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ORIGINAL PAPER

Health effects of the 2012 Valencia (Spain) wildfires on children in a cohort study

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Abstract In July 2012, two simultaneous wildfires burnt a big area in Valencia (Spain), where a birth cohort study (INMA) is being developed. The heavy smoke covered the whole INMA study area for several days. We aimed at evaluating the 2012 Valencia wildfire effects on the health of children enrolled in the INMA-Valencia cohort. Two weeks after the extinction of the wildfires, a phone survey was conducted and finally 460 individuals were enrolled. We considered a wildfire period (12-day interval when they were active) and a control period (12-day interval just before wildfires). Parents were asked about respiratory symptoms experienced during both periods, and during wildfires only about the preventive measures adopted and the perception of exposure, along with individual data collected through the different follow-up surveys of the cohort. Conditional logistic regression models were applied, and we included interaction terms for asthma/rhinitis and level of perception of exposure; 82.4 % perceived smoke smell outdoors, 40 % indoors and more than 90 % of the families observed the presence of ash. An adjusted odds ratio of 3.11 [95 % confidence interval 1.62–5.97] for itchy/watery eyes and 3.02 [1.41–6.44] for sore throat was obtained. Significant interaction terms for rhinitis and asthma in itchy/watery eyes and sneezing, and only asthma for sore throat were obtained. Exposure to wildfire smoke was associated with increased respiratory symptoms in this child population, particularly affecting susceptible individuals with asthma or rhinitis.

Keywords Wildfire · Children · Allergy · Air pollution · Cohort · Asthma · Rhinitis

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Introduction

At the end of June 2012, two separate wildfires broke out almost simultaneously 30 kilometers (18 miles) west of the city of Valencia, on Spain's eastern coast. The fires, which remained active for 5 and 6 days respectively, devastated an area of 50,000 hectares of forest, more than a half of the total area burned in Spain during the preceding year of 2011. They were

considered the worst wildfires for more than a decade in the Valencia region. Almost three thousand people were evacuated from their homes in twenty municipalities, and fourteen main roads were closed. The fires began after a week in which temperatures across many parts of Spain soared to close to 40 degrees Celsius and came after one of the driest winters in 70 years. Air quality in the region was severely affected, and thousands of people were exposed to quantities of wildfire-generated particulate matter (PM) greatly in excess of the current standards. The heavy smoke was visible more than 50 km away from the wildfires' seats, and it covered a vast area of high population density, including the city of Valencia. In fact, according to the data of the Air Quality Control Network of the Valencia Region (http://www.cma.gva.es/web/indice.aspx?nodo=27&idioma=C), the monitors located near the wildfires and in the city of Valencia registered daily maximum levels above 175 $\mu g/m^3$ of particulate matter (PM) with aerodynamic diameter up to 10 μm (PM10) during the wildfires. Also, the size distribution of the PM changed with an increase in the ratio of fine and ultrafine particles per PM10 mass up to a maximum of 0.9.

Previous research of wildfire effects was mainly focused on adult mortality and morbidity endpoints (Analitis et al. 2012; Caamano-Isorna et al. 2011; Crabbe 2012; Delfino et al. 2009; Elliott et al. 2013; Emmanuel 2000; Hanigan et al. 2008; Johnston et al. 2007; Vora et al. 2011). However, to date, there is still limited research on the impact of wildfire smoke on vulnerable population groups, such as children (Jalaludin et al. 2000; Künzli et al. 2006; Mirabelli et al. 2009). PM exposure on children, which is the main air constituent of wildfire smoke, has been associated in air pollution studies with deficits in lung function (Gao et al. 2013; Gauderman et al. 2004), increased respiratory illness and symptoms (Gruzieva et al. 2013), increased school absences (Makino 2000; Peters et al. 1997), and hospitalizations for respiratory disease (Iskandar et al. 2012; Ostro et al. 2009). Also, there is substantial and growing evidence that air pollution is a risk factor for increased mortality in infants and young children (Woodruff et al. 2006).

This environmental disaster poses a huge threat to Valencia's population, where it is included the INMA-Valencia cohort. Unfortunately, 30 % of the forest included in the rural study area of the INMA-Valencia cohort was burnt, and the smoke covered almost the whole study area for several days (Fig. 1). We assessed the acute effects of exposure to fire smoke on children's health enrolled in the INMA-Valencia cohort.

