

Sunny hours and variations in the prevalence of asthma in schoolchildren according to the International Study of Asthma and Allergies (ISAAC) Phase III in Spain

Alberto Arnedo-Pena · Luis García-Marcos · Jorge Fuertes Fernández-Espinar ·
Alberto Bercedo-Sanz · Ines Aguinaga-Ontoso · Carlos González-Díaz ·
Ignacio Carvajal-Urueña · Rosa Busquet-Monge · Maria Morales Suárez-Varela ·
Nagore García de Andoin · Juan Batlles-Garrido · Alfredo Blanco-Quirós ·
Angel López-Silvarrey Varela · Gloria García-Hernández

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Abstract The objective of this study was to estimate the relationship between the prevalence of asthma in schoolchildren aged 6–7 years and 13–14 years and the mean annual sunny hours (MASH) in Spain, and to explore predictive models for asthma prevalence. The prevalence of

asthma was obtained from the International Study of Asthma and Allergies (ISAAC) Phase III 2002–2003, and climate and socio-economic variables from official sources. Nine centres were studied and a further four centres, two of which are in ISAAC, to test the predictive models. Logistic

A. Arnedo-Pena (✉)
Epidemiology Division, Centre of Public Health,
C/ L'Olivera 5, 2-C,
12005 Castellón, Spain
e-mail: arnedo_alb@gva.es

L. García-Marcos
Pediatric Respiratory and Allergy Units,
“Arrixaca” University Children’s Hospital, University of Murcia,
and CIBER of Epidemiology and Public Health (CIBERSP),
Murcia, Spain

J. F. Fernández-Espinar
“Perpetuo Socorro” Health Center,
Huesca, Spain

A. Bercedo-Sanz
Buelna. Health Center. Los Corrales de Buelna,
Cantabria, Spain

I. Aguinaga-Ontoso
Department of Health Sciences, Public University of Navarra,
Pamplona, Spain

C. González-Díaz
Department of Pediatrics, Basurto Hospital,
Bilbao, Spain

I. Carvajal-Urueña
“La Eria” Health Center,
Health Service of the Principality of Asturias,
Oviedo, Asturias, Spain

R. Busquet-Monge
Department of Pediatrics, Hospital del Mar,
Barcelona, Spain

M. M. Suárez-Varela
Public and Environmental Health Unit,
Department of Preventive Medicine, University of Valencia,
and CIBER of Epidemiology and Public Health,
Valencia, Spain

N. G. de Andoin
Department of Pediatrics, “Donostia” Hospital, San Sebastián,
Guipuzcoa, Spain

J. Batlles-Garrido
Department of Pediatrics, “Torrecárdenas” Hospital,
Almería, Spain

A. Blanco-Quirós
Department of Pediatrics, University of Valladolid,
Valladolid, Spain

A. L.-S. Varela
María José Jove Foundation,
La Coruña, Spain

G. García-Hernández
Pediatric Allergy and Pulmonology Unit,
“12 de Octubre” University Children’s Hospital,
Madrid, Spain

regression was used to estimate adjusted prevalence rates of asthma for each centre, and multiple regression models to study the effects of MASH and other meteorological and socio-economic variables. The adjusted prevalence rate of asthma decreased 0.6% [95% confidence interval (CI) 0.4–0.8%] for the 6–7 years group and 1.1% (95% CI 0.8–1.3%) for the 13–14 years group with an increase in the MASH of 100 h. Relative humidity was negatively associated with asthma in the older age group, and gross province product per capita (GPP) was positively associated with asthma in the younger age group. The predictive models, which included MASH, gender, relative humidity, and GPP, anticipated prevalence rates of asthma without significant differences between the levels observed and those expected in 9 of the 11 measurements carried out. The results indicate that sunny hours have a protective effect on the prevalence of asthma in schoolchildren.

