

Indoor pet allergen exposures modify the effects of chemical air pollutants on respiratory symptoms

N. Baiz,¹ C. Billonnet,¹ S. Kirchner,² F. de Blay,³ I. Annesi-Maesano¹

¹Epidémiologie des maladies Allergiques et Respiratoires, Institut Pierre Louis d'Epidémiologie et de Santé Publique, Sorbonne University and Institut national de la santé et de la recherche médicale, Saint Antoine Medical School, Paris, ²F-77420, Observatoire de la qualité de l'air intérieur, Centre Scientifique et Technique du Bâtiment, Paris Est University, Champs sur Marne, ³Unité de pneumologie, d'allergologie et de pathologie respiratoire de l'environnement des Hôpitaux universitaires de Strasbourg, Strasbourg, France

SUMMARY

SETTING: Indoor volatile organic compound (VOC) levels, which are generally correlated with each other, may have an additive or synergistic effect on health. VOC synergy with allergens is a suspected mechanism affecting respiration.

OBJECTIVE: To determine the effect of exposure to interactions between VOCs and allergens on respiratory symptoms in individuals aged ≥ 15 years.

DESIGN: A national cross-sectional survey measured 20 VOCs and dog and cat aeroallergens in 490 main residential dwellings in France. A standardised questionnaire was used to elicit responses on respiratory conditions in 1012 inhabitants. Four VOC factor scores (linear combinations of VOCs) were generated using principal component analysis. In order to take into account the phenomenon of multi-pollution, marginal models were used to model the relationships between

exposure to VOC mixture and respiratory conditions. Stratified models were used to examine the interaction between allergens and VOCs.

RESULTS: The aromatic hydrocarbon score was associated with rhinitis and wheezing, the aliphatic hydrocarbon score with asthma and cough, the halogenated hydrocarbons with asthma, wheezing and rhinitis. Aldehydes and *Can f1* had a significant synergistic effect on wheezing and rhinitis. Aliphatic hydrocarbons had an antagonist effect with *Can f1* on wheezing.

CONCLUSION: Our data support evidence of adverse effects of exposure to VOC mixture on respiratory conditions; this effect is aggravated in the presence of pet allergens.

KEY WORDS: volatile organic compounds; asthma; allergic rhinitis; wheezing; aeroallergens

Environmental and lifestyle factors have been implicated in the increase of respiratory and allergic disorders. As most people in industrialised countries spend the majority of their time indoors, indoor air quality is of great importance.¹ Over the past decades, there has been an increasing concern about respiratory health effects of exposure to indoor air pollution.^{2–4} Several recent studies have suggested that volatile organic compounds (VOCs) were implicated in various respiratory disorders, including asthma.^{5,6} VOCs are ubiquitous at home, where they are emitted by various sources, such as building material and equipment, combustion processes, cleaning products and tobacco smoke.

Most studies on indoor respiratory effects consider each VOC as having an isolated effect.^{6–9} However, in practice, individuals are exposed to a mixture of VOCs that are correlated to each other, with potential additive or synergistic effects. Findings from single pollutant models and the proper role of each

pollutant may therefore be difficult to interpret. This makes it necessary to consider exposure to multi-VOC mixtures. In recent years, some studies on exposure to multi-pollutant mixtures have been carried out. Arif et al. found a significant association between asthma in adults and a mixture of aromatic compounds.⁵

Not only do VOCs interact with each other, but they can interact with other air pollutants. One potential mechanism for the link between asthma and allergy and VOCs may be involve synergy between VOCs and allergens.¹⁰ Although experimental studies^{11–13} and a small number of epidemiological studies^{14,15} have demonstrated an interaction between traffic-related pollutants and pollens, the interaction between VOCs and indoor allergens have rarely been explored.⁶

The aim of the present paper was to explore the relationships between exposure to multi-VOC mixtures and asthma, rhinitis and other respiratory

conditions by taking into account possible interactions between VOCs and allergens.

METHODS

Study sample

A national cross-sectional representative survey was conducted by the Indoor Air Quality Observatory (*Observatoire de la qualité de l'air intérieur*, OQAI) between October 2003 and December 2005 in France. The final sample included 567 main residences distributed across 74 municipalities of 19 regions. In total, 1612 individuals (age range: 15–89 years; median age: 44 years) aged ≥ 15 years participated in the study. Information regarding the participants' health status and characteristics was collected using standardised questionnaires (see Billionnet et al.¹⁶ and Kirchner et al.^{17,18} for more details about the sample selection).

Ethical approval

Written informed consent was obtained from all participants. The protocol of this study was approved by a duly constituted ethics committee (Comité de Protection des Personnes, Paris, France).

