Ecological association between childhood asthma and availability of indoor chlorinated swimming pools in Europe

M