Keywords Asthma · Schoolchildren · Climate · Sunny hours · Vitamin D

Introduction

The hypothesis of the protective action of vitamin D in infant asthma is recent (Litonjua and Weiss 2007; Weiss and Litonjua 2007), but controversy exists, since for some authors its effect on the reduction of infectious diseases could be a risk factor for the origin of asthma according to the hygiene hypothesis (Wjst and Dold 1999), and some cohort studies in new-borns have described a greater risk of asthma or atopic dermatitis in relation with higher intake of vitamin D (Kull et al. 2006; Gale et al. 2008; Hipponen et al. 2004; Back et al. 2009). However, other cohort studies in new-borns have observed lower incidence of wheezing at 3 years and of asthma at 5 years in those children whose mothers had higher levels of vitamin D consumption during gestation (Camargo et al. 2007a, b; Devereux et al. 2007; Erkkola et al. 2009). Likewise, low levels of this vitamin have been associated to greater asthma severity in children (Brehm et al. 2009). In the light of this situation, the importance of carrying out clinical trials has been indicated to clarify the function of vitamin D in asthma (Devereux et al. 2009), and some authors indicate that the situation is complex and still requires considerable research (Shaheen 2008; Schaubert and Gallo 2008).

Observational epidemiological studies of the prevalence of asthma in different geographical areas could have a certain value. Thus, the ISAAC studies in Spain (Grupo ISAAC España 1999; Carvajal-Urueña et al. 2005) have found marked differences in the prevalence

of asthma and have detailed that recent symptoms of asthma are more acute in the northern and Mediterranean coast zones than in the central plateau (García-Marcos et al. 2009); recent severe asthma was associated with a greater concentration of SO₂ (Arnedo-Pena et al. 2009). In this context, the study of the association between the prevalence of asthma and sunny hours could be of interest, bearing in mind that vitamin D is formed in the skin by solar radiation and could be a “proxy” for the levels of vitamin D in the population. Therefore, the objective of this study has been to estimate the relationship between the prevalence of asthma and the mean annual sunny hours (MASH), and to explore by means of predictive models the prevalence of asthma according to the MASH of different zones.

Materials and methods

The design of study was semi-individual population based (Künzli and Tager 1997). The data for asthma prevalence were obtained from the ISAAC study for the groups of 6–7 years and 13–14 years from Phase III from the years 2002–2003 and included the centres in Asturias, Barcelona, Bilbao, Cartagena, La Coruña, Madrid, San Sebastian, Valencia and Valladolid. The study conditions have been described previously (García-Marcos et al. 2004) and are based on standardised questionnaires for asthma, rhinitis, and eczema answered by the adolescents of 13–14 years, and by the parents in the case of the 6- to 7-year-old schoolchildren, with the mean participation being 88.5% in the older age group, and 72.3% in the younger age group (Carvajal-Urueña et al. 2005).

An asthma case was defined as a positive answer to the question:

‘Have you ever had asthma? Has your son/daughter ever had asthma?’

Risk factors for asthma were taken according to the questionnaire developed by the ISAAC centre in New Zealand (<http://isaac.auckland.ac.nz>), including questions on exposure to animals at home, environmental tobacco smoke, heating and cooking fuel, siblings, maternal education, physical activity, frequency of truck traffic on the street of residence, use of antibiotics and paracetamol, birth weight, breast feeding, and use of contraceptives by the mother. Logistic regression models were employed to quantify the association between the prevalence of asthma (dependent variable) and the risk factors together with centres (independent variables). Cartagena was baseline centre. The factors associated with a $p < 0.25$ were included in the logistic regression models, to finally obtain those associated with a $p < 0.05$. From these models,

adjusted odds ratios of asthma of each centre were converted to adjusted prevalence rates. All the models studied presented a good fit according to Hosmer and Lemeshow (1989).

For each centre the following variables were obtained: MASH, altitude above sea-level, mean annual temperature, mean annual rainfall, and mean annual relative humidity for the period 1971–2000, according to data from the Ministry for the Environment (www.aemet.es/es/elclima), and gross province product per capita (GPP) (year 2002) from the Spanish National Statistical Institute (www.ine.es). For Asturias, the mean of meteorological variables were obtained from the stations in Gijón, Oviedo, and Oviedo Airport, and for Valladolid, from the station in the capital. For Cartagena, the data from the city itself were taken for the period 1994–2000, and MASH and mean annual rainfall from the station of San Javier. The GPP corresponds to the province where the ISAAC centre is located. Pearson's correlations were carried out for meteorological and socio-economic variables in order to study the collinearity. A linear regression was calculated using the crude and adjusted prevalence rates of asthma for gender and MASH of each centre.

Multiple regression was performed with the adjusted prevalence asthma (dependent variable) and MASH, altitude, temperature, humidity, GPP, and gender (independent variables). Mean annual of rainfall was not included because the high collinearity with MASH. Finally, the regression models included independent variables with $p < 0.05$. These models complied with the application conditions: graphics of residuals, Ramsey test, homoskedasticity, and Cook–Weisberg for heteroskedasticity, except this last for the 6–7 years group ($p = 0.0432$).