Air pollution assessments

Air quality measurements were performed in homes over 7 days. The selection of measured pollutants was based on their potential impact on air quality or comfort, and their toxicity and ubiquitous nature according to a hierarchical classification designed by a panel of experts (<http://www.air-interieur.org>)⁽¹⁹⁾. Measurements were performed for 20 VOCs, including 4 aldehydes, 12 hydrocarbons and 4 glycol ethers and 4 common allergens (dust mite allergens: *Der p1* and *Der f1*; dog and cat allergens: *Can f1* and *Fel d1*). Measurements were performed by radial diffusive sampling onto 2,4-dinitrophenylhydrazine-coated Florisil for aldehydes. Aldehyde hydrazones formed in the cartridge were eluted using acetonitrile solvent and analysed using liquid chromatography associated with an ultraviolet detector. Other VOCs were collected onto Carbograph 4 adsorbents (Radiello™; Fondazione Salvatore Maugeri [FSM], Pavia, Italy). Adsorbed VOCs were extracted using thermodesorption and analysed using gas phase chromatography equipped with flame ionization detector and/or mass spectrometry. Dog and cat allergen concentrations were assessed in the air of the living room using vacuum pumps connected to cassette filters operating for 1 h at 20 L/min to collect suspended particulate matter (PM) on 37 mm diameter glass microfibre filters (Millipore, Burlington, MA, USA). The air samples were analysed using enzyme-linked immunosorbent assay (ELISA). Limits of detection were 0.18 ng/m³ for *Fel d1* and 1.02 ng/m³ for *Can f1*. The VOCs were assessed by CSTB-POLLEM Laboratory

(Marne La Vallée, France) and FSM; the allergens were assessed by the Allergology Laboratory of Strasbourg University Hospitals (Strasbourg, France).

Additional information regarding air pollution assessments can be found in the Supplementary Data. For detailed information about measurement protocols and quality control for field sampling strategy and laboratory analysis, see also Ramalho et al.²⁰ and Derbez et al.²¹ for questionnaires and validation procedure for the data collected for this study. Information on dwelling characteristics and households were collected using nine detailed questionnaires (Derbez et al.²¹). In addition, a weekly diary about activities and time spent at home was completed by the inhabitants.

Respiratory health outcomes

A standardised self-administered questionnaire derived from the European Community Respiratory Health Survey (ECRHS) (<http://www.ecrhs.org/>) and the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaires was filled out by individuals aged ≥ 15 years living in the residential dwelling. Individual symptoms included sneezing, runny or blocked nose without cold in the last 12 months (rhinitis) and wheezing without cold in the past 12 months (wheezing). Asthma in the past year was defined as the presence of one of the following criteria: 1) having an asthma attack in the last 12 months, 2) being woken by an attack of shortness of breath in the last 12 months, and 3) currently using asthma medicine. Two chronic symptoms were also considered: frequent cough on getting up in winter due to cough and frequent phlegm on getting up in winter due to phlegm.

Statistical analysis

The population and dwelling characteristics of the responding group were compared with those of the non-responding group. We used the median test for continuous variables and χ^2 test for categorical variables. We checked the correlations between pollutants using Spearman's rank correlation coefficient.

Exposure to multi-VOC mixtures was assessed using a method based on VOC factor scores, i.e., linear combinations of VOCs, identified using principal component analysis. The latter allowed us to explore interactions with allergens by reducing the number of VOC variables. We used the SAS (SAS Institute Inc, Cary, NC, USA) factor procedure with varimax (orthogonal) rotations. Eighteen original VOC variables were entered into principal component analysis. We chose variables with loadings ≥ 0.5 for interpreting and naming individual factors.²² Each factor (VOC score) is a linear combination of variables among the 18 VOC variables initially included in the analysis.

Table 1 Characteristics of the population and of the dwellings

Characteristics	n (%)
Population (n = 1012)	
Sex	
Male	485 (48)
Female	527 (52)
Age, years	
15–30	251 (25)
30–45	287 (28)
45–60	291 (29)
>60	183 (18)
Smoking status	
Current smokers	268 (27)
Former smokers	301 (30)
No smokers	442 (44)
Origin	
French	967 (96)
Other	41 (4)
Higher educational level in the dwelling	
≤High school	255 (25)
>High school	233 (23)
Respiratory health	
Asthma	85 (9)
Wheezing	73 (7)
Rhinitis	384 (38)
Cough	121 (12)
Phlegm	100 (10)
Dwellings (n = 490)	
Time of survey	
Summer (April–August)	707 (70)
Winter	305 (30)
Presence of pets	
Yes	264 (54)
No	226 (46)
Relative humidity, median	48.7
Presence of mould	
Yes	191 (39)
No	299 (61)
Outdoor pollution	
Yes	284 (59)
No	199 (41)

The relationships between VOC scores and respiratory outcomes were analysed using the generalised estimating equation approach (GEE) with exchangeable covariance pattern to adjust for correlations within people belonging to the same residential dwelling. In order to explore the interactions, a model for each VOC factor–allergen pair was created by introducing an interaction term. Sensitivity analyses were conducted in the sub-sample of individuals who slept in the room where the VOCs were measured.

