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► **To cite this version:**

Emilie Burte, Bénédicte Leynaert, Roberto Bono, Bert Brunekreef, Jean Bousquet, et al.. Association between air pollution and rhinitis incidence in two European cohorts. *Environment International*, 2018, 115, pp.257 - 266. 10.1016/j.envint.2018.03.021 . inserm-01814823

**HAL Id: inserm-01814823**

**<https://inserm.hal.science/inserm-01814823v1>**

Submitted on 13 Jun 2018

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# 1 Association between air pollution and rhinitis incidence in two European cohorts

2  
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6 Mark<sup>3,4,9,10</sup>, Pin Isabelle<sup>20,21</sup>, Stempfelet Morgane<sup>22</sup>, Sunyer Jordi<sup>3,4,9,10</sup>, Villani Simona<sup>23</sup>,  
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8

## 9 Acknowledgment and Funding:

### Funding:

10 ECRHS was supported by the European Commission, as part of their Quality of Life program.

11 The coordination of ECRHS II was supported by the European Commission, as part of their Quality of  
12 Life program.

13 The following bodies funded the local studies in ECRHS II in this article: **Albacete**-Fondo de  
14 Investigaciones Santarias (grant code: 97/0035-01, 13 99/0034-01, and 99/0034-02), Hospital  
15 Universitario de Albacete, Consejería de Sanidad. **Antwerp**-FWO (Fund for Scientific Research)-  
16 Flanders Belgium (grant code: G.0402.00), University of Antwerp, Flemish Health Ministry.  
17 **Barcelona**-Fondo de Investigaciones Sanitarias (grant code: 99/0034- 01, and 99/0034-02), Red  
18 Respira (RTIC 03/11 ISC IIF). Ciber of Epidemiology and Public Health has been established and  
19 founded by Instituto de Salud Carlos III. **Erfurt**-GSF–National Research Centre for Environment &  
20 Health, Deutsche Forschungsgemeinschaft (DFG) (grant code FR 1526/1-1). **Galdakao**-Basque  
21 Health Department. **Grenoble**-Programme Hospitalier de Recherche Clinique-DRC de Grenoble 2000  
22 no.2610, Ministry of Health, Direction de la Recherche Clinique, Ministère de l’Emploi et de la  
23 Solidarité, Direction Générale de la Santé, CHU de Grenoble, Comité des Maladies Respiratoires de  
24 l’Isère. **Ipswich and Norwich** National Asthma Campaign (UK). **Huelva**-Fondo de Investigaciones  
25 Santarias (FIS) (grant code: 97/0035-01, 99/0034-01, and 99/0034-02). **Oviedo**-Fondo de  
26 Investigaciones Santarias (FIS) (grant code: 97/0035-01, 99/0034-01, and 99/0034-02). **Paris**-  
27 Ministère de l’Emploi et de la Solidarité, Direction Générale de la Santé, UCBPharma (France),  
28 Aventis (France), Glaxo France, Programme Hospitalier de Recherche Clinique-DRC de Grenoble  
29 2000 no. 2610, Ministry of Health, Direction de la Recherche Clinique, CHU de Grenoble. **Pavia**-  
30 Glaxo, Smith & Kline Italy, Italian Ministry of University and Scientific and Technological Research  
31 3 (MURST), Local University Funding for Research 1998 & 1999 (Pavia, Italy). **Turin**-ASL 4  
32 Regione Piemonte (Italy), AO CTO/ICORMA Regione Piemonte (Italy), Ministero dell’Università e  
33 della Ricerca Scientifica (Italy), Glaxo Wellcome spa (Verona, Italy). **Umeå**- Swedish Heart Lung  
34 Foundation, Swedish Foundation for Health Care Sciences & Allergy Research, Swedish Asthma &  
35 Allergy Foundation, Swedish Cancer & Allergy Foundation. **Verona**-University of Verona; Italian  
36 Ministry of University and Scientific and Technological Research (MURST); Glaxo, Smith & Kline  
37 Italy.

38  
39 EGEA is funded in part by PHRC-Paris, PHRC-Grenoble, ANR 05-SEST-020-02/05-9-97, ANR-06-  
40 CEBS, ANR-CES-2009, Région Nord Pas-de-Calais, Merck Sharp & Dohme (MSD)

41  
42 Acknowledgment:

#### 43 ECRHS

44 The ECRHS data incorporated in this analysis would not have been available without the collaboration  
45 of the following individuals and their research teams:

46 **ECRHS Co-ordinating centre:** P Burney, D Jarvis, S Chinn, J Knox (ECRHS II), C Luczynska+ , J  
47 Potts.

48 **Steering Committee for ECRHS II:** P Burney, D Jarvis, S Chinn, J.M Anto, I.Cerveri, R.deMarco ,  
49 T.Gislason, J.Heinrich, C. Janson, N. Kunzli, B. Leynaert, F. Neukirch, T. Rochat, J. Schouten, J.  
50 Sunyer; C. Svanes, P. Vermeire+ , M. Wjst.  
51 **Principal Investigators and Senior Scientific Teams for ECRHS II:** Australia: Melbourne (M  
52 Abramson, R Woods, EH Walters, F Thien), Belgium: South Antwerp & Antwerp City (P Vermeire+ ,  
53 J Weyler, M Van Sprundel, V Nelen), Denmark: Aarhus (EJ Jensen), Estonia: Tartu (R Jogi, A Soon),  
54 France: Paris (F Neukirch, B Leynaert, R Liard, M Zureik), Grenoble (I Pin, J Ferran-Quentin),  
55 Bordeaux (A Taytard, C Raheison), Montpellier (J Bousquet, P Demoly)Germany: Erfurt (J Heinrich,  
56 M Wjst, C Frye, I Meyer) Hamburg (K Richter),Iceland: Reykjavik (T Gislason, E Bjornsson, D  
57 Gislason, T Blondal, A Karlsdottir), Italy: Turin (M Bugiani, R Bono, P Piccioni, E Caria, A Carosso,  
58 E Migliore, G Castiglioni), Verona (R de 5 Marco, G Verlato, E Zanolin, S Accordini, A Poli, V Lo  
59 Cascio, M Ferrari), Pavia (A Marinoni, S Villani, M Ponzio, F Frigerio, M Comelli, M Grassi, I  
60 Cerveri, A Corsico),Netherlands: Groningen & Geleen (J Schouten, M Kerkhof), Norway: Bergen (A  
61 Gulsvik, E Omenaas, C Svanes, B Laerum), Spain: Barcelona (JM Anto, J Sunyer, M Kogevinas, JP  
62 Zock, X Basagana, A Jaen, F Burgos), Huelva (J Maldonado, A Pereira, JL Sanchez), Albacete (J  
63 MartinezMoratalla Rovira, E Almar), Galdakao (N Muniozguren, I Urritia), Oviedo (F Payo), Sweden:  
64 Uppsala (C Janson, G Boman, D Norback, M Gunnbjornsdottir), Goteborg (K Toren, L Lillienberg,  
65 AC Olin, B Balder, A Pfeifer-Nilsson, R Sundberg), Umea (E Norrman, M Soderberg, K Franklin, B  
66 Lundback, B Forsberg, L Nystrom),Switzerland: Basel (N Kunzli, B Dibbert, M Hazenkamp, M  
67 Brutsche, U Ackermann-Liebrich); UK: Norwich (D Jarvis, B Harrison), Ipswich (D Jarvis, R Hall, D  
68 Seaton), USA: Portland (M Osborne, S Buist, W Vollmer, L Johnson)