The prevalence of asthma in schoolchildren was taken in two ISAAC centres, Castellón and Pamplona, which carried out the Phase III of the ISAAC study in 2002 and 2001, respectively. The former is located on the Mediterranean coast and the latter in the interior of the north-east of the Iberian Peninsula; both centres employed another questionnaire relating to risk factors. The centres of Huesca, from the northwest interior of the Iberian Peninsula, and Santander, on the Atlantic coast, were added because they had carried out studies on the prevalence of asthma using the ISAAC methodology in the years 2000 (Fuentes et al. 2001) and 2002 (Bercedo et al. 2004), respectively; in total, these centres studied 15,989 schoolchildren, with a median of participation of 91.2% in the older age group and 88.0% in the younger age group. For Castellón, Pamplona, Huesca and Santander, the expected rates were calculated according to the multiple regression models and were compared with the rates observed for asthma prevalence in these studies, and the prevalence ratio was calculated (observed rates/

expected rates). A non-parametric significance test, the Chi² test, was done to value the significance. Stata version 9 software was used (StataCorp 2005).

Results

Table 1 shows the basic variables studied. In total, 21,355 schoolchildren aged 6–7 years and 24,301 adolescents of 13–14 years were studied in nine centres. Four centres are located in the Atlantic zone, three in the Mediterranean zone, and two in the central plateau, with important variations with regard to MASH and other meteorological variables which correspond to three clearly differentiated climatic areas: Atlantic (wet, temperate and high rainfall), Mediterranean (humid, hot and low rainfall), and Central Plateau (dry, extreme climate, low rainfall) (Table 2).

Table 3 shows the Pearson coefficients of correlation for meteorological and socio-economic variables. MASH presented a high negative correlation with rainfall ($r = -0.8754$). Other high negative correlations were relative humidity with MASH ($r = -0.6125$), GPP ($r = -0.6338$) and altitude ($r = -0.7339$).

The linear regression between the crude and adjusted prevalence rates of asthma for gender and the MASH for each ISAAC centre is showed in Table 4 (6–7 years) and Table 5 (13–14 years) with significant and negative regression coefficients. The coefficients of determination of adjusted prevalence rate were higher elevated for the young age group (0.788) than the old age group (0.641 for girls and 0.646 for boys).

Table 6 shows the multiple regression models for the two age groups. In both models, a negative association between the adjusted prevalence of asthma and MASH was observed: an increase of MASH corresponds to a decrease prevalence of asthma. The regression coefficients were -0.00594 [95% confidence interval (CI) -0.00747 to -0.0044] for the 6–7 years group and -0.01053 (95% CI -0.01296 to -0.00808) for the 13–14 years group; for each 100 h of MASH, the adjusted prevalence of asthma decreased 0.6 and 1.1%, respectively. In the younger age group, the GPP was positively associated with asthma, and in the older age group, the relative humidity was negatively associated with the disease. In addition, masculine gender was positively associated with asthma in both groups. The coefficients of determination were 0.8954 for the 6–7 years group and 0.8843 for the 13–14 years group.

The regression models for both age groups (Table 7) compare the expected rates with the observed rates in different centres for each gender in Castellón, Pamplona, and Santander, and in Huesca for both genders. It is observed that in the 6–7 years group there are no

Table 1 Population characteristics and climate variables of the ISAAC centres in Spain. Schoolchildren aged 6–7 years ($n=21,355$)^a and 13–14 years ($n=24,301$)^a

Variables	Values	%
Age		
6 years	10,353	49%
7 years	10,681	51%
13 years	11,727	48%
14 years	12,559	42%
Gender		
6–7 years		
Boys	10,630	50%
Girls	10,681	50%
13–14 years		
Boys	12,506	52%
Girls	11,773	48%
Geographic area		
Atlantic	La Coruña, Asturias, Bilbao, San Sebastian	
Central plateau	Valladolid, Madrid	
Mediterranean	Barcelona, Valencia, Cartagena	
Climate		
Mean annual sunny hours (MASH)		
Range	1,584–2,769	
Median	2,500	
Mean ± SD	2,251.41±432.72	
Average annual temperature °C		
Range	11.3–20.2	
Median	14.8	
Mean ± SD	15.4±2.5	
Average annual relative humidity (%)		
Range	57–81	
Median	71	
Mean ± SD	71.1±6.8	
Altitude (m)		
Range	6–691	
Median	19	
Mean ± SD	174.8.1±278.7	
Average annual rainfall (mm)		
Range	339–1,738	
Median	640	
Mean ± SD	808.1±454.3	
Gross province product (GPP) per capita euros/1,000 ^b		
Range	13.88–21.99	
Median	18.07	
Mean ± SD	17.78±2.99	

