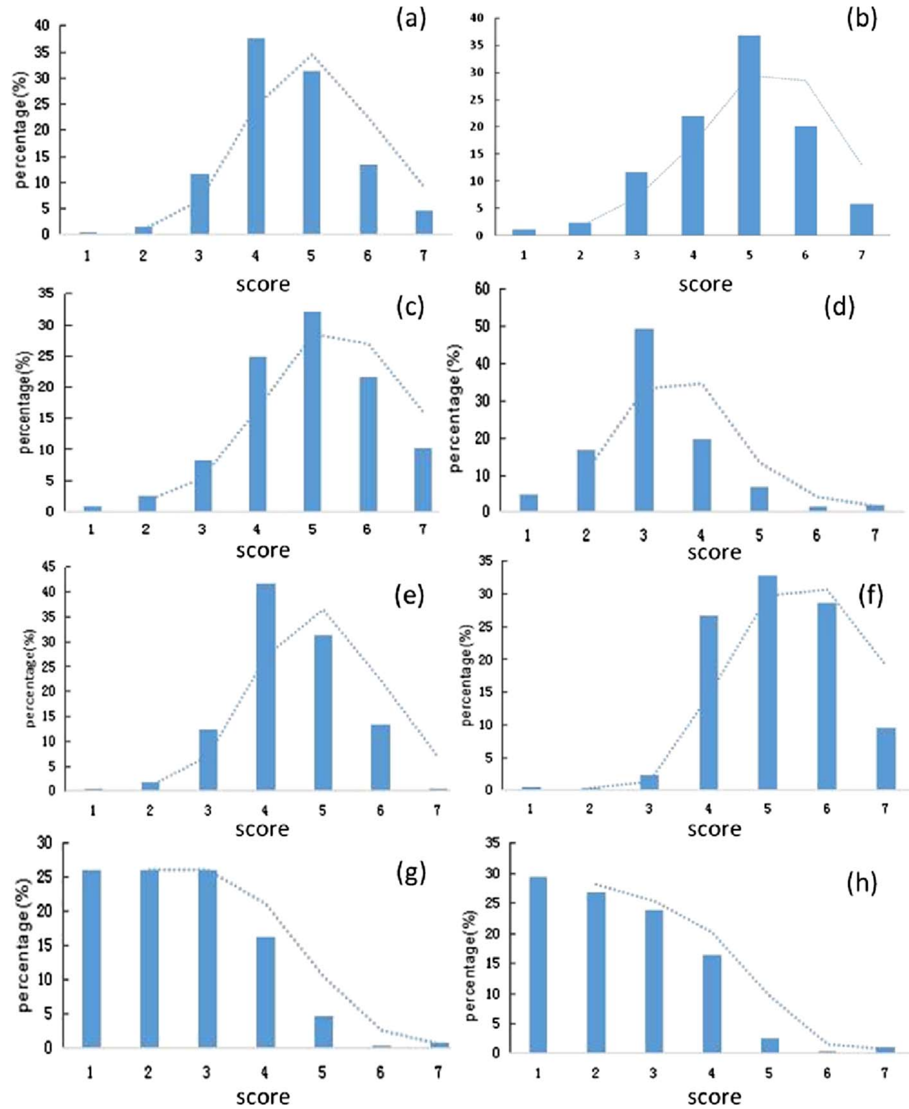

Fig. A.2. Individual perception levels. (a) Perceived knowledge (1 = know little about smog, 7 = know a great deal about smog); (b) Perceived familiarity (1 = not familiar with smog at all, 7 = very familiar with smog); (c) Perceived concern (1 = little concerned with smog, 7 = very concerned with smog); (d) Perceived controllability (1 = could not be avoided at all, 7 = could be avoided easily); (e) Perceived severity of smog air pollution (1 = not serious at all, 7 = very serious); (f) Perceived severity of related health risk (1 = not serious at all, 7 = very serious); (g) Perceived acceptance of smog air pollution (1 = unacceptable at all, 7 = very acceptable); and (h) Perceived acceptance of related health risk (1 = unacceptable at all, 7 = very acceptable).

Appendix 6

Table A3
Results of Chi-square test for individual changes in air purifier usage for different income groups.