Methods

Study design and data collection

The INMA project is a network of birth cohorts in Spain that aims to study the role of environmental pollutants in air, water and diet during pregnancy and early childhood in relation to child growth and development (www.proyectoinma.org; Guxens et al. 2012). The INMA-Valencia cohort is one of the seven Spanish birth cohorts included in this project.

Two weeks after the extinction of the wildfires, a phone survey was conducted: All families enrolled in the 5-year-old follow-up of the INMA-Valencia cohort (whose survey process was underway from April 2012 to June 2013) were phoned by two trained interviewers. In a final attempt to obtain as many respondents as possible, we sent the survey by email to the untraceable families. These were families who had not answered calls on at least three occasions at different times of the day.

For study design purposes, we considered two different study periods: the wildfire period (June 28th–July 8th), when wildfires were active or there were still smoldering ashes in the burnt area, and also a control period that corresponded to the 12-day interval just before wildfires (June 16th–27th). The survey was based on one used in a recent study of Künzli and colleagues, whose aim was to study the acute effects of fire smoke produced in the 2003 Southern California wildfires on the health of a schoolchildren cohort (Künzli et al. 2006). Parents, or in their absence, any other adult who lived with the child, were asked to answer simple questions about the presence of several health symptoms during the wildfire and control periods: wheezing, sneezing, itchy/watery eyes, dry or wet cough, asthma attack, bronchitis, sore throat, and cold. Information about the adoption of preventive measures due to wildfires was also collected: evacuation to a refuge, air-conditioning, use of mask, closed windows, or if children were less time outdoors than usual. And, finally, families were asked about the perception of exposure, such as smoke smell (outside