69

#### 70 EGEA:

71 **Coordination:** V Siroux (epidemiology, PI since 2013); F Demenais (genetics); I Pin (clinical  
72 aspects); R Nadif (biology); F Kauffmann (PI 1992-2012). **Respiratory epidemiology:** Inserm U 700,  
73 Paris: M Korobaëff (Egea1), F Neukirch (Egea1); Inserm U 707, Paris: I Annesi-Maesano (Egea1-2);  
74 Inserm CESP/U 1018, Villejuif: F Kauffmann, N Le Moual, R Nadif, MP Oryszczyn (Egea1-2), R  
75 Varraso; Inserm U 823, Grenoble: V Siroux. **Genetics:** Inserm U 393, Paris: J Feingold; Inserm U  
76 946, Paris: E Bouzigon, F Demenais, MH Dizier; CNG, Evry: I Gut (now CNAG, Barcelona, Spain),  
77 M Lathrop (now Univ McGill, Montreal, Canada). Clinical centers: Grenoble: I Pin, C Pison; Lyon: D  
78 Ecochard (Egea1), F Gormand, Y Pacheco; Marseille: D Charpin (Egea1), D Vervloet (Egea1-2);  
79 Montpellier: J Bousquet; Paris Cochin: A Lockhart (Egea1), R Matran (now in Lille); Paris Necker: E  
80 Paty (Egea1-2), P Scheinmann (Egea1-2); 6 Paris-Trousseau: A Grimfeld (Egea1-2), J Just. **Data and**  
81 **quality management:** Inserm exU155 (Egea1): J Hochez; Inserm CESP/U 1018, Villejuif: N Le  
82 Moual; Inserm ex-U780: C Ravault (Egea1-2); Inserm ex-U794: N Chateigner (Egea1-2); Grenoble: J  
83 Quentin-Ferran (Egea1-2).

84

85 Valerie Siroux has received speaker honorarium from TEVA, AstraZeneca and Novartis-France,  
86 outside the submitted work. No other relevant disclosure.

87

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94

95 **Short running title: Air pollution and incident rhinitis**

96 **Manuscript word count: 4243**

97 **Abstract word count: 220**

Abstract:

98 Background: The association between air pollution and rhinitis is not well established.

99 Aim: The aim of this longitudinal analysis was to study the association between modeled air  
100 pollution at the subjects' home addresses and self-reported incidence of rhinitis.

101 Methods: We used data from 1533 adults from two multicentre cohorts' studies (EGEA and  
102 ECRHS). Rhinitis incidence was defined as reporting rhinitis at the second follow-up (2011 to  
103 2013) but not at the first follow-up (2000 to 2007). Annual exposure to NO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub>  
104 at the participants' home addresses was estimated using land-use regression models developed  
105 by the ESCAPE project for the 2009-2010 period. Incidence rate ratios (IRR) were computed  
106 using Poisson regression. Pooled analysis, analyses by city and meta-regression testing for  
107 heterogeneity were carried out.

108 Results: No association between long-term air pollution exposure and incidence of rhinitis  
109 was found (adjusted IRR (aIRR) for an increase of 10 µg.m<sup>-3</sup> of NO<sub>2</sub>: 1.00[0.91-1.09], for an  
110 increase of 5µg.m<sup>-3</sup> of PM<sub>2.5</sub>: 0.88[0.73-1.04]). Similar results were found in the two-  
111 pollutant model (aIRR for an increase of 10 µg.m<sup>-3</sup> of NO<sub>2</sub>: 1.01[0.87-1.17], for an increase of  
112 5µg.m<sup>-3</sup> of PM<sub>2.5</sub>: 0.87[0.68-1.08]). Results differed depending on the city, but no regional  
113 pattern emerged for any of the pollutants.

114 Conclusions: This study did not find any consistent evidence of an association between long-  
115 term air pollution and incident rhinitis.

116 Introduction:

117 The prevalence of rhinitis varies between 10 and 50% worldwide (Bousquet et al. 2008; Wang  
118 et al. 2014) and has strongly increased during the last decades, mostly in industrialized  
119 countries (de Marco et al. 2012; Zhang and Zhang 2014). Although rhinitis is usually  
120 considered as a minor respiratory condition, it is often associated with a strong impairment in  
121 daily life and has an important economical and societal impact (Bousquet et al. 2017;  
122 Leynaert and Soussan 2003; Linneberg et al. 2016). Although environmental determinants of  
123 rhinitis are not well-known, environmental changes are suspected to be a major driver in the  
124 rise of allergy. During the past years, the link between outdoor air pollution and allergy  
125 continues to strengthen, both in children and in adults (Carlsten and Rider 2017).

126 Rhinitis is a complex disease, frequently associated with asthma, whatever the allergic  
127 sensitization status (Shaaban et al. 2008). In adults there is growing evidence associating air  
128 pollution with asthma (Guarnieri and Balmes 2014). There are also evidences of the adverse  
129 effect of outdoor air pollution on allergic diseases (HEI 2010; Heinrich and Wichmann 2004),  
130 even if this association is not consistently reported (Lindgren et al. 2009). However, there are  
131 very few studies on the effect of air pollution on rhinitis (Deng et al. 2016; Jang et al. 2016;  
132 Ranci re et al. 2016). It has been shown that air pollution and particularly diesel exhaust  
133 particles have the capability of enhancing immunological responses to allergens and elicit  
134 inflammatory reactions in the airways at relatively low concentrations and even with short  
135 exposure durations (Brunekreef and Sunyer 2003). Traffic-related air pollutants modify  
136 responses to allergens in the nasal mucosa (Peden 2001), and several studies have shown an  
137 increase in daily consultations for allergic rhinitis in general practitioners due to short-term air  
138 pollution exposure (Hajat et al. 2001; Zhang et al. 2011). Traffic-related air pollution has been  
139 consistently associated with prevalence of rhinitis among an Italian population, but only  
140 among non-smokers (Cesaroni et al. 2008). Furthermore, proximity to traffic has been

141 associated with allergic rhinitis prevalence among Swedish adults (Lindgren et al. 2009).  
142 However, no study has ever assessed the association between exposure to long-term air  
143 pollution and the incidence of rhinitis in adults.