The confounders that were selected included sex, age, smoking habit, the highest educational level

among individuals of the residential dwelling, time of survey, relative humidity, presence of mould, presence of pets and outdoor sources of pollution (highways, rail, airports, industrial plant and sewage treatment plants within a 500 m radius). The variable “proportion of time spent at home” was not associated with the outcomes and did not affect the statistical significance of VOCs when introduced in the models.

All statistical analyses were performed using SAS v9.3. Statistical tests have been conducted with a type I risk of 5% (see the Supplementary Data for additional details).

RESULTS

Table 1 presents the sociodemographic and dwelling characteristics of the individuals who reported respiratory outcomes. The non-responding population (inhabitants of the 77 residential dwellings with measurements who did not complete the health questionnaire) did not differ from the responding population with respect to characteristics, including sex distribution and educational level, but was significantly younger (median age: 36 vs. 44 years).

VOC and allergen distributions

Formaldehyde appeared to have the highest median and 3rd quartile concentrations (respectively 19.4 µg/m³ and 28.3 µg/m³). Correlation coefficients between VOCs varied from 0.15 to 0.95. The highest correlations were observed between ethylbenzene and m/p-xylene (0.95), ethylbenzene and o-xylene (0.91), n-decane and n-undecane (0.84), and acrolein and acetaldehyde (0.72). Compared to the 490 residential dwellings of our study, the 77 dwellings excluded had significantly higher concentrations for nine VOCs. Table 2 presents the proportions of residential dwellings with allergen concentrations below the limit of quantification and the distribution of allergen concentrations within the 490 dwellings. Respectively 75% and 80% of residential dwellings had a concentration value below the limit of quantification for *Can f1* and *Fel d1*.

Exposure to multi-VOC mixture

Four VOC factor scores accounted for 62% of the

Table 2 Proportions of residential dwellings with allergen concentrations below the LQ and distribution of allergens measured in the studied dwellings

	<i>Fel d1</i> (ng/m ³)	<i>Can f1</i> (ng/m ³)	<i>Der p1</i> (µg/g)	<i>Der f1</i> (µg/g)
Dwellings with a valid measure, n	472	472	377	377
LQ	0.18	1.02	0.02	0.01
Proportion of dwellings <LQ, %	75	89	9	3
Concentration				
Quartile 3	LQ	<LQ	8.1	10.5
Maximum	27.4	12.0	128.1	608.0

LQ = limit of quantification.

Table 3 Classification of the VOC scores

	Rotated factor loadings*
Factor 1 (aromatic hydrocarbons)	
m/p-xylene	0.93
Ethylbenzene	0.93
Toluene	0.89
O-xylene	0.87
Benzene	0.80
Factor 2 (aldehydes)	
Acrolein	0.84
Acetaldehyde	0.79
Hexaldehyde	0.64
Formaldehyde	0.57
Factor 3 (aliphatic hydrocarbons)	
n-undecane	0.90
n-decane	0.89
Factor 4 (halogenated hydrocarbons)	
Tetrachloroethylene	0.66
Trichloroethylene	0.56
1,4-dichlorobenzene	0.53

* Principal component analysis, high loading variables.
VOC = volatile organic compound.

total variance in the dataset on the principal component analysis (Table 3). These corresponded to VOC families: Factor 1 or aromatic hydrocarbons, Factor 2 or aliphatic hydrocarbons, Factor 3 or aldehydes and Factor 4 or halogenated hydrocarbons.

Relationships between exposure to multi-VOC mixture and respiratory health

The marginal model adjusted for confounders showed significant linear positive associations between respiratory conditions and VOC scores (Table 4). Aromatic hydrocarbons was significantly associated with rhinitis (odds ratio [OR] 1.16, 95% confidence interval [CI] 1.00–1.35), aliphatic hydrocarbons with asthma (OR 1.25, 95% CI 1.02–1.53) and cough (OR 1.30, 95% CI 1.08–1.56). We found significant non-linear associations between halogenated hydrocarbons and asthma, wheezing and rhinitis: the ORs decreased before a certain value and increased after (Figure 1). Significant non-linear associations were also found between aromatic hydrocarbons and wheezing and between aldehydes and phlegm: the ORs increased until they reached a certain value and then became constant. The sensi-

tivity analysis showed similar results for asthma, rhinitis, cough and wheezing. Exposure to aliphatic hydrocarbons was significantly associated with phlegm (OR 1.29, 95% CI 1.02–1.63).