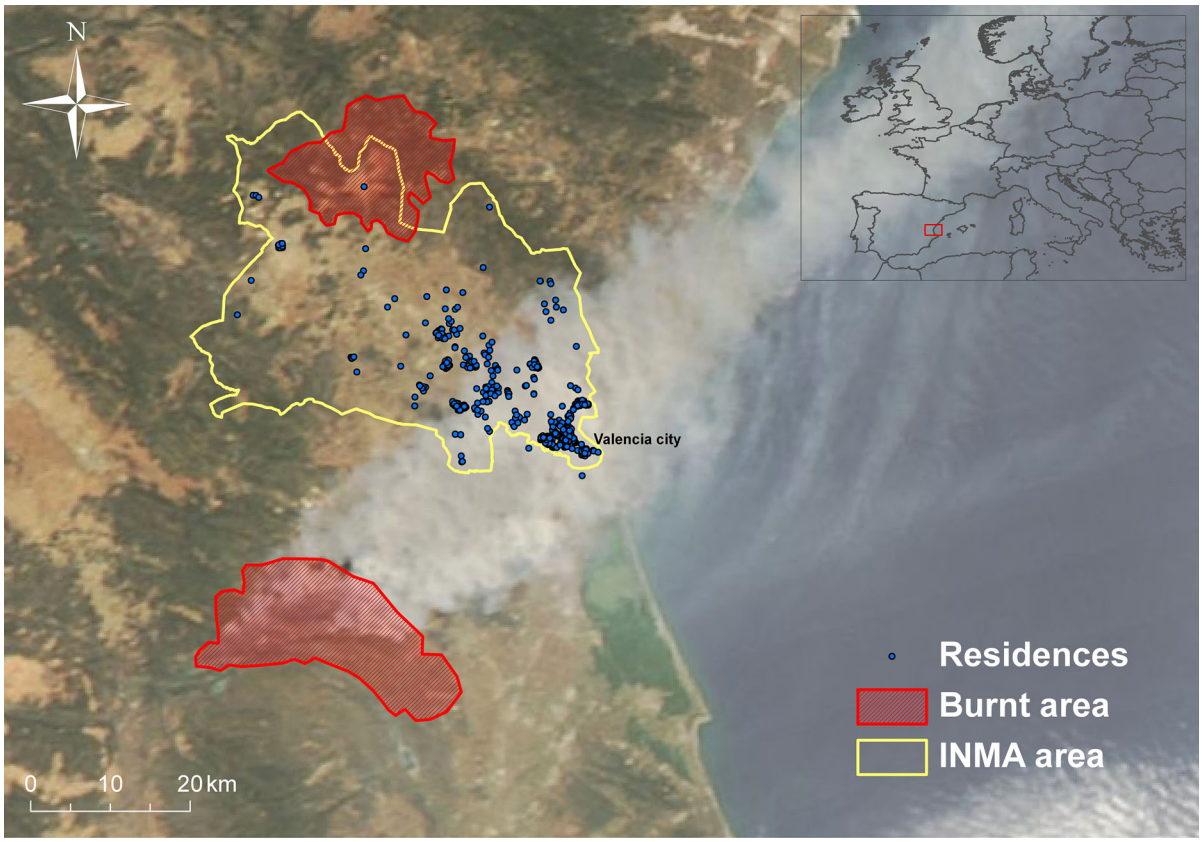

Fig. 1 Satellite image of the INMA-Valencia study area during the summer 2012 wildfires, showing the INMA and burnt areas along with the residential addresses of the individuals (July 29, 2012; *Source* MODIS-NASA sensor, Aqua satellite)

and inside their homes), dense air and the presence of ashes in the air. In both questionnaire sections, parents were asked to select in each case between "never"/"1–3 days"/"4–6 days"/"everyday," and they referred to the wildfire period alone. Parents were asked about the minimum distance that their children were from the fires.

Likewise, we collected some information about the location(s) of the child during both periods. With these data, we were able to identify the children who were in the surroundings of the affected wildfire area and had been exposed to wildfire smoke to some extent. Families were asked to report how many days the child was at home and/or in an alternative location, choosing between "every day," "4–6 days," "1–3 days" and "never". Also, the full address of the alternative location (if any) was collected. The study area for this purpose was considered as the INMA-Valencia area along with all the towns or villages which were not exactly within this area, but were located approximately 10 km from wildfires.

Similarly, general information of the individuals was obtained from the most updated data collected through the different INMA follow-up surveys: gender, environmental exposure to tobacco smoke (if in the 4-year-old follow-up families reported that the child was usually exposed to environmental tobacco smoke at home or anywhere else), social class and type of area where the residence is located (Domingo-Salvany et al. 2000). Likewise, children who reported ever being diagnosed with asthma or rhinitis by a doctor in the 5-year-old follow-up were considered as individuals with asthma and/or rhinitis.

Statistical analysis

Random-effects logistic regression was used to estimate the odds of each respiratory symptom in relation

to the exposure (during the wildfire vs before) with random intercepts to account for the potential correlation among observations within the same child (e.g., within-child correlation). Models were adjusted for sex, social class, exposure to environmental tobacco smoke and type of area. Asthma, rhinitis and each exposure perception indicator were also tested separately as potential effect modification factors. All analyses were performed using STATA software version 11 (StataCorp, College Station, TX, USA). In all instances, a p value <0.05 was considered statistically significant.

Results

From the initial sample of 536 children who were enrolled in the INMA 5-year follow-up in Valencia, finally 496 families accepted participating in the phone survey (response rate of 92.5 %). Those 40 remaining cases corresponded to families who refused to participate or did not answer our calls on at least three occasions at different times of the day. In these cases, they were sent the survey by e-mail, but no answer was received.

A total of 337 children (67.9 %) reported remaining at their usual residential address everyday during the control and case periods. But 418 (84.2 %) reported that the child had been at home or in an alternative location within the study area everyday during both periods, and 460 children (93 %) were there on at least 50 % of the days during both periods too. For the purposes of this study, we considered this last group as the selected study population, as a means of balancing between assuring that the entire study sample was exposed to wildfires, and not reducing the sample size significantly.

Regarding the general characteristics of the selected study population (Table 1), there was a slightly higher number of males, nearly half of the families belonged to the lower category of social class [that is, skilled and partly skilled manual workers (IV) and unskilled manual workers (V)], three quarters of the families reported that the child was exposed to environmental tobacco smoke and more than half of the selected population reported living in a urban or metropolitan area. Likewise, around 4–6 % of the children reported in the 5-year-old follow-up that they were diagnosed with asthma and/or rhinitis by the doctor.