144 The aim of the present study was to assess the association between long term modeled air  
145 pollution exposure at the participant's home addresses and the incidence of self-reported  
146 rhinitis among adults from two large European studies.

#### 147 Methods:

##### 148 *Study design and participants*

149 The data came from two multicentre epidemiological European studies: the French  
150 Epidemiological case-control and family-based study of the Genetics and Environment of  
151 Asthma (EGEA, (Kauffmann et al. 1997)), and the population-based study: the European  
152 Community Respiratory Health Survey (ECRHS, (Burney et al. 1994)).

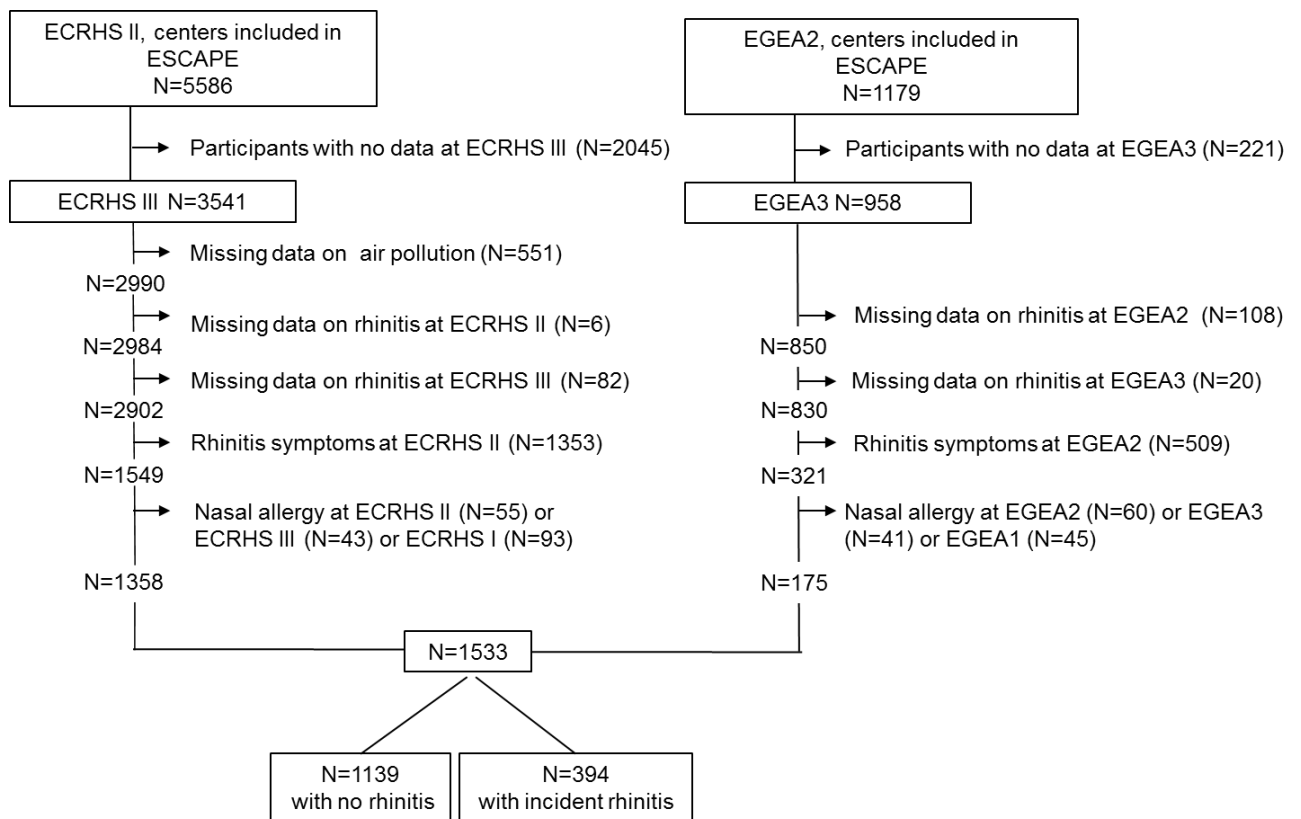
153 EGEA is a cohort study based on an initial group of asthma cases recruited in chest clinics  
154 between 1991 and 1995 from 5 French cities (EGEA1, <https://egeanet.vjf.inserm.fr/>) along  
155 with their first-degree relatives, and a group of controls (n=2,047). A first follow-up (EGEA2,  
156 (Kauffmann 1999; Kauffmann et al. 1997)) was conducted between 2003 and 2007 (n=2121)  
157 and a second follow-up (EGEA3) between 2011 and 2013 using self-completed questionnaire  
158 (n=1558) (Bouzigon et al. 2015).

159 ECRHS is a random population-based multicentre cohort of young adults, aged 20 to 44 years  
160 at recruitment, enriched with participants with respiratory symptoms, recruited from 1992 to  
161 1994 in 28 western European cities (ECRHS I, n=17880 <http://www.ecrhs.org/>) and followed  
162 up twice: between 2000 and 2002 (ECRHS II, n=10933 (Jarvis 2002; Kogevinas et al. 2007))  
163 and between 2011 and 2013 (ECRHS III, n=7040).



164 Both cohort studies applied standardized protocols and comparable detailed questionnaires on  
 165 respiratory health and risk factors for the two follow-up. Ethical approval was obtained in  
 166 each cohort from the appropriate institutional ethics committees, and written consent was  
 167 obtained from each participant.

168 The present longitudinal analysis includes a subsample of 1533 adults from 17 European  
 169 cities who reported no rhinitis at the first follow-up (EGEA2, ECRHS II), and with available  
 170 data on rhinitis and air pollution exposure at the second follow up (EGEA3, ECRHS III,  
 171 Figure 1).