Interaction between VOC scores and allergens

The results of the models exploring interactions are presented in Figure 2. Aldehydes and *Can f1* had a significant synergistic effect on wheezing, rhinitis, cough and phlegm, which persisted when restricting the population to the individual who slept in the room where the VOCs were measured. Aromatic hydrocarbons had a significant synergistic effect with *Can f1* on cough and phlegm, which persists in the restricted population, and with *Fel d1* on wheezing in the restricted population alone. Aliphatic hydrocarbons had a synergistic effect with *Fel d1* on phlegm and an antagonist effect with *Can f1* on wheezing only in the restricted population. Aromatic hydrocarbons and *Fel d1* had a significant antagonist effect on asthma, which disappeared in the restricted population. Only two interactions involving dust mite allergens were found: a synergistic effect of aldehydes and *Der p1* on wheezing and an antagonist effect of aromatic hydrocarbons and *Der p1* on rhinitis, which persisted in the restricted population. The VOC scores and allergen concentrations were not highly correlated (Spearman correlations ranged from –0.07 to 0.04 between *Can f1* and the VOC scores, and from –0.10 to 0.04 between *Fel d1* and the VOC scores).

DISCUSSION

Main findings

In our representative sample of residential dwellings, we found a significant synergistic effect between VOC families and pet allergens, in particular dog allergens, on asthma and rhinitis. The associations between VOCs and respiratory outcomes were stronger in the presence of allergens. Aldehydes and *Can f1* had a significant synergistic effect on wheezing, rhinitis, cough and phlegm. Aromatic hydrocarbons with *Can f1* had a significant synergis-

Table 4 Adjusted associations between VOC factors and respiratory health outcomes*

	<i>n</i>	Aromatic hydrocarbons aOR (95% CI)	Aliphatic hydrocarbons aOR (95% CI)	Aldehydes aOR (95% CI)	Halogenated hydrocarbons aOR (95% CI)
Rhinitis	916	1.16 (1.00–1.35) ^{†‡}	1.08 (0.95–1.23)	1.00 (0.87–1.16)	1.12 (0.97–1.30)
Asthma	905	1.21 (0.99–1.47)	1.25 (1.02–1.53) [†]	0.98 (0.74–1.29)	1.16 (0.93–1.46)
Cough	920	1.04 (0.84–1.30)	1.30 (1.08–1.56) [§]	1.07 (0.84–1.36)	1.04 (0.81–1.33)
Wheezing	921	1.10 (0.90–1.36)	1.00 (0.75–1.33)	1.10 (0.83–1.43)	1.00 (0.75–1.34)
Phlegm	910	1.13 (0.92–1.38)	1.19 (0.94–1.50)	0.93 (0.71–1.21)	0.95 (0.74–1.23)

* ORs are adjusted for sex, age, smoking habit, relative humidity, time of survey, presence of pets, presence of mould and the highest educational level among individuals of the dwelling and outdoor air pollution.

[†] $P < 0.05$.

[‡] Statistically significant.

[§] $P < 0.01$.

VOC = volatile organic compound; aOR = adjusted odds ratio; CI = confidence interval.