	Increase	Remain unchanged	Reduce	Never use air purifier	χ^2 (P value)
< 700	4.0%	8.0%	0%	88.0%	19.03
700–1400	2.9%	1.4%	0%	95.7%	(0.088)
1400–5000	9.0%	5.6%	0.3%	85.2%	
5000–10,000	12.1%	5.6%	0.4%	81.9%	
≥ 10,000	10.3%	10.3%	3.4%	75.9%	

References

Batterman, S., Godwin, C., Jia, C., 2005. Long duration tests of room air filters in cigarette smokers' homes. Environ. Sci. Technol. 39, 7260–7268.
Chan, C.K., Yao, X., 2008. Air pollution in mega cities in China. Atmos. Environ. 42, 1–42. http://dx.doi.org/10.1016/j.atmosenv.2007.09.003.
Chen, R., Zhao, A., Chen, H., Zhao, Z., Cai, J., Wang, C., Yang, C., Li, H., Xu, X., Ha, S., Li,

T., Kan, H., 2015. Cardiopulmonary benefits of reducing indoor particles of outdoor origin: a randomized, double-blind crossover trial of air purifiers. J. Am. Coll. Cardiol. 65, 2279–2287. http://dx.doi.org/10.1016/j.jacc.2015.03.553.

China Internet Network Information Center, 2016. The 38th statistical report on internet development in China. Available at: http://wwwcnniccn/hlwfzyj/hlwxzbg/hlwtjbg/201608/P020160803367337470363.pdf (Accessed on Dec 15th 2016).

Elias, W., Shiftan, Y., 2012. The influence of individual's risk perception and attitudes on travel behavior. Transp. Res. A Policy Pract. 46, 1241–1251. http://dx.doi.org/10.1016/j.tra.2012.05.013.

Ellis, J.H., 2013. Implications of climate change for regional air pollution, health effects and energy consumption behavior. Eur. J. Med. Chem. 66, 438–449.

Garvill, J., Marell, A., Nordlund, A., 2003. Effects of increased awareness on choice of travel mode. Transportation 30, 63–79. http://dx.doi.org/10.1023/A:1021286608889.

Giles, L.V., Barn, P., Künzli, N., Romieu, I., Mittleman, M.A., van Eeden, S., Allen, R., Carlsten, C., Stieb, D., Noonan, C., Smargiassi, A., Kaufman, J.D., Hajat, S., Kosatsky, T., Brauer, M., 2011. From good intentions to proven interventions: effectiveness of actions to reduce the health impacts of air pollution. Environ. Health Perspect. 119, 29–36. http://dx.doi.org/10.1289/ehp.1002246.

Huang, L., Zhou, Y., Han, Y., Hammitt, J.K., Bi, J., Liu, Y., 2013. Effect of the Fukushima nuclear accident on the risk perception of residents near a nuclear power plant in China. Proc. Natl. Acad. Sci. U. S. A. 110, 19742–19747. http://dx.doi.org/10.1073/pnas.1313825110.

Ji, W., Zhao, B., 2015. Estimating mortality derived from indoor exposure to particles of outdoor origin. PLoS One 10. http://dx.doi.org/10.1371/journal.pone.0124238.

Karagulian, F., Belis, C.A., Dora, C.F.C., Prüss-Ustün, A.M., Bonjour, S., Adair-Rohani, H., Amann, M., 2015. Contributions to cities' ambient particulate matter (PM): a systematic review of local source contributions at global level. Atmos. Environ. 120, 475–483. http://dx.doi.org/10.1016/j.atmosenv.2015.08.087.

Laumbach, R., Meng, Q., Kipen, H., 2015. What can individuals do to reduce personal health risks from air pollution? J. Thorac. Dis. 7, 96.