172

173 *Figure 1 Flow-chart of the participants*

174 **Estimation of air pollution exposure**

175 Within the frame of the European Study of Cohorts for Air Pollution Effects (ESCAPE  
 176 [www.escapeproject.eu](http://www.escapeproject.eu) (Beelen et al. 2013; Eeftens et al. 2012)), the place of residence of  
 177 each subject at the first follow-up of the two studies (EGEA2 and ECRHS II) was geocoded

178 and linked with NO<sub>2</sub> (nitrogen dioxide), PM<sub>10</sub> (airborne particles with an aerodynamical  
179 diameter ≤10 μm) and PM<sub>2.5</sub> (airborne particles with an aerodynamical diameter ≤25 μm)  
180 model estimates developed between 2009 and 2010. Estimates of NO<sub>2</sub> are available for 17  
181 cities (Umea, Norwich, Ipswich, Antwerp, Erfurt, Paris, Lyon, Grenoble, Marseille, Verona,  
182 Pavia, Turin, Oviedo, Galdakao, Barcelona, Albacete and Huelva). Given that PM were  
183 measured only in a subset of cities within ESCAPE, estimates of PM were available for 6  
184 cities (Norwich, Ipswich, Antwerp, Paris, Grenoble, Turin and Barcelona). Annual averages –  
185 average of daily exposure over one year- of air pollutant concentrations were estimated at  
186 participants' residential addresses with land use regression models. Results are reported for an  
187 increase of 10 μg.m<sup>-3</sup> for PM<sub>10</sub> and NO<sub>2</sub> and 5 μg.m<sup>-3</sup> for PM<sub>2.5</sub>, following the ESCAPE  
188 protocol (Beelen et al. 2014). Assessment of air pollution exposure is detailed in the  
189 Supplementary material.

190 The main results for estimates of NO<sub>x</sub> (nitrogen oxides), PM<sub>2.5</sub>absorbance, PM<sub>coarse</sub> and two  
191 traffic exposure indicators - traffic intensity (on the nearest road), and traffic load (in a 100m  
192 buffer) - are available in the supplementary material.

### 193 **Definition of rhinitis, asthma and allergic sensitization**

194 Rhinitis was defined by a positive response to “*Have you ever had a problem with sneezing,*  
195 *or a runny or a blocked nose when you did not have a cold or the flu?*” in EGEA and ECRHS.  
196 Incident rhinitis was defined by a positive response at EGEA3/ECRHS III and a negative  
197 response at EGEA 2/ECRHS II. This definition does not distinguish between rhinitis  
198 subtypes; to differentiate between participants with nonallergic rhinitis and those with allergic  
199 rhinitis, stratified analyses by allergic sensitization were used. In order to ensure that incident  
200 cases were real incident cases of rhinitis, several steps of caution were taken: 1) participants  
201 that have declared nasal symptoms (EGEA1) or nasal allergy (ECRHS I) at inclusion were

202 excluded, 2) participants with a positive response to “*Have you ever had allergic rhinitis?*” or  
203 “*Have you ever had hay fever?*” at EGEA2 or ECRHS II were not considered in the analysis,  
204 3) participants with no rhinitis at both first (EGEA2 or ECRHS II ) and second follow-up  
205 (EGEA3 or ECRHS III ) but who had answered yes to “*Have you ever had allergic rhinitis?*”  
206 or “*Have you ever had hay fever?*” at EGEA3 or ECRHS III were also excluded from the  
207 analyses. In a sensitivity analysis, incidence of allergic rhinitis, defined by a positive response  
208 to “*Have you ever had allergic rhinitis?*” or “*Have you ever had hay fever?*” was considered.  
209 “Asthma ever” was defined (Siroux et al. 2011) by a positive response to “*Have you ever had*  
210 *asthma?*” in ECRHS; and by a positive response to one of the following questions “*Have you*  
211 *ever had attacks of breathlessness at rest with wheezing?*” or “*Have you ever had asthma*  
212 *attacks?*” or by being recruited as an asthmatic case in EGEA.

213 Allergic sensitization was defined using the skin-prick test (SPT) for 12 aeroallergens in  
214 EGEA2 (a wheal diameter  $\geq 3$  mm and superior to the negative control wheal to at least one of  
215 the allergen among: cat, *Dermatophagoides pteronyssinus*, *Blattella germanica*, olive,  
216 birch, *Parietaria judaica*, timothy grass, ragweed pollen, *Aspergillus*, *Cladosporium*  
217 *herbarum*, *Alternaria tenuis*). Allergic sensitization was defined using specific  
218 Immunoglobulin E (IgE) to four allergens in ECRHS II (specific IgE  $\geq 35$  kU/ml to at least one  
219 of the allergen among: cat, *Dermatophagoides pteronyssinus*, *Cladosporium*, and timothy  
220 grass).

## 221 **Statistical analysis**

222 The differences in general characteristics between the two studies were evaluated using the  
223 Student test for quantitative variables and the Chi-square test or Fisher exact test for  
224 qualitative variables.

225 Incident rates of rhinitis were estimated as the ratio between the number of new cases at  
226 ECRHS III/EGEA3 and the number of person-years at risk (per 1,000), which were  
227 considered to be equal to the length of the follow-up (between ECRHS II/EGEA2 and  
228 ECRHS III/EGEA3) (De Marco et al. 2011) for each participant of the cohort who was  
229 rhinitis-free at baseline. Exact 95% confidence intervals were computed using the Poisson  
230 distribution. Correlations between pollutants were assessed using the Spearman coefficient.

231 Associations between air pollutants and incident rhinitis were evaluated using incidence rate  
232 ratio (IRR) in a pooled dataset. The IRRs were computed using Poisson regression models,  
233 with a random-intercept at city level (level 2), and the follow-up time as an offset. Based on  
234 the ESCAPE protocol, estimates were calculated for an increase of  $10 \mu\text{g}/\text{m}^3$  for  $\text{NO}_2$  and  
235  $\text{PM}_{10}$ ,  $5 \mu\text{g}/\text{m}^3$  for  $\text{PM}_{2.5}$  and  $\text{PM}_{\text{coarse}}$ ,  $10 \mu\text{g}/\text{m}^3$  for  $\text{NO}_X$ , 4,000,000 vehicles\*m/day for  
236 traffic load on all major roads in a 100m buffer and 5,000 vehicles/day for traffic density on  
237 the nearest road. The estimates were adjusted for pre-selected variables -at ECRHS II/  
238 EGEA2- based on previous literature: age, sex, number of siblings, family history of allergy,  
239 smoking status, educational level -as a proxy of socio-economic status- and asthma status.

240 Analyses with traffic density or traffic load were also adjusted for  $\text{NO}_2$  background level. In a  
241 sensitivity analysis, the fully adjusted model was additionally adjusted for study  
242 (EGEA/ECRHS). Analyses were subsequently stratified according to pre-set subgroups,  
243 namely asthma status, allergic sensitization status, sex, smoking, and finally study  
244 (EGEA/ECRHS) because of the different recruitment criteria in EGEA and ECRHS.

245 In a second step, analysis by city and meta-regression were applied to study the association  
246 between air pollution and incident rhinitis for each city. The DerSimonian-Laird approach  
247 was used to estimate the between-study variance and heterogeneity was measured by  $I^2$ ,  
248 which ranges from 0% to 100%. The  $I^2$  statistic describes the percentage of variation across  
249 studies that is due to heterogeneity rather than chance (Higgins and Thompson 2002; Higgins

250 et al. 2003). These meta-regressions were adjusted only for age as the number of incident  
 251 cases was too small in some cities to adjust for other factors.