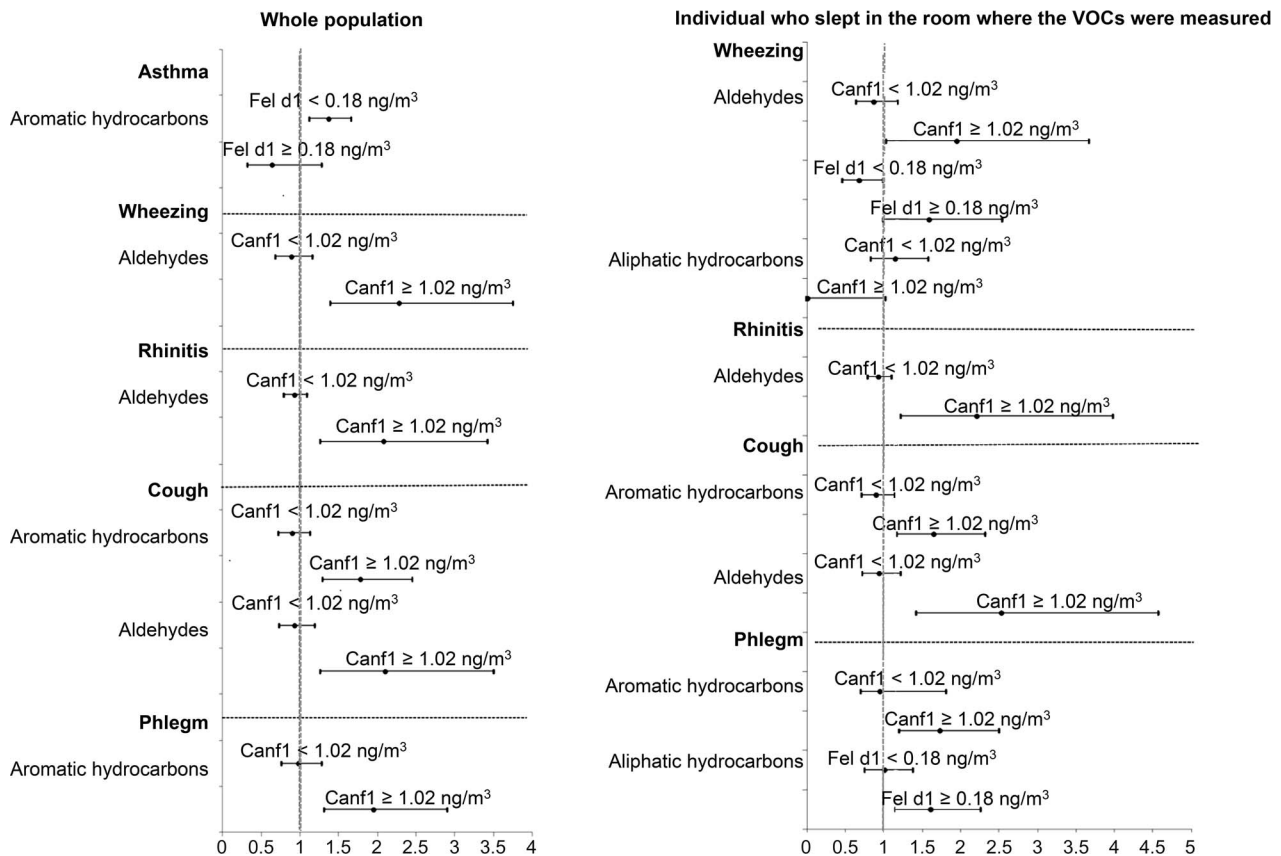


Figure 1 Non-linear associations between VOC factor and respiratory outcomes using the GEE model with cubic splines. Only non-linear associations with $P < 5\%$ are shown. CL = confidence limits (values defining the range of the confidence intervals); VOC = volatile organic compound.

tic effect on cough and phlegm. Aliphatic hydrocarbons with *Fel d1* had a synergistic effect on phlegm.

Literature

Our results are consistent with our previous findings on asthma and rhinitis.¹⁶ Most importantly, we were able to show a synergistic effect of VOCs and allergens on respiratory health. Interactions between VOCs and indoor allergens have rarely been explored. Rumchev et al. found a significant interaction between toluene and house dust mite on asthma in young children.⁶ McConnell et al. reported that bronchitis symptoms of air pollution were higher among children who owned both a cat and a dog, with the largest effect observed for elemental and organic carbon.²³ Carlsten et al. found an increasing risk of asthma in a high-risk birth cohort after early concomitant exposure to dog allergen and nitrogen dioxide (NO₂) or environmental tobacco smoke.²⁴

Potential mechanisms

There is evidence that predisposed individuals have increased airway reactivity induced by air pollution and increased bronchial responsiveness to inhaled pollen allergens.²⁵ Chemical pollutants may have an adjuvant immunological effect on immunoglobulin

E synthesis in atopic individuals, as already shown with diesel exhaust particles.²⁶ The following three experimental studies highlighted interactions between chemical pollutants and allergens. Motta et al. showed that traffic-related pollutants can trigger the release of allergen-containing granules from grass pollen and increase the bioavailability of airborne pollen allergens.¹¹ Jenkins et al. showed that exposure for 3h to 200 ppb ozone (O₃), 400 parts per billion (ppb) NO₂, and 200 ppb O₃ + 400 ppb NO₂ significantly decreased the dose of allergen required to decrease the forced expiratory volume in 1 second by 20% in mild atopic patients with asthma.¹² Devalia et al. showed that exposure to a combination of sulphur dioxide and NO₂ enhances the airway response to inhaled allergen.¹³ A study reported that exposure to VOCs may increase the allergic immune response by interfering with dendritic cell function and by inducing oxidative stress.²⁷ Interactions may also occur in mucous membranes and the skin: VOCs may impair mucociliary clearance and consequently facilitate the penetration of inhaled allergens.²⁸

Strengths and limitations

Strengths include the large population-based sample of residential dwellings randomly selected and the use