SD Standard deviation

^a Incomplete data in some values^b Year 2002

significant differences between what is expected and what is observed, while for the 13–14 years group, there is a significant difference in those from Pamplona.

Discussion

The results indicate that solar radiation is associated as a protective factor with the prevalence of asthma in the centres studied, and that this solar radiation explains a high proportion of the geographical variations of this prevalence in the ISAAC studies carried out in Spain. The protection of the solar radiation was observed in both age groups, being higher in the 13–14 years group with greater significance. In the multiple regression models, the predictions of the prevalence of asthma were acceptable for Castellon, Santander and Huesca, for both age groups, and for Pamplona only in the younger age group, with significant differences existing for the 13–14 years group for both sexes, indicating a better prediction for the younger age group.

The stations to measure the sunny hours are located in or very near the cities studied, except in the case of Cartagena where the station is located around 25 km away; in the population centres of the entire province studied, an average was taken (Asturias) or the reading of the largest population centre (Valladolid). The sunny hours were measured with the Campbell–Stokes heliograph standardised method in the measuring stations in Spain, which has a long tradition in this sense (Martín-Vidé et al. 2003), and the areas of our study coincide with those indicated in Spain, as being very markedly different with regard to sunshine in our country (Capel and Viedma 1997). However, our measurements of ultraviolet solar radiation have not been as precise as those indicated by Gale et al. (2008), adjusting for seasonal variations, and Staples et al. (2003) utilising three indices of ultraviolet radiation.

The influence of weather conditions on asthma have been studied; however, the results are not definitive (Fleischer and Asnani 1978; Epton et al. 1997; Atkinson and Strachan 2004; Reid and Gamble 2009). It has been accepted that the climate could have a direct action on airways or indirectly on allergen and pollutant levels (D'Amato and Cecchi 2008). The airways can be affected by cooling or irritating, and exacerbations of asthma have been associated with low temperature, humidity and sudden fall in temperature (Rossi et al. 1993). Some studies on geographical variations in the prevalence of asthma and the climate have employed sunny hours or solar radiation with different results to those obtained here. Thus, in an ecological study (Staples et al. 2003) on the prevalence of asthma in the general population in Australia (59,000 people aged 4–70 years) from the National Health Survey,

Table 2 Distribution of the study population by ISAAC centres, age, gender, mean annual sunny hours, mean annual relative humidity, mean annual temperature and mean annual of rainfall and gross province product per capita (1971–2000)

Centres	Age 6–7years total boys (%)	Age 13–14years total boys (%)	Sunny hours	Relative humidity (%)	Temperature ° C	Rainfall (mm)	Gross province product ^a
Atlantic area							
Bilbao	3,039 (48)	2,879 (48)	1,584	72	14.3	1,195	20.35
Asturias	3,027 (50)	2,973 (49)	1,711 ^b	79	13.3	1,028	14.35
San Sebastián	897 (52)	1,085 (52)	1,724	75	14.4	1,738	20.83
La Coruña	3,017(49)	2,981 (52)	1,966	77	14.4	1,008	14.49
Mediterranean area							
Barcelona	2,902 (53)	2,786 (48)	2,524	72	15.5	640	19.46
Valencia	3,393 (49)	3,129 (54)	2,660	65	17.8	454	16.59
Cartagena	2,726 (50)	2,856 (50)	2,500 ^c	80	19.7	334 ^c	13.88
Central plateau							
Valladolid	-	2,947 (53)	2,534 ^d	65	12.3	435	18.07
Madrid	2,344 (50)	2,643 (57)	2,769	57	4.6	436	21.99

^a Gross province product per capita euros/1,000^b Mean value Oviedo, Gijón, and Oviedo Airport.^c San Javier station, 25 km from Cartagena. Other variables from Cartagena 1994–2000^d City of Valladolid station.