252 Analyses were done using R statistical software (R Core Team, 2012).

253 Results:

254 A total of 1533 adults from 17 European cities (Table 1) were included in the analyses: 1358  
 255 from ECRHS (mean age=43.3 years, 51.4% female) and 175 from EGEA (mean age=44.4  
 256 years, 49.7% female). The crude incident rate at the 3<sup>rd</sup> follow-up was 23.4 per 1000 person-  
 257 years (95% CI: [21.2-25.8]) with 394 participants reporting incident rhinitis and a median  
 258 length of the follow-up of 11 years. Participants with incident rhinitis were younger and  
 259 reported more often a history of asthma than those without rhinitis (Table 1).

<b>Variables</b>	<b>All (N=1533)</b>	<b>No rhinitis (N=1139)</b>	<b>Incident rhinitis (N=394)</b>	<b>p crude overall</b>
<b>Age, mean±sd</b>	43.4±8.9 (N=1533)	43.7±8.9	42.7±8.9	0.06
<b>Study, % EGEA</b>	11.4 (N=1533)	11.4	11.4	1
<b>Sex=women</b>	51.2 (N=1533)	50.1	54.3	0.17
<b>BMI, %</b>	(N=1374)			0.27
<b>&lt;18</b>	1.8	2.0	1.4	
<b>18-25</b>	49.6	48.1	54.1	
<b>25-30</b>	34.2	35.2	31.4	
<b>&gt;=30</b>	14.3	14.7	13.2	
<b>Smoking status, %</b>	(N=1520)			0.34
<b>current</b>	30.7	29.7	33.7	
<b>ex-smoker</b>	27.8	28.2	26.5	
<b>never</b>	41.5	42.1	39.8	
<b>Educational level, %</b>	(N=1529)			0.49
<b>low</b>	26.3	26.8	24.7	
<b>medium</b>	34.7	34.9	33.8	
<b>high</b>	39.0	38.2	41.5	
<b>Asthma ever, %</b>	5.1 (N=1533)	4.1	7.9	<0.01
<b>Asthma age of onset, mean±sd</b>	17.8±16.2 (N=75)	18.6±16.9	16.7±15.4	0.61
<b>Report of hay fever or AR ever, %</b>	5.6 (N=1522)	0	22.2	<0.01
<b>Allergic sensitization, %</b>	18.4 (N=1306)	17.6	22.2	0.25
<b>NO<sub>2</sub>, µ g.m<sup>-3</sup>, mean±sd*</b>	29.3±15.1 (N=1533)	28.9±15.4	30.3±14.2	0.11
<b>PM<sub>10</sub>, µ g.m<sup>-3</sup>, mean±sd*</b>	26.9±8.3 (N=738)	27.2±8.7	26.2±7.1	0.09

<b>PM<sub>2.5</sub>, <math>\mu\text{g}\cdot\text{m}^{-3}</math>, mean<math>\pm</math>sd*</b>	16.4 $\pm$ 4.9 (N=738)	16.6 $\pm$ 5.2	15.9 $\pm$ 4.4	0.08
<b>*Annual.averaged</b>				

260 *Table 1 General characteristics of all the participants at ECRHS II/EGEA2, and according to rhinitis status*

261 Correlations between the three pollutants were high (0.71 between NO<sub>2</sub> and PM<sub>10</sub>, 0.70  
 262 between NO<sub>2</sub> and PM<sub>2.5</sub> and 0.77 between PM<sub>10</sub> and PM<sub>2.5</sub>, Table 1 in Supplementary  
 263 material).

264 *Main analysis*

265 Pooled analyses of the associations between NO<sub>2</sub>, PM<sub>10</sub> or PM<sub>2.5</sub> and incident rhinitis showed  
 266 no statistically significant results (Table 2). In a two-pollutant model including NO<sub>2</sub> and  
 267 PM<sub>2.5</sub>, results were very similar to those of the single pollutant-model. No association was  
 268 found when considering other pollutants or traffic measures (NO<sub>x</sub>, PM<sub>2.5</sub> absorbance, PM  
 269 coarse or traffic measures, Supplemental Material, Table 2). The sensitivity analysis studying  
 270 incident allergic rhinitis showed similar results (Table 2).

271 *Stratifying by study*

272 When stratifying by study, estimates of the associations were positive in the EGEA study for  
 273 the three air pollutants and statistically significant for NO<sub>2</sub> in the crude analysis (Table 2). In  
 274 the adjusted model, this estimate was similar and borderline. No statistically significant  
 275 association was found in ECRHS, where results were similar to those from the main analysis.

276 *Stratifying by asthma status*

277 When stratifying by asthma status, estimates were positive in participants with asthma and  
 278 similar to the main analysis in those without asthma for the three air pollutants. However,  
 279 none of the results were statistically significant (Table 2).

280 *Stratifying by allergic sensitization status*

281 Among the sensitized participants, estimates were negative for PM<sub>10</sub> and PM<sub>2.5</sub>. Results were  
282 statistically significant only for PM<sub>2.5</sub> (Table 2). The strength of the associations increases in  
283 the adjusted model. Among non-sensitized participants, no statistically significant association  
284 was found with any of the three pollutants.

285 *Stratifying by sex*

286 Among males only, estimates were negative for PM<sub>10</sub> and PM<sub>2.5</sub> and statistically significant  
287 only for PM<sub>2.5</sub> (Table 2). No statistically significant association was found among females or  
288 with NO<sub>2</sub>.

289 *Stratifying by smoking status*

290 Finally, when stratifying by smoking status, a borderline positive association of rhinitis with  
291 NO<sub>2</sub> was found among non-smokers, while an inverse significant relationship was found with  
292 PM<sub>10</sub> among smokers (Table 2).

293 Additionally, adjusting the results for study did not change any of the results (data not  
294 shown).

295 *Analysis by city and meta-regression*

296 Estimates for NO<sub>2</sub> were positive in 8 out of 17 cities but reached statistical significance only  
297 in Paris. Estimates were negative in 9 cities but not statistically significant (Figure 2).  
298 Similarly, positive and negative estimates were found according to the city for PM<sub>10</sub> and  
299 PM<sub>2.5</sub>. However, no statistical heterogeneity between cities was found in the meta-regression,  
300 with I<sup>2</sup> values ranging from 0% for PM<sub>2.5</sub> to 36% for PM<sub>10</sub>. No significant association was  
301 found in the meta-regressions (Figure 2).