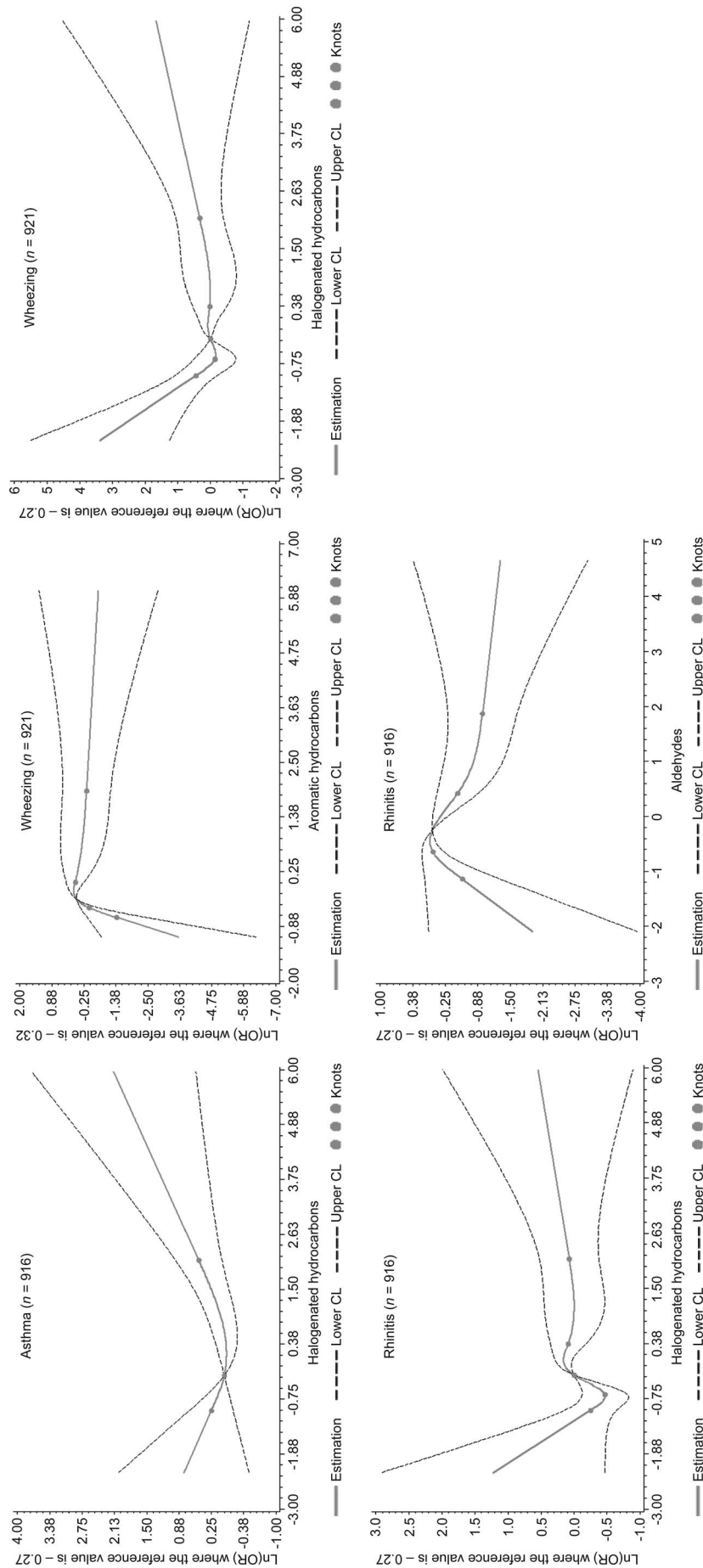


Figure 2 Interaction between VOC factors and pet allergens. Adjusted associations between VOC factors and health according to the level of *Fel d1* and *Can f1*. Only significant interactions are shown. ORs (and 95% confidence intervals) are adjusted for sex, age, smoking habit, relative humidity, time of survey, presence of moulds and the highest educational level among individuals of the dwelling and outdoor air pollution. The number of individuals included in each model was as follows: 874 for asthma, 889 for wheezing, 885 for rhinitis, 889 for cough and 880 for phlegm in the whole population, and 716 for asthma, 728 for wheezing, 723 for rhinitis, 728 for cough and 720 for phlegm in the restricted population. OR = odds ratio; CL = confidence limits; VOC = volatile organic compound.

of a wide range of quantitatively assessed VOCs, leading to a better evaluation of individual exposure. In addition, our study conducted a multi-pollutant analysis and interactions with allergens were explored. Our method, which was based on the categorisation of each component, gave a priori equal importance to each pollutant. Finally, our health data, collected using a standardised questionnaire, are consistent with previous findings.²⁹