Liao, X., Tu, H., Maddock, J.E., Fan, S., Lan, G., Wu, Y., Yuan, Z.K., Lu, Y., 2015. Residents' perception of air quality, pollution sources, and air pollution control in Nanchang, China. Atmos. Pollut. Res. 6, 835–841. http://dx.doi.org/10.5094/APR.2015.092.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., AlMazroa, M.A., Amann, M., Anderson, H.R., Andrews, K.G., Aryee, M., Atkinson, C., Bacchus, L.J., Bahalim, A.N., Balakrishnan, K., Balmes, J., Barker-Collo, S., Baxter, A., Bell, M.L., Blore, J.D., Blyth, F., Bonner, C., Borges, G., Bourne, R., Boussinesq, M., Brauer, M., Brooks, P., Bruce, N.G., Brunekreef, B., Bryan-Hancock, C., Bucello, C., Buchbinder, R., Bull, F., Burnett, R.T., Byers, T.E., Calabria, B., Carapetis, J., Carnahan, E., Chafe, Z., Charlson, F., Chen, H., Chen, J.S., Cheng, A.T.-A., Child, J.C., Cohen, A., Colson, K.E., Cowie, B.C., Darby, S., Darling, S., Davis, A., Degenhardt, L., Dentener, F., Des Jarlais, D.C., Devries, K., Dherani, M., Ding, E.L., Dorsey, E.R., Driscoll, T., Edmond, K., Ali, S.E., Engell, R.E., Erwin, P.J., Fahimi, S., Falder, G., Farzadfar, F., Ferrari, A., Finucane, M.M., Flaxman, S., Fowkes, F.G.R., Freedman, G., Freeman, M.K., Gakidou, E., Ghosh, S., Giovannucci, E., Gmel, G., Graham, K., Grainger, R., Grant, B., Gunnell, D., Gutierrez, H.R., Hall, W., Hoek, H.W., Hogan, A., Hosgood III, H.D., Hoy, D., Hu, H., Hubbell, B.J., Hutchings, S.J., Ibeanusi, S.E., Jacklyn, G.L., Jasrasaria, R., Jonas, J.B., Kan, H., Kanis, J.A., Kassebaum, N., Kawakami, N., Khang, Y.-H., Khatibzadeh, S., Khoo, J.-P., Kok, C., Laden, F., Lalloo, R., Lan, Q., Lathlean, T., Leasher, J.L., Leigh, J., Li, Y., Lin, J.K., Lipshultz, S.E., London, S., Lozano, R., Lu, Y., Mak, J., Malekzadeh, R., Mallinger, L., Marcenes, W., March, L., Marks, R., Martin, R., McGale, P., McGrath, J., Mehta, S., Memish, Z.A., Mensah, G.A., Merriman, T.R., Micha, R., Michaud, C., Mishra, V., Hanafiah, K.M., Mokdad, A.A., Morawska, L., Mozaffarian, D., Murphy, T., Naghavi, M., Neal, B., Nelson, P.K., Nolla, J.M., Norman, R., Olives, C., Omer, S.B., Orchard, J., Osborne, R., Ostro, B., Page, A., Pandey, K.D., Parry, C.D., Passmore, E., Patra, J., Pearce, N., Pelizzari, P.M., Petzold, M., Phillips, M.R., Pope, D., Pope III, C.A., Powles, J., Rao, M., Razavi, H., Rehfuess, E.A., Rehm, J.T., Ritz, B., Rivara, F.P., Roberts, T., Robinson, C., Rodriguez-Portales, J.A., Romieu, I., Room, R., Rosenfeld, L.C., Roy, A., Rushton, L., Salomon, J.A., Sampson, U., Sanchez-Riera, L., Sanman, E., Sapkota, A., Seedat, S., Shi, P., Shield, K., Shivakoti, R., Singh, G.M., Sleet, D.A., Smith, E., Smith, K.R., Stapelberg, N.J., Steenland, K., Stöckl, H., Stovner, L.J., Straif, K., Straney, L., Thurston, G.D., Tran, J.H., Van Dingenen, R., van Donkelaar, A., Veerman, J.L., Vijayakumar, L., Weintraub, R., Weissman, M.M., White, R.A., Whiteford, H., Wiersma, S.T., Wilkinson, J.D., Williams, H.C., Williams, W., Wilson, N., Woolf, A.D., Yip, P., Zielinski, J.M., Lopez, A.D., Murray, C.J., Ezzati, M., 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. Lancet 380, 2224–2260. http://dx.doi.org/10.1016/S0140-6736(12)61766-8.

Liobikienė, G., Juknys, R., 2016. The role of values, environmental risk perception, awareness of consequences, and willingness to assume responsibility for environmentally-friendly behaviour: the Lithuanian case. J. Clean. Prod. 112 (Part 4), 3413–3422. http://dx.doi.org/10.1016/j.jclepro.2015.10.049.

Liu, J., Diamond, J., 2005. China's environment in a globalizing world. Nature 435, 1179–1186. http://dx.doi.org/10.1038/4351179a.

Liu, X., Zhu, H., Hu, Y., Feng, S., Chu, Y., Wu, Y., Wang, C., Zhang, Y., Yuan, Z., Lu, Y., 2016. Public's health risk awareness on urban air pollution in Chinese megacities: the cases of Shanghai, Wuhan and Nanchang. Int. J. Environ. Res. Public Health 13. http://dx.doi.org/10.3390/ijerph13090845.

Madaniyazi, L., Nagashima, T., Guo, Y., Yu, W., Tong, S., 2015. Projecting fine particulate matter-related mortality in East China. Environ. Sci. Technol. 49, 11141–11150. http://dx.doi.org/10.1021/acs.est.5b01478.

Nanjing Environmental Protection Agency, 2014. Annual Environment Report 2013. Nanjing Environmental Protection Agency, Nanjing.

Pui, D.Y.H., Chen, S.-C., Zuo, Z., 2014. PM2.5 in China: measurements, sources, visibility and health effects, and mitigation. Particuology 13, 1–26. http://dx.doi.org/10.1016/j.partic.2013.11.001.

Rajagopalan, S., Brook, R.D., 2015. Personalizing your airspace and your health. J. Am. Coll. Cardiol. 65, 2288–2290. http://dx.doi.org/10.1016/j.jacc.2015.04.010.