302 A sensitivity analysis considering participants separately from EGEA and ECRHS, and from  
303 Grenoble and Paris, showed that among the same city, results differed according to the study  
304 (Figure 1 in Online Repository)



Analyses	No of subjects (No of incident cases) in adjusted model		crude IRR (95%CI)			aIRR (95%CI)		
	NO <sub>2</sub>	PM <sub>10</sub> and PM <sub>2.5</sub>	NO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	NO <sub>2</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>
<b>Main analyses</b>	1372(354)	645(187)	1.02[0.93-1.11]	0.90[0.73-1.10]	0.89[0.73-1.05]	1.00[0.91-1.09]	0.88[0.72-1.08]	0.88[0.73-1.04]
Two-pollutant model (NO <sub>2</sub> , PM <sub>2.5</sub> )			1.05[0.91-1.21]		0.84[0.66-1.05]	1.01[0.87-1.17]		0.87[0.68-1.08]
<b>Stratified analyses</b>								
By study						**		
EGEA	112(30)	80(21)	<b>1.42[1.12-1.82]</b>	1.77[0.67-4.35]	1.82[0.73-4.88]	1.38[0.99-2.06]	2.57[0.54-10.2]	2.22[0.55-9.14]
ECRHS	1260(324)	565(166)	0.98[0.89-1.07]	0.88[0.71-1.08]	0.87[0.70-1.03]	0.98[0.89-1.07]	0.87[0.70-1.08]	0.87[0.71-1.04]
By asthma status								
Asthmatics	65(25)	40(16)	1.16[0.94-1.39]	0.98[0.55-1.60]	0.90[0.51-1.43]	1.09[0.84-1.39]	1.15[0.54-2.22]	1.11[0.55-2.13]
Non-asthmatics	1307(329)	605(171)	1.00[0.91-1.09]	0.89[0.71-1.10]	0.89[0.72-1.07]	0.99[0.90-1.08]	0.86[0.69-1.07]	0.87[0.71-1.04]
By allergic sensitization status								
atopic	202(59)	112(37)	0.96[0.81-1.12]	0.76[0.49-1.11]	<b>0.66[0.35-0.95]</b>	0.95[0.77-1.14]	0.73[0.42-1.15]	<b>0.52[0.29-0.87]</b>
non-atopic	962(250)	442(132)	1.05[0.95-1.15]	0.93[0.76-1.17]	0.95[0.79-1.14]	1.05[0.95-1.15]	0.90[0.72-1.15]	0.93[0.76-1.14]
By smoking status							*	
smoker	803(212)	364(106)	0.98[0.88-1.09]	0.79[0.60-1.05]	0.83[0.62-1.07]	0.96[0.85-1.07]	<b>0.75[0.56-0.99]</b>	0.80[0.60-1.03]
non-smoker	569(142)	281(81)	1.09[0.99-1.20]	1.03[0.80-1.31]	0.96[0.77-1.16]	1.10[0.99-1.22]	1.10[0.84-1.41]	0.99[0.78-1.22]
By gender								
Male	659(159)	304(82)	1.01[0.90-1.11]	0.83[0.63-1.07]	<b>0.78[0.61-0.98]</b>	0.99[0.88-1.10]	0.83[0.61-1.08]	<b>0.76[0.57-0.98]</b>
Female	713(195)	341(105)	1.04[0.93-1.17]	0.95[0.70-1.28]	0.98[0.75-1.26]	1.04[0.92-1.16]	0.92[0.68-1.24]	0.96[0.74-1.25]
<b>Secondary analysis</b>								
Incidence of allergic rhinitis	1128	530	1.09[0.94-1.25]	0.91[0.70-1.17]	0.92[0.73-1.13]	1.07[0.92-1.23]	0.95[0.72-1.26]	0.94[0.73-1.17]

aIIRR : Incidence Rate Ratio adjusted for age, sex, number of siblings, family history of allergy, smoking status, educational level and asthma status. IRR with duration of follow-up as offset and a random intercept at city level ,for an increase of 10 µg.m<sup>-3</sup> for NO<sub>2</sub> and PM<sub>10</sub> and for an increase of 5 µg.m<sup>-3</sup> for PM<sub>2.5</sub>. \*\*: p-interaction= 0.047, \*: p-interaction=0.08, all other p-interaction>0.12.

305 Table 2 IRR of the associations between pollutants (NO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>) and incident rhinitis, in all, and stratifying by study, asthma status, allergic sensitization and smoking