Our study also had some limitations. The measurement was performed for a single week and may be a poor proxy for past year exposure. Nevertheless, at least 97% of the reference subjects had already lived in their current residence the year preceding the survey. Besides, people were asked not to alter their lifestyle during the period of the survey. Although homes were not all surveyed at the same time, survey season adjustment did not change the results. Our study failed to assess the individual's total exposure in the past year, since the concentrations at home are not representative of the outdoor, as well as of air exposure in other indoor spaces. Indeed, we cannot exclude the probability that reported symptoms were due to past indoor or outdoor exposures. Moreover, it is possible that unmeasured pollutants or environmental conditions played a role as potential confounders. Although ambient environment such as major air pollutants were not measured, it is clear that ambient air pollutants penetrate indoors, when they become a major source of indoor pollution as well. In addition, as information on atopy was not available, we could not consider it among other risk factors. This may have led to an overestimation of the effects of the VOCs. However, since the sample was randomly selected, we may expect to obtain a potentially equal distribution of atopic individuals across all the homes with high VOC concentrations and those with low concentrations. Rhinitis and asthma diagnoses were not confirmed by a physician, which can lead to misclassifications in case of some individuals. However, in France, it has been shown that 75% of asthma reported on a questionnaire is confirmed by a physician.³⁰ Finally, the large number of missing values (20%) on house dust mite allergens in our database should lead us to remain cautious about the interpretation of our results.

CONCLUSION

Our findings suggest that indoor VOCs are associated with asthma, rhinitis and other respiratory conditions and may have stronger effects in the presence of pet allergens. This cross-sectional study lays the foundation for further cohort and toxicological studies on the health impact of VOCs at concentrations commonly found in indoor air and

the possible causal relationship between VOCs and respiratory conditions. Reducing exposure to high concentrations of indoor VOCs, as well as a better control of allergens should be a focus of public health interventions.

Acknowledgments

The authors would like to thank D Sherrill (University of Arizona, Tucson, AZ, USA) for useful discussions and J-P Lucas, A Gregoire and M Derbez (Centre Scientifique et Technique du Bâtiment [CSTB]) for their help with data management.

This study received support from the French Ministry of Construction and Urbanism, the French Ministry of Environment, the French Ministry of Health, the French Ministry of Research, the Centre Scientifique et Technique du Bâtiment, the Agency for Environment and Energy Management (ADEME), the *Agence Nationale pour l'Amélioration de l'Habitat* (National Housing Agency) and the *Institut de Veille Sanitaire* (Health Monitoring Institute), Paris, France.

Conflict of interests: none declared.

References

- 1 Leech JA, et al. It's about time: a comparison of Canadian and American time-activity patterns. *J Expo Anal Environ Epidemiol* 2002; 12(6): 427–432.
- 2 Mendell MJ. Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review. *Indoor Air* 2007; 17(4): 259–277.
- 3 Viegi G, et al. Indoor air pollution and airway disease. *Int J Tuberc Lung Dis* 2004; 8(12): 1401–1415.
- 4 Bernstein JA, et al. The health effects of non-industrial indoor air pollution. *J Allergy Clin Immunol* 2008; 121(3): 585–591.
- 5 Arif AA, Shah SM. Association between personal exposure to volatile organic compounds and asthma among US adult population. *Int Arch Occup Environ Health* 2007; 80(8): 711–719.
- 6 Rumchev K, et al. Association of domestic exposure to volatile organic compounds with asthma in young children. *Thorax* 2004; 59(9): 746–751.
- 7 McGwin G, Lienert J, Kennedy JI. Formaldehyde exposure and asthma in children: a systematic review. *Environ Health Perspect* 2010; 118(3): 313–317.
- 8 Rumchev KB, et al. Domestic exposure to formaldehyde significantly increases the risk of asthma in young children. *Eur Respir J* 2002; 20(2): 403–408.
- 9 Zhao Z, et al. Asthmatic symptoms among pupils in relation to winter indoor and outdoor air pollution in schools in Taiyuan, China. *Environ Health Perspect* 2008; 116(1): 90–97.
- 10 Wolkoff P. Volatile organic compounds sources, measurements, emissions, and the impact on indoor air quality. *Indoor Air* 1995; 5(S3): 5–73.
- 11 Motta AC, et al. Traffic-related air pollutants induce the release of allergen-containing cytoplasmic granules from grass pollen. *Int Arch Allergy Immunol* 2006; 139(4): 294–298.
- 12 Jenkins HS, et al. The effect of exposure to ozone and nitrogen dioxide on the airway response of atopic asthmatics to inhaled allergen: dose- and time-dependent effects. *Am J Respir Crit Care Med* 1999; 160(1): 33–39.
- 13 Devalia JL, et al. Effect of nitrogen dioxide and sulphur dioxide on airway response of mild asthmatic patients to allergen inhalation. *Lancet* 1994; 344(8938): 1668–1671.
- 14 D'Amato G, et al. Allergenic pollen and pollen allergy in Europe. *Allergy* 2007; 62(9): 976–990.
- 15 Scannell C, et al. Greater ozone-induced inflammatory responses in subjects with asthma. *Am J Respir Crit Care Med* 1996; 154(1): 24–29.