Table 1 General characteristics of the study population ($N = 460$; data from the 5-year-old INMA follow-up survey)

	N	%
Gender		
Boy	234	50.9
Girl	226	49.1
Social class		
I + II	130	28.3
III	118	25.7
IV + V	212	46.1
Exposure to tobacco smoke*	337	75.6
Area		
Urban–metropolitan	263	57.2
Semiurban	165	35.9
Rural	32	7.0
Rhinitis**	24	5.8
Asthma***	21	4.9

* $N = 446$, ** $N = 413$; *** $N = 433$

Nearly 40 % of families reported that they used air-conditioning and/or their children spent less time than usual outdoors due to wildfires at least 1 day during the wildfire period (Table 2). More than half of the population kept their windows closed at least 1 day during wildfires, ten families were evacuated from their homes and just two children wore a mask. Likewise, almost every family reported that they had seen ashes in the air at least 1 day during the wildfire period. A high percentage of families smelled smoke outdoors at least 1 day, whereas almost half of the population reported smoke smell indoors. The same percentage reported that air was so dense that they could not see further than a few blocks, and they were <30 km from the fires. We observed slight discrepancies when we compared these percentages with those obtained in each asthmatic and rhinitis population: In general, the percentages were higher in these groups, especially for the perception of smoke smell indoors for asthmatics, and keeping their windows closed for both groups, but no statistical differences were obtained.

Larger prevalences were obtained for itchy/watery eyes, sneezing, sore throat and dry cough (Table 3); 9.4 % of children answered having itchy or watery eyes during wildfires, which is the most reported outcome, followed by sneezing (8.7 %) and sore throat (6.7 %).

Table 2 Reported perception of exposure and preventive measures during wildfire period (at least 1 day)

	Total		Rhinitis ($N = 24$)		Asthma ($N = 21$)	
	N	%	*N*	%	*N*	%
Perception of exposure						
Smoke smell outside home	378	82.4	22	91.7	19	90.5
Smoke smell inside home	183	39.9	11	45.8	13	61.9
Dense air outside home	185	40.5	8	33.3	10	47.6
Ashes in the air	438	96.1	24	100.0	21	100.0
Near to fires (<30 km)	184	42.6	8	36.4	7	35.0
Preventive measures						
Staying in an evacuation center (by authorities)	6	1.3	0	0.0	1	4.8
Staying in an evacuation center (own decision)	4	0.9	0	0.0	0	0.0
Use of air-conditioning	184	40.4	11	45.8	9	42.9
Keeping windows closed	264	58.2	18	75.0	16	76.2
Use of mask	2	0.4	0	0.0	0	0.0
Less time than usual outside home	176	38.5	11	45.8	11	52.4

Table 3 Prevalence of health effects reported during the control and wildfire periods

	Control period		Wildfire period		*p* value*
	N	%	*N*	%	
Itchy/Watery eyes	16	3.48	43	9.35	<0.001
Sneezing	34	7.39	40	8.70	0.376
Sore throat	12	2.61	31	6.74	0.002
Dry cough	20	4.35	26	5.65	0.304
Cold	12	2.61	14	3.04	0.637
Wet cough	8	1.74	9	1.96	0.763
Whistling and wheezing**	4	0.87	3	0.65	–
Asthma attack**	1	0.22	2	0.43	–
Bronchitis**	1	0.22	0	0.00	–

* *p* value McNemar test.
** Unable to perform the test due to the low sample size

Figure 2 shows the main effects of wildfires on the four most reported outcomes in terms of adjusted odds ratio (aOR). Itchy or watery eyes reported a consistent aOR of 3.11 [95 % confidence interval (CI) 1.62–5.97; numerical results in Table S1 Supplemental File]. A similar result was obtained for sore throat, with an aOR of 3.02 (95 % CI 1.41–6.44). By subgroups of perception of wildfire exposure, in general the OR estimates were slightly higher for those who perceived the exposure on at least 1 day, but they did not reach statistical significance. Nevertheless, when we evaluated the wildfire effect on children's health with/without rhinitis or asthma separately, significant interaction terms for rhinitis and asthma in itchy/watery eyes and sneezing, and only asthma with sore throat were obtained. In detail, a higher risk of itchy/watery eyes due to wildfires was found in children with asthma [9.26 (95 % CI 2.14–40.12)] and in children with rhinitis [8.06 (95 % CI 1.98–32.88)], compared to the non-asthmatic population [aOR 3.23 (95 % CI 1.63–6.40)] and children without rhinitis [aOR 3.23 (95 % CI 1.58–6.59)]. In the case of sneezing, we obtained that the wildfire effect was 7.19 (95 % CI 1.35–38.58) and 11.40 (95 % CI 2.01–64.52) in children with rhinitis or asthma, respectively, whereas no effect was obtained in the non-rhinitis and non-asthma population, or even in the whole study sample. Inconsistent