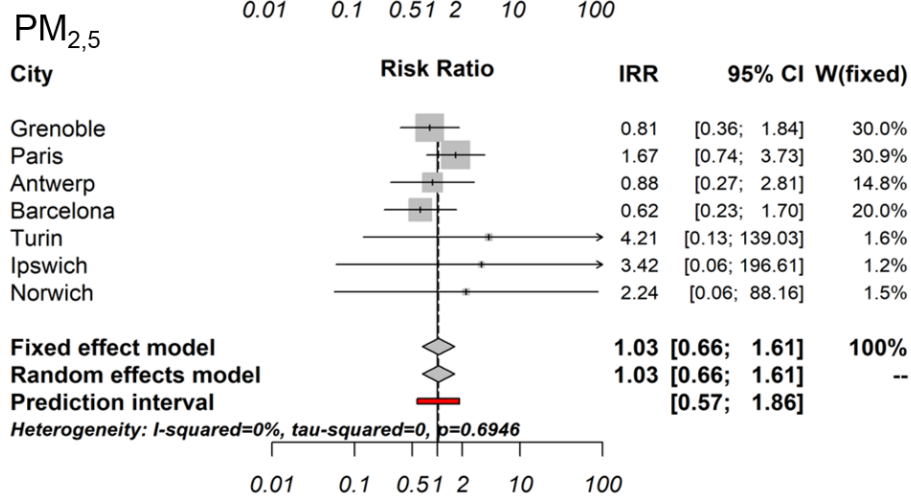
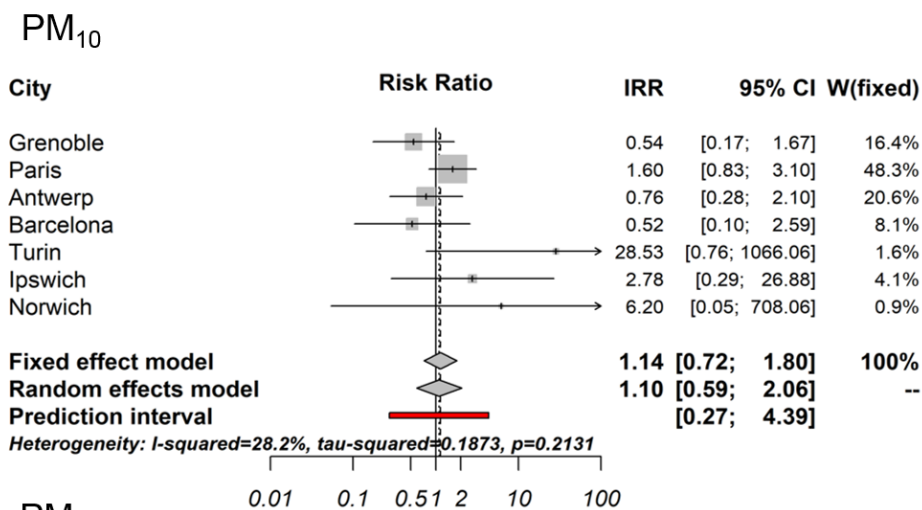
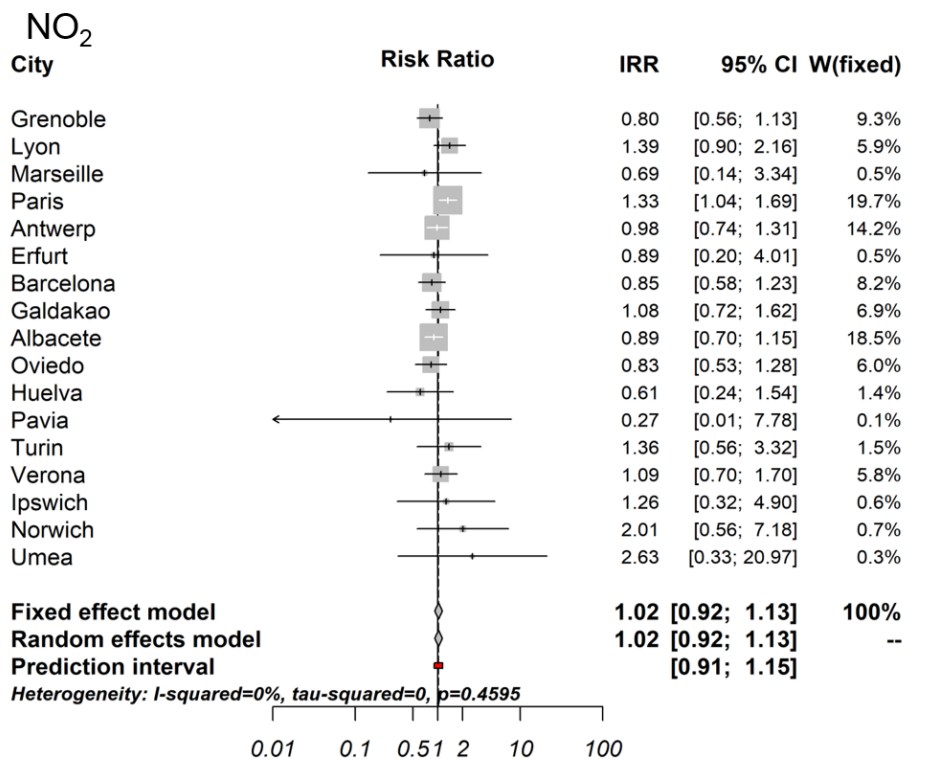


Figure 2 Association between NO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub> and incident rhinitis by city and meta-regression

## Discussion

In this longitudinal analysis of two multicentre cohorts' studies, we could not observe any clear or consistent association between modeled annual average residential exposure to air pollution and incident rhinitis. In stratified analyses, exposure to PM<sub>2.5</sub> was associated with smaller risk of rhinitis among participants with allergic sensitization and among males. Our results are difficult to compare with the literature as our study is the first to have investigated the association between long-term air pollution and incident rhinitis in adults. However, our reported overall null findings reported are in line with the literature in children where results are mixed according to the age, the window of exposure and the pollutant (Deng et al. 2016; Jang et al. 2016; Ranci re et al. 2016). It is also worthy to note that our incident rate of rhinitis may seem high at first glance. However, there is little information on rhinitis incidence in adults in the literature, and the inclusion criteria of our analysis combined with a population enriched in asthmatics cases could explain this high rate. We showed that the strength and direction of the associations between air pollutants and incident rhinitis differed across the 17 European cities and also according to the study: an increase in NO<sub>2</sub> being associated with rhinitis incidence among participants in EGEA but not in ECRHS. This result could be due to the fact that there are more cities included in ECRHS and given that air pollution strongly differs according to the city, air pollution also varies a lot according to the study. However, when looking at Paris and Grenoble, included in both EGEA and ECRHS, results strongly differ according to the study in the same city. Thus, it seems that there is a study effect which could be explained by the higher prevalence of asthmatics in the EGEA study due to its recruitment specificity. Indeed, when adjusting for asthma status, no statistically significant results appear but the effect of air pollution exposure on rhinitis incidence was increased among participants with asthma compared to those without asthma.

In stratified analyses, we found that PM exposure was negatively associated with incidence of rhinitis in some groups, even if there were no significant interactions. Due to the lack of studies on air pollution and incident rhinitis in adults, we have compared our results with literature in children and with studies on the association between air pollution and prevalence of rhinitis. We found that exposure to PM<sub>2.5</sub> was negatively associated with incident rhinitis among males, and no effect was found among females. In a study on the association between proximity to traffic and prevalence of rhinitis in a Swedish population, no differences according to sex were found (Lindgren et al. 2009). Our results are also discordant with the paper by Deng who found a significant risk effect of early life exposure to traffic-related air pollutants and development of allergic rhinitis in males and with other studies in children discussed in the same paper (Deng et al. 2016). However, regarding rhinitis more broadly, a male predominance in childhood for allergic rhinitis has been shown in some studies (Alm et al. 2011) whereas there is no clear sex ratio among adults, although there might be a possible higher risk of non-allergic rhinitis among females (Cazzoletti et al. 2015). In our study, stratifying by smoking status gave discordant results according to air pollutant: a higher exposure to NO<sub>2</sub> was associated with a non-significant increase in incident rhinitis among non-smokers whereas a higher exposure to PM<sub>10</sub> was negatively and significantly associated with incident rhinitis among smokers. Among Italian adults, Cesaroni et al. (Cesaroni et al. 2008) showed a positive association between an index of traffic exposure related to air pollution - based on self-report of traffic intensity, distance to busy road, concentrations of PM and NO<sub>2</sub> - and prevalence of rhinitis among non-smokers only. Our results are thus not concordant for PM<sub>10</sub> but concordant for NO<sub>2</sub>, a good marker of traffic and therefore more comparable to the index of traffic exposure related to air pollution used by Cesaroni et al. Rhinitis is a complex phenotype, often associated with asthma and/or allergic sensitization. Based on this fact and on literature showing a possible effect of allergic sensitization in the