positively associated the prevalence of asthma, measured by questionnaire, with solar radiation in the winter period. In New Zealand, Hales et al. (1998), in an ecological study on a population of young adults between 20 and 44 years, found no association between sunny hours and asthma symptoms, and in Brisbane (Australia) (Derrick 1969), the weeks with more hospital admissions for asthma had more sunshine hours, among other meteorological variables. On the other hand, negative correlations have been observed between hospital admissions for asthma and sunny hours in adults and schoolchildren in Taiwan (Chen et al. 2006; Xirasagar et al. 2006), and more exacerbations among asthmatics in the winter season in Bosnia (Santic et al. 2002). In the United States of America (Moorman et al. 2007), the prevalence of asthma in the general population is higher in the northwest region of the country with lower sunshine than in the south; similarly, greater consumption of an anti-anaphylactic medicine (Epipen[®]) has been

observed in this region with respect to the other regions (Camargo et al. 2007a, b). The European Study on Respiratory Health in young adults aged 20–44 years (Verlato et al. 2002) found greater asthma prevalence in countries with an Atlantic coast and which are English speaking, and greater prevalence of allergic rhinitis at greater latitudes but with wide geographical variations (Wjst et al. 2005). In addition, a high prevalence of asthma in young adults and schoolchildren has been found in Canary Islands (Spain), suggesting that climate conditions (hot temperature and stable high humidity) could be associated (Julià et al. 2005; Sánchez-Lerma et al. 2009). In relation to altitude, which means a greater exposure to ultraviolet radiation, studies in Mexico (Vargas et al. 1999) and Greece (Gourgoulisanis et al. 2001) have found lower asthma prevalence at higher altitude, as has also been observed in France (Vervloet et al. 1994) although with contradictory results (Kielchl-Kohlendorfer et al. 2007),

Table 3 Pearson coefficients of correlation for meteorological and socio-economic variables in the ISAAC centres

Variables	Sunny hours (MASH)	Temperature °C	Relative humidity (%)	Rainfall (mm)	Altitude (m)	Gross province product (GPP) capita Euros
MASH	1.0000					
Temperature	0.4042	1.0000				
Humidity	−0.6125	0.1994	1.0000			
Rainfall	−0.8754	−0.4139	0.4257	1.0000		
Altitude	0.4855	−0.4642	−0.7339	−0.4418	1.0000	
GPP	0.0651	−0.3455	−0.6338	0.2353	0.3567	1.0000

Table 4 Linear regression of crude and adjusted prevalence rates of asthma for gender and mean annual sunny hours at ISAAC centres: 6–7 years group

Centre	Crude prevalence rate % ^a		Adjusted prevalence rate%	
	Girls	Boys	Girls	Boys
Bilbao	17.2	25.2	13.5	18.50
Asturias	13.5	16.7	10.2	14.1
San Sebastián	11.7	15.6	9.9	13.6
La Coruña	12.0	16.4	9.1	12.6
Cartagena	9.0	13.3	5.4	7.7
Barcelona	11.0	11.8	8.1	11.2
Valencia	7.2	10.7	5.7	8.0
Madrid	7.9	12.6	6.6	9.3
Regression coefficients	−0.0046, <i>p</i> =0.002	−0.0067, <i>p</i> =0.003	−0.0049, <i>p</i> =0.003	−0.0067, <i>p</i> =0.003
Determination coefficients	0.776, <i>p</i> =0.004	0.670, <i>p</i> =0.013	0.788, <i>p</i> =0.003	0.788, <i>p</i> =0.003

^a Adjusted for maternal smoking, use of antibiotics or paracetamol in the first year of life, older siblings, cat in the house in the first year of life, and weekly physical exercise.

with higher hospital admissions rates in children who live at altitudes between 450–1,800 m in Austria. On the other hand, the high mountain climate has been shown to be beneficial for asthma sufferers (Schultze-Werninghaus 2008). It is worthwhile to point out that the lowest asthma prevalence rate in 13- to 14-year-old schoolchildren (1.1%), according to the ISAAC study, has been observed in Lhasa (Tibet), at an altitude of 3,658 metres with low humidity and more than 3,000 sunny hours annually (Droma et al. 2007).