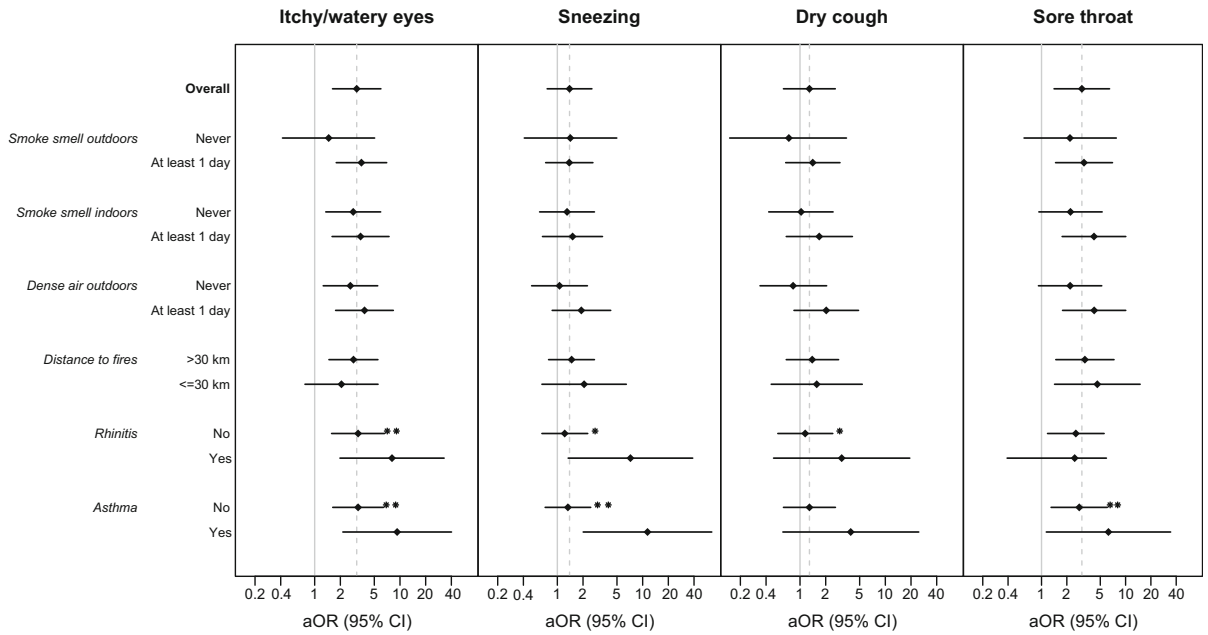

Fig. 2 Main effects of wildfires on selected outcomes [adjusted odds ratio (aOR) and 95 % confidence intervals (CI), with interaction terms for asthma/rhinitis and variables of perception of exposure]. Adjusted by sex, social class, exposure to environmental tobacco smoke and type of area.*Interaction p value = 0.05–0.01. **Interaction p value <0.01

results were obtained for dry cough, while an elevated risk of sore throat was observed in children with asthma [6.25 (95 % CI 1.14–34.30)], and aOR estimates of around 2 were obtained for this symptom in other three population subgroups.

Discussion

The Valencia 2012 wildfires posed a potential threat to the Valencia population due to their size, great strength and proximity to highly populated areas. Moreover, the meteorological conditions were crucial in the flame spread and in the direction and dispersion of the smoke plume: The strong southwest winds during the initial days caused the fires to spread rapidly through a huge forest area which finally resulted in 50 thousand hectares burnt. It could even be observed in the satellite image provided that the wildfire smoke covered the city of Valencia for several days due to the prevailing wind direction (Fig. 1).