association between air pollution and rhinitis or asthma (Burte et al. 2016; Lindgren et al. 2009), we stratified our results by allergic sensitization to obtain results for allergic rhinitis and nonallergic rhinitis separately. We found that a higher exposure to air pollutants was negatively associated with incident rhinitis among sensitized participants (allergic rhinitis). This is discordant with the study by Lindgren et al. who found a positive association between air pollution and prevalence of allergic rhinitis, but not with rhinitis triggered by non-allergic factors. These discrepancies may be due to the fact that allergic sensitization was based on objective tests (SPT or specific IgE) in our analysis, whereas Lindgren et al. used self-reported triggers of rhinitis symptoms to distinguish between the two types of rhinitis. Our results also discord with several studies in children where exposure to air pollution has been associated to the development of allergic rhinitis (Brauer et al. 2007; Deng et al. 2016; Gehring et al. 2010). However, phenotypes of rhinitis are not the same in adults and in children (Izquierdo-Domínguez et al. 2013) and particularly regarding allergic rhinitis that is an integral part of the allergic march in children, but not in adults. The mechanisms explaining the differences in results according to allergic sensitization are unclear. However, the interaction between air pollution and allergens and particularly with pollen, further discussed below, is likely to play an important role.

There are complex interactions between climate change, air pollution and allergens (Carlsten and Rider 2017; D'Amato et al. 2018; Reinmuth-Selzle et al. 2017), and in particular pollen (Annesi-Maesano et al. 2012). A study in Italy has shown that NO<sub>2</sub> exposure was associated with an increase in allergic rhinitis prevalence, but only among participants living in the Mediterranean region, and not in the subcontinental one (de Marco et al. 2002). Data from our study came from 17 cities from all over Europe, reflecting different climates. However, we found no clear geographical pattern of the association between air pollution and rhinitis incidence when looking at each city separately. Climate is associated with air pollution levels

and may also act on the allergens by altering local and regional allergen production or by increasing the allergenicity of pollen (D'Amato et al. 2016; Sénéchal et al. 2015). Air pollution acts directly on pollen (D'Amato et al. 2007), and particles carrying pollen allergen molecules are likely to play a role in the association between air pollution and respiratory allergic diseases (Bono et al. 2016; Marchetti et al. 2017). Finally, the level of pollen exposure is associated to allergic rhinitis incidence and prevalence and has also been associated to severity of rhinitis (Annesi-Maesano et al. 2012). Unfortunately, data were not available on climate change or on allergen concentration. This would have helped to better understand our results, and particularly among those with allergic rhinitis for which allergen-pollution interaction may drive an important part of the association. In future studies, it will be important to consider these factors when studying air pollution exposure and allergic diseases, particularly hay fever.

Socio-economic status may play a role in the relation between air pollution and respiratory symptoms and particularly asthma (Burte et al. 2016). However, in our study, adjusting for educational level did not change the results. Furthermore, the association between socio economic status and air pollution is not clearly established in Europe and is very heterogeneous according to the city (Temam et al. 2017). Similarly, our study, which also used data from ESCAPE, found results that varied considerably according to the city with no clear pattern.

In our study, stratifying by allergic sensitization enabled us to distinguish results for allergic and nonallergic rhinitis but not for the other phenotypes of rhinitis, e.g mixed rhinitis (subjects having both allergic and nonallergic rhinitis). However, it is difficult to catch subjects with such phenotypes in epidemiological studies when allergy is based only on skin prick test or specific IgE. Another limitation of the present study is that despite the individual measure of air pollution, this measure was carried out using residential address and therefore

may not have taken into account the correct annual personal exposure of each participant. However, this is a limitation that often arises when dealing with long-term air pollution measurements. Another limitation is that analyses by city and meta-regression were adjusted only for age due to small sample size. Further adjustment would probably not have changed the results since in the general analysis adjusted results were similar to the crude analysis. However, results of the meta-regression have to be considered with caution because of the small sample size and the wide confidence intervals. For the same reason, results on the effect of PM exposure should also be considered with caution.

The major strength of this study is that the population comes from two multicentric cohorts, followed for more than 20 years and including 17 European cities. Furthermore, there is a detailed characterization on respiratory phenotypes at both first and second follow-up as well as an individual measure of exposure to air pollution, obtained within the ESCAPE project. We were therefore able to perform a longitudinal analysis studying the long-term air pollution effect on incidence of rhinitis. Rhinitis definition is often based on the report of nasal allergy, hay fever or allergic rhinitis (de Marco et al. 2012; Smit et al. 2014). However, in our study we aimed to study the incidence of all types of rhinitis and not only the allergic subtypes. We therefore based our definition of rhinitis on nasal symptoms (Cazzoletti et al. 2015; Rancière et al. 2016). This choice also enabled the stratification of results by allergic sensitization and the possibility to distinguish the two types of rhinitis. Nevertheless, the definition of rhinitis is questionnaire-based and thus may not be as reliable as a physician diagnosis as it is often the case in epidemiological studies.

The total air pollution exposure of an individual is not restricted to outdoor air pollution but is actually composed of a cocktail of pollutants, with both outdoor and indoor sources. The present study focused on the association between outdoor air pollution and rhinitis outcomes. We acknowledge that our study suffers from the lack of data on indoor air pollution exposures

that are very important as we spend most of the time indoor. Future studies should integrate both sources of pollution to give a more complete overview of the effects of air pollution on rhinitis.

The inconsistent results may also reflect the fact that single factors – such as air pollution – may play a relevant role in the etiology of very complex multifactorial and often allergic diseases, mostly under multi-factorial interrelationships of many co-factors, among which climate change and allergen concentrations. This is consistent with the findings of the long-term association between air pollution and onset of asthma: inconsistent findings (Guarnieri and Balmes 2014) have also been reported and a more specific definition of traffic-related exposures such as typically encountered in high concentrations among those living very close to busy roads resulted in more consistent results. It will be interesting to investigate the role of air pollution in the development of rhinitis or other atopic diseases in countries with very high levels of air pollution but with very different patterns of possibly relevant etiologic co-factors. For example in low income countries with so far rather low prevalence of asthma or atopic diseases.

Overall, no clear association was found between air pollution and incident rhinitis, whether in the main analysis, the bi-pollutant model or the stratified analysis.

Conclusions: In this longitudinal study, we have analysed the effect of long-term exposure to air pollution on the incidence of rhinitis among 1533 adults, including 394 incident cases, from 17 European cities. We have found no clear association between long-term air pollution exposure and incident rhinitis. However, it could be interesting to look further into the association between air pollution and rhinitis, concentrating on the effect of air pollution on rhinitis phenotypes or rhinitis characteristics such as type of symptoms or severity.



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