Rojas-Rueda, D., de Nazelle, A., Teixidó, O., Nieuwenhuijsen, M.J., 2012. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: a health impact assessment study. Environ. Int. 49, 100–109. http://dx.doi.org/10.1016/j.envint.2012.08.009.

Semenza, J.C., Wilson, D.J., Parra, J., Bontempo, B.D., Hart, M., Sailor, D.J., George, L.A., 2008. Public perception and behavior change in relationship to hot weather and air pollution. Environ. Res. 107, 401–411. http://dx.doi.org/10.1016/j.envres.2008.03.005.

Shapiro, R.J., Hassett, K.A., Arnold, F.S., 2002. Conserving energy and preserving the environment: the role of public transportation. Available at: http://www.fypower.org/pdf/RES171664_shapiro.pdf (Accessed on Dec 15th 2016).

Siegrist, M., Keller, C., Kiers, H.A.L., 2005. A new look at the psychometric paradigm of perception of hazards. Risk Anal. 25, 211–222. http://dx.doi.org/10.1111/j.0272-4332.2005.00580.x.

Slovic, P., 1987. Perception of risk. Science 236, 280–285.

Tam, J., McDaniels, T.L., 2013. Understanding individual risk perceptions and preferences for climate change adaptations in biological conservation. Environ. Sci. Pol. 27, 114–123. http://dx.doi.org/10.1016/j.envsci.2012.12.004.

Tanaka, S., 2015. Environmental regulations on air pollution in China and their impact on infant mortality. J. Health Econ. 42, 90–103. http://dx.doi.org/10.1016/j.jhealeco.2015.02.004.

Wang, B., Cao, S., Ma, J., Huang, N., Nie, J., Wang, Z., Duan, X., 2015. 5 - time-activity factors related to air exposure. In: Duan, X., Zhao, X., Wang, B., Chen, Y., Cao, S. (Eds.), Highlights of the Chinese Exposure Factors Handbook. Academic Press, pp. 31–39.

Wang, S., Xing, J., Zhao, B., Jang, C., Hao, J., 2014. Effectiveness of national air pollution control policies on the air quality in metropolitan areas of China. J. Environ. Sci. 26, 13–22. http://dx.doi.org/10.1016/S1001-0742(13)60381-2.

Xia, T., Nitschke, M., Zhang, Y., Shah, P., Crabb, S., Hansen, A., 2015. Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. Environ. Int. 74, 281–290. http://dx.doi.org/10.1016/j.envint.2014.10.004.

Xu, H., 2013. Concerns to health and $PM_{2.5}$—indoor air contamination and correct selection of house air cleaner. Contam. Control Air Cond. Technol. 2, 111–116.

Zhang, L., Yuan, Z., Maddock, J.E., Zhang, P., Jiang, Z., Lee, T., Zou, J., Lu, Y., 2014. Air quality and environmental protection concerns among residents in Nanchang, China. Air Qual. Atmos. Health 7, 441–448. http://dx.doi.org/10.1007/s11869-014-0255-x.

Zhang, W., 2015. Red alert last for 53 hours in Beijing. China Econ. Wkly 28–29.

Zheng, G.J., Duan, F.K., Su, H., Ma, Y.L., Cheng, Y., Zheng, B., Zhang, Q., Huang, T., Kimoto, T., Chang, D., Pöschl, U., Cheng, Y.F., He, K.B., 2015. Exploring the severe winter haze in Beijing: the impact of synoptic weather, regional transport and heterogeneous reactions. Atmos. Chem. Phys. 15, 2969–2983. http://dx.doi.org/10.5194/acp-15-2969-2015.

Zhou, M., Wang, H., Zhu, J., Chen, W., Wang, L., Liu, S., Li, Y., Wang, L., Liu, Y., Yin, P., Liu, J., Yu, S., Tan, F., Barber, R.M., Coates, M.M., Dicker, D., Fraser, M., González-Medina, D., Hamavid, H., Hao, Y., Hu, G., Jiang, G., Kan, H., Lopez, A.D., Phillips, M.R., She, J., Vos, T., Wan, X., Xu, G., Yan, L.L., Yu, C., Zhao, Y., Zheng, Y., Zou, X., Naghavi, M., Wang, Y., Murray, C.J.L., Yang, G., Liang, X., 2016. Cause-specific mortality for 240 causes in China during 1990–2013: a systematic subnational analysis for the global burden of disease study 2013. Lancet 387, 251–272. http://dx.doi.org/10.1016/S0140-6736(15)00551-6.

Zhou, Y., Jerrett, M., 2014. Linking exposure and health in environmental public health tracking. Environ. Res. 134, 453. http://dx.doi.org/10.1016/j.envres.2014.08.001.