In this study, we obtained evidence to show that the Valencia 2012 wildfires affected the INMA-Valencia children. Fires were associated with a positive risk of itchy/watery eyes and sore throat in our study population. These results are in line with those observed in previous studies: Künzli et al. (2006) showed that the exposure to wildfire smoke was associated with increased eye and respiratory symptoms in a study conducted in a schoolchildren cohort of South California (USA). Other occupational studies involving firefighters showed that wildfire smoke lead to acute exacerbations of respiratory and eye symptoms (Amster et al. 2013; Miranda et al. 2012; Ribeiro et al. 2009).

Over the last decades, attention has been paid to the effects of wildfire smoke on population health. A recent study of Johnston et al. (2012) obtained an average global mortality attributable to landscape fire smoke was 339,000 deaths annually. PM is the predominant air pollutant seen in wildfire smoke, which is caused particularly by the burning of vegetation and wood. The health effects associated with particulate air pollution are well documented, and they are mostly related to the respiratory and cardiovascular functions (Analitis et al. 2012; Anderson et al. 2012; Betha et al. 2014; Crabbe 2012; Delfino et al. 2009; Johnston et al. 2002; Pavagadhi et al. 2013).

We obtained evidence of a higher tendency of individuals with asthma or rhinitis to several health effects due to their exposure to wildfires. It is reported

that PM pollution increases oxidative stress and aggravates background inflammation of the airways (MacNee and Donaldson 2003). The exposure to elevated quantities to PM is associated with a more severe detrimental lung function in individuals affected by respiratory diseases.(Pope and Dockery 2006) With regard to wildfire episodes, time series studies performed in several locations obtained an increasing number of hospital admissions due to asthma during wildfire period (Elliott et al. 2013; Johnston et al. 2002). Vora et al. (2011) showed that the 2007 San Diego wildfires may have led to an increase in airways inflammation in asthmatics.

Our results are consistent with these findings, with higher estimated risks in the affected population compared to the non-rhinitis or non-asthmatic groups for the selected health outcomes. Specifically, we obtained a general wildfire effect on itchy/watery eyes that remained positive and statistically significant after stratifying between children with or without rhinitis/asthma. However, the risks for these affected groups were three times higher than the estimate obtained for the non-affected populations. Similar patterns could be observed in the risk estimates for sore throat, but an increased risk was obtained only in asthmatic individuals. It seems that in general the wildfires themselves lead to an increase in itchy/watery eyes and sore throat symptoms since it could be considered as a more unspecific health outcome compared to the rest. But they especially affected the group of children with rhinitis or asthma, maybe to an exacerbation of their current inflammatory status. On the other hand, a risk of sneezing was only observed in individuals with rhinitis or asthma, showing that this symptom could be mediated by an allergic status of the individual. However, we did not observe evidence of asthma exacerbations or deterioration of their allergic status in terms of higher risk of dry cough due to wildfires. Our results suggest that there may be different "patterns" in the relationship between asthma/rhinitis with the reported health outcomes. This could be due to the nature of the symptoms and their relationship with the pathologic background of asthma and rhinitis.

Also, we generally observed a common trend consisting of slightly higher risks among individuals who reported having perceived smoke smell in/outdoors and dense air on at least 1 day. But none of the interaction terms in these cases was statistically significant, maybe due to the lack of statistical power. However, the results of the variable "distance to fires" seemed to be unclear: The estimates were very similar for both categories, or even with contradictory results for itchy/watery eyes. It could be partly due to the potential inaccuracy of the reported distance, since it might depend on the capability of the adult to approximately measure the distance and it might be also influenced by the individual perception of the proximity of the wildfire, as stated in previous questionnaire-based exposure assessment studies (Kuehni et al. 2006). Unfortunately, we did not have information on the exact time-activity pattern of the child during the study period to objectively measure the minimum distance to wildfires. And besides that, it seems that the distance was not a good proxy of the exposure since the dispersion of the smoke plume greatly depended on the wind direction, as stated below.