- 16 Billionnet C, et al. Quantitative assessments of indoor air pollution and respiratory health in a population-based sample of French dwellings. *Environ Res* 2011; 111(3): 425–434.
- 17 Kirchner S, et al. Air quality in French homes. *Environnement, Risques et Santé* 2007; 6: 259–269.
- 18 Kirchner S, et al. Indoor air quality in French dwellings. Sint-Stevens-Woluwe, Belgium: Air Infiltration and Ventilation Centre, 2008.
- 19 Mosqueron LN, et al. Ranking indoor pollutants according to their potential health effect, for action priorities and costs optimization in the French permanent survey on indoor air quality. Paper presented at Healthy Building 7th International Conference, 7–11 December 2003, Singapore; 3: pp 138–143.
- 20 Ramalho O, et al. French permanent survey on indoor air quality. Part 1: Measurement protocols and quality control. Healthy Building, 2006, 4–8 June 2006 2006, Lisbon, Portugal: pp 321–326.
- 21 Derbez M, et al. French permanent survey on indoor air quality. Part 2: Questionnaires and validation procedure of collected data. Healthy Building, 2006, 4–8 June 2006 2006, Lisbon, Portugal: pp 327–331.
- 22 Kachigan SK. Multivariate statistical analysis: a conceptual introduction. New York, NY, USA: Radius Press, 1991.
- 23 McConnell R, et al. Dog ownership enhances symptomatic responses to air pollution in children with asthma. *Environ Health Perspect* 2006; 114(12): 1910–1915.
- 24 Carlsten C, et al. Combined exposure to dog and indoor pollution: incident asthma in a high-risk birth cohort. *Eur Respir J* 2011; 37(2): 324–330.
- 25 Peden DB, Setzer RW, Jr, Devlin RB. Ozone exposure has both a priming effect on allergen-induced responses and an intrinsic inflammatory action in the nasal airways of perennially allergic asthmatics. *Am J Respir Crit Care Med* 1995; 151(5): 1336–1345.
- 26 Troise C, et al. Allergy to pollens from *Betulaceae* and *Corylaceae* in a Mediterranean area (Genoa, Italy) — a ten-year retrospective study. *J Investig Allergol Clin Immunol* 1992; 2(6): 313–317.
- 27 Bonisch U, et al. Volatile organic compounds enhance allergic airway inflammation in an experimental mouse model. *PLoS One* 2012; 7(7): e39817.
- 28 Knox RB, et al. Major grass pollen allergen Lol p 1 binds to diesel exhaust particles: implications for asthma and air pollution. *Clin Exp Allergy* 1997; 27(3): 246–251.
- 29 European Community Respiratory Health Survey. Variations in the prevalence of respiratory symptoms, self-reported asthma attacks, and use of asthma medication in the European Community Respiratory Health Survey (ECRHS). *Eur Respir J* 1996; 9(4): 687–695.
- 30 Moreau D, et al. Prevalence and severity of asthma in adolescents in France. Cross-sectional and retrospective analyses of a large population-based sample. *Int J Tuberc Lung Dis* 2000; 4(7): 639–648.

R É S U M É

CONTEXTE : Les composés organiques volatiles (VOC) sont généralement corrélés les uns aux autres à l'intérieur des bâtiments et peuvent avoir un effet additif ou synergique sur la santé. Une synergie avec des allergènes est un mécanisme soupçonné d'être impliqué dans un effet respiratoire.

OBJECTIF : Déterminer les effets de l'exposition aux interactions entre VOC et allergènes sur les symptômes respiratoires chez les individus âgés de ≥ 15 ans.

SCHÉMA : Une enquête nationale transversale a mesuré 20 VOC et des allergènes aériens de chiens et chats dans 490 habitations en France. Un questionnaire standardisé a suivi les conditions respiratoires chez 1012 habitants. Quatre facteurs de score de VOC, à savoir des combinaisons linéaires, ont été générées grâce à une analyse du composant principal. Pour tenir compte du phénomène de multiple pollution, des

modèles marginaux ont été utilisés pour modéliser les relations entre exposition au mélange de VOC et conditions respiratoires. Des modèles stratifiés ont été mis en œuvre pour examiner l'interaction entre allergènes et VOC.

RÉSULTATS : Le score d'hydrocarbures aromatiques été associé à une rhinite et à un wheezing, le score d'hydrocarbures aliphatiques avec l'asthme et la toux, les hydrocarbures halogénés avec l'asthme, un wheezing et une rhinite. Les aldéhydes et *Can f1* ont eu un effet synergique significatif sur le wheezing et la rhinite. Les hydrocarbures aliphatiques ont eu un effet antagoniste avec *Can f1* sur le wheezing.

CONCLUSION : Nos données confirment les effets secondaires de l'exposition au mélange de VOC sur les problèmes respiratoires, renforcé par la présence d'allergènes d'animaux domestiques.