At world level, the ISAAC study did not find an association between climate conditions and the preva-

lence of asthma symptoms (Weiland et al. 2004), although sunny hours were not included in the study. However, in the countries of Western Europe, negative associations can be found between altitude, annual temperature variations and the symptoms of wheezing in the last 12 months and severe wheezing. On the other hand, the annual mean humidity in the interior of the home was positively associated with the prevalence of wheezing in the last 12 months. Our results in the 6–7 years group go in the same direction but not in the 13–14 years group. For this age group, the relative humidity had a negative association with asthma following the multivariate model.

Table 5 Linear regression of crude and adjusted prevalence rates of asthma for gender and mean annual sunny hours at ISAAC centres: 13–14 years group

Centre	Crude prevalence rate % ^a		Adjusted prevalence rate%	
	Girls	Boys	Girls	Boys
Bilbao	19.4	23.5	15.6	20.4
Asturias	17.0	20.7	12.9	16.9
San Sebastián	17.4	26.8	17.4	22.3
La Coruña	14.7	22.9	13.5	17.6
Cartagena	10.0	13.1	5.3	7.1
Barcelona	12.3	12.0	9.3	12.3
Valencia	13.5	13.8	9.7	12.7
Madrid	12.9	15.7	10.8	14.1
Valladolid	11.1	14.0	9.3	12.3
Regression coefficients	−0.0059, <i>p</i> =0.002	−0.0103, <i>p</i> =0.001	−0.006338, <i>p</i> =0.01	−0.00805, <i>p</i> =0.009
Determination coefficients	0.790, <i>p</i> =0.001	0.760, <i>p</i> =0.002	0.641, <i>p</i> =0.01	0.646, <i>p</i> =0.009

^a Adjusted for frequency of trucks on the street of residence, maternal education, maternal smoking, paracetamol use in the last 12 months, and presence of a dog in the house in the last 12 months.

Table 6 Multiple regression models between adjusted prevalence rate of asthma and independent variables at ISAAC centres: 6–7 years and 13–14 years groups

Variables	Regression coefficient	95% Confidence interval	<i>p</i> value
Group 6–7 years			
MASH /100 ^a	–0.00594	–0.00747 to –0.00440	0.000
Gender (boys=1)	0.03291	0.01908–0.04675	0.000
GPP/1,000 ^b	0.00298	0.00073–0.00523	0.014
Intercept	0.16251	0.11097–0.21405	0.000
Coefficient of determination $r^2=0.8964$, $p < 0.0001$			
Group 13–14 years			
MASH/100	–0.01053	–0.01296 to –0.00808	0.000
Gender (boys=1)	0.03534	0.0183–0.05231	0.010
Relative humidity %	–0.00334	–0.004832 to –0.00184	0.000
Intercept	0.58694	0.44021–0.73367	0.000
Coefficient of determination $r^2=0.8843$, $p < 0.0001$			

^a Mean annual sunny hours^b Gross province product per capita euros

On the other hand, there are contradictory results of humidity in relation of pollen release (Taylor et al. 2007; D'Amato and Cecchi 2008), and high humidity could develop some mould species and not others (Oliveira et al. 2008); however, high humidity is associated with increase of house dust mite sensitisation and asthma (Platts-Mills et al. 1997). Another study on asthma and climate in Italy in young adults aged between 20 and 44 years (Zanolin et al. 2004) observed a higher prevalence of asthma and symptoms in the central and southern zones of Italy, near to the coast, than in the interior zone of the northern continental climate. This result would go against ours, although sunshine was not studied, it was an adult population and recent asthma symptoms or asthma being treated were studied. In another Italian study in schoolchildren aged 6–7 years in the central and northern zones, the prevalence of asthma was higher in the centre, but the hospitalisations due to asthma were more frequent in the northern zone (SIDRIA 1997). In Turkey, Kurt et al. (2007) studied 25,843 schoolchildren of different geographical areas and prevalence of asthma was associated with altitude <1,000 m and relative humidity >70%; temperature <15°C was a protector. In contrast, Franco et al. (2009) in 8 ISAAC centres of Brazil found that the active asthma was positively associated with latitude and negatively with temperature. García-Marcos et al. (2009) indicated higher prevalence of recent asthma symptoms in the coastal zone than in the interior, considering Phases I and III of the ISAAC study in Spain, and this could be attributable to the higher relative humidity in the coastal zone with respect to the interior. In Spain, Phase III of the ISAAC study (Morales et al. 2008) indicated that the prevalence of atopic eczema is inversely associated with the annual number of sunny hours, and the Atlantic coast presented the highest prevalence of atopic eczema. In relation to the positive association between prevalence of

asthma and GPP in the young age group, an ISAAC study (Stewart et al. 2001) indicated positive association between the gross national product per capita in 56 countries and symptoms of wheezing in the last 12 months in the 13–14 years group but not in the 6–7 years group. A more recent ISAAC study (Lai et al. 2009) indicated an increase of prevalence of asthma in countries with higher income. However, some epidemiological studies found that asthma (prevalence and incidence) is higher among children from low-income families (Shannon et al. 2008; Kozyrskyj et al. 2010).

Among the factors which would produce geographical variations in the prevalence of asthma is air pollution, which can be important in certain zones. Although a pollution factor was included in the logistic regression models with the passing of trucks along the street of residence, it could be that this is not sufficient to control this variable, since de Marco et al. (2002) in Italy and Guo et al. (1999) in Taiwan have indicated its effect on the prevalence of asthma in young adults and schoolchildren, respectively. On the other hand, air pollution means a drop in the solar radiation which reaches the earth's surface. It may be of interest to point out that a fall in solar radiation has been observed from the 1960s to the 1990s in our planet, which is attributed to human activity, being most notable in developed industrial zones (Stanhill and Cohen 2001; Alpert et al. 2005), which could coincide with an increase in the asthma observed in western countries.

These results can be interpreted in at least two non-exclusive manners. The first would indicate the protective effect of the solar radiation due to the increase in vitamin D which is produced in the people who live in zones with greater solar radiation, and these people could have higher levels of vitamin D in blood than people who inhabit zones of less sunshine. In general, different studies have found higher levels of vitamin D in blood in

Table 7 Comparison between observed (*OBR*) and expected (*EXR*) of prevalence rates of asthma, according to multiple regression models for the 6–7 years and 13–14 years groups, with prevalence ratio, confidence intervals (*CI*) of 95%, mean annual sunny hours and mean relative humidity (1971–2000), and gross provincial product per capita euros (*GPP*)

Centres		% Observed rate (<i>OBR</i>)	% Expected rate (<i>EXP</i>)	Prevalence ratio (<i>OBR/EXP</i>)	95% CI <i>p</i> value
Group 6–7 years					
Castellon					
Sunny hours	2,689				
Relative humidity	67%				
GPP/1,000	18.84				
Girls = 1,833		6.0	5.9	1.02	(0.79–1.32) 0.889
Boys = 1,980		8.6	9.2	0.93	(0.77–1.20) 0.503
Pamplona					
Sunny hours	2,201				
Relative humidity	68%				
GPP/1000	20.77				
Girls = 1 470		8.2	9.3	0.88	(0.70–1.12) 0.300
Boys = 1,477		11.3	12.7	0.89	(0.73–1.08) 0.235
Huesca					
Sunny hours	2,682				
Relative humidity	63%				
GPP/1,000	17.61				
Total=920 (girls and boys)		6.6	7.9	0.84	(0.60–1.16) 0.282
Group 13–14 years					
Castellon					
Girls = 1,976		8.3	8.0	1.04	(0.84–1.28) 0.727
Boys = 2,007		9.9	11.6	0.85	(0.71–1.02) 0.083
Pamplona					
Girls = 1,190		8.6	12.8	0.67	(0.53–0.85) 0.001
Boys = 1,333		12.2	16.4	0.74	(0.62–0.90) 0.002
Santander					
Sunny hours	1,638				
Relative humidity	75%				
GPP/1,000	16.37				
Girls = 923		15.7	16.4	0.96	(0.78–1.18) 0.704
Boys = 880		18.0	20.0	0.90	(0.74–1.09) 0.295

people who live at lower latitudes; although cultural habits relating to exposure to sun are a determining factor (Rodríguez-Sangrador 2006; van der Weilen et al. 1995). The protective effect of vitamin D would derive from its regulatory action on the immune system (Walker and Modlin 2009), due to its preventive action in the face of infectious respiratory diseases (Grant 2009). And it has been postulated that viral infections would have more incidence in the cold months of the year in western countries due to a fall in vitamin D levels in the population (Cannell et al. 2008). It has been indicated that this protective effect of vitamin D could be principally prenatal, as has been observed in three cohorts of newborns on the incidence of asthma and allergic rhinitis symptoms (Camargo et al. 2007a, b; Devereux et al. 2007; Erkkola et al. 2009). On the other hand, the immunosup-

pression effect of the ultraviolet radiations on the immune system has been indicated (McMichael and Moll 1997), and in animal experimentation this effect has been demonstrated (McGlade et al. 2007). Another aspect is that the effect of the solar radiation on the environment with a drop in humidity and an increase in the temperature would make life more difficult for agents that have been related with the aetiology of asthma: dust mites, moulds, and other allergens. Similarly, it is known that in the interior zones with dry, sunny climates the prevalence of asthma is low compared to hot, humid, coastal zones (Peat et al. 1993; Bener et al. 1993; Laor et al. 1993). In general, the sensitisation to house dust mite is higher in coastal regions than the inland regions and pollen sensitisation is higher inland than in coastal regions (Peat et al. 1995; Li et al. 2009). In Spain, García-Marcos et al. (2007) found higher sensitisation to grass and tree pollens

and lower to house dust mite in schoolchildren from Madrid (central plateau) than from Cartagena (Mediterranean coast). In addition, moulds allergen can play a role in the geographic differences of the prevalence of asthma (Diette et al. 2008; Richardson et al. 2005). Moulds live in indoor and outdoor environments, and high temperature and humidity may facilitate their development, although their concentrations present important variations in function of meteorological conditions and mould species (Oliveira et al. 2009). Dampness depends on indoor humidity and poor building design or structural deficiencies (Richardson et al. 2005), and on weather factors such as high humidity and rains (Ivey et al. 2003). Dampness could be a marker for moulds, dust mites, endotoxins and poor ventilation (Dales et al. 2008). Recently, the incidence of wheezing in a Finland birth cohort was associated with dampness (Karvonen et al. 2009). In addition, MASH and mean annual of rainfall presented a high correlation suggesting that the two variables measured a related aspect of climate. High MASH is associated with low rainfall and vice versa. This collinearity limits multivariate analysis. Meteorological variables with high correlations were not put together in the multivariate models of Weiland et al. (2004) in the study of climate and the Phase I of ISAAC. Collinearity prevents the distinguishing of the separate effects of MASH and rainfall on the prevalence of asthma. However, the effects of these variables are probably complementary. In this context, our results cannot differentiate these effects; however, when the observed and expected rates of the prevalence of asthma between Castellon and Huesca were compared, despite the climate variations (Mediterranean vs continental climate), small differences were noted, as occurs with the sunny hours in Pamplona, situated around 150 kms from Huesca but with fewer sunny hours, and Santander, on the Atlantic coast, which presented higher rates.

In the present study, it has been possible to configure models with high determination coefficient, which permits differentiation between the two coastal zones—Atlantic and Mediterranean—from the annual sunny hours, and generates a hypothesis on the multi-factorial aetiology of asthma. The size of the study was large, and although the number of centres was small, their location in the three areas of solar radiation in Spain made for an acceptable discrimination. Logistic regression models were utilised and some factors were analysed, and potential confounding factors were controlled.

Limitations of the study: the existence of other factors not studied (genetics, diet, food supplements, lifestyles, etc.) (Kim et al. 2009) may be of importance and, recently, the exposure to disinfection products in the swimming pool environment (Weisel et al. 2009). The use of swimming pools could be more frequent in areas with cold and rainy weather. It is a transversal study,

with aggregated data for meteorological and socio-economic variables, including sunny hours for all the schoolchildren in each centre, and this could have some classification bias in relation to each schoolchildren. Then, sunny hours exposition is related to cultural and lifestyle habits (sports and outdoor activities, avoiding the sun, use of sun creams, protection from the sun, etc.), this exposure may vary in each centre. Similarly, the other aggregate data could have some classification bias. The prevalence of asthma was studied by means of a question answered by the parents and the adolescents and there may be bias in the comprehension of the question. However, the questionnaire used has been validated in our field and its use has been shown. Since it asks about a disease in which some variation may exist in the access to medical specialists for the diagnosis of asthma; however, the health system is similar throughout the country. Population migration could exercise some effect but considering the age of the schoolchildren this would be minor. Information on pollen counts, buildings with dampness, or mite allergy were not available in all ISAAC centres.

The protective effect of solar radiation is confirmed but without being able to differentiate the effects on the human being, and on the environment. Indirectly, the results could support the hypothesis of the protective effect of vitamin D in the prevalence of asthma in schoolchildren.

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