In this study, we took advantage of the valuable individual data collected through the different follow-up surveys in the INMA-Valencia cohort to evaluate the different susceptibility of children to the wildfire health effects. This fact is of especial interest since we could obtain effect estimates for small vulnerable populations that other epidemiological studies such as time series are not able to. In fact, the availability of a great amount of individual data is one of the main strengths of this study. This information will be useful in further future analyses, where individual risk factors related to their socioeconomic, educational or baseline health status in association with wildfire effects would be the object of our investigations.

However, these results should be interpreted with caution due to the presence of several limitations. Recall bias could be present in this study, but we consider that it could have been reduced due to the short time interval between the wildfires and the survey (just 2 weeks). Besides that, we asked parents about health symptoms during both periods at the same time after the wildfire episode. So, there could be a potential over-reporting of the effects, since parents could be prone to reporting more symptoms during the wildfires rather than in the control period according to the magnitude of the perception of risk. Likewise, families with affected children could be expected to show more concern about the exposure risk to wildfires. So, we cannot neglect the possibility that the different risk estimates for each asthma/rhinitis category could be due to the fact that parents of asthmatic or rhinitis children could have over-reported

the severity of health symptoms during wildfires. However, according to our results shown in Table 3, there were no statistically significant differences in the prevalence of the reported preventive measures and the level of perception of exposure between these subcategories of asthma/rhinitis and in the total population. Therefore, we could consider that the differences observed in the susceptibility of rhinitis and asthmatic individuals to wildfire effects were not only attributable to the presence of bias.

Furthermore, we should take into account the potential inaccuracy in the effect estimates introduced by the parental self-reported health data. However, the information about asthma and rhinitis diagnosis was collected in previous follow-up surveys, and not after the wildfires. But we assumed the risk of losing the cases of asthma or rhinitis that could have been diagnosed during the period between the 5- and the 7-year-old surveys. We considered not using the health data of the 7-year-old INMA survey since it was underway during the wildfire period. So, the collected respiratory symptoms could be partly due to exposure to fire smoke and, by using these data in the study, we could introduce bias.

One of the main weaknesses of this work is the evaluation of the exposure to wildfire smoke. Unfortunately, the scarce number of monitors with good data quality in the study area (only 5 out of 11 monitors with 80 % of the PM daily measurements completed during both study periods in an area of approximately 1400 km^2) made unfeasible the assignment of PM concentrations to each individual through different exposure assessment methods such as neighbor network monitoring or geographical information system procedures. On the other hand, as mentioned previously, we considered that the distance to wildfires' seats could not be representative of the real exposure to wildfire smoke: The wind speed and direction were the determining factors in the smoke spread especially in the northeast of the seats. So, it seemed that the distance was not as important as the geographical location from seats. That is, children with the same distance to wildfires could be exposed to smoke in a different way depending on their position.

The crucial step in terms of exposure evaluation was the selection of the study population: We included those children who were in the study area on at least 50 % of the days during both sub-periods as a way to obtain a study sample that was exposed to wildfires to some extent and with a similar exposure during the control period (same environmental conditions, not exposed to other wildfires, etc.). So, all children should not have been exposed to wildfires during the control period, and exposed to them during the wildfire period, regardless of intensity or duration. The collection of this information was necessary since the control period coincided with the beginning of summer holidays for schoolchildren. So, it would be more likely that children could be in places other than their usual home on these days (summer camps, holiday home, etc.).

On the other hand, the reduced number of participants limited the statistical power of this study. This fact could be observed in the wide confidence intervals of the OR estimates, and thus, reduced number of statistically significant results in the analysis of interaction terms between population subgroups. However, it should be taken into account that our study population is a cohort of participants enrolled in the INMA-Valencia project since weeks after their conception. Therefore, the reduced sample size is understandable considering the nature of the cohort studies along with the possible loss of follow-up inherent to this. And finally, in the present study the response rate was 92.5 %, which might be considered as moderately/relatively high, compared to the general average response rate other questionnaire-based studies.

Conclusions

To conclude, this investigation provides evidence that the 2012 Valencia wildfires affected the health status of our INMA-Valencia children population, especially in the case of susceptible individuals. It is predicted that wildfire frequency and intensity may increase due to climate change; therefore, it would be crucial to further understand the health effects and public awareness of wildfires, as well as to identify susceptible individuals, and to design public health strategies to protect them.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no actual or potential competing financial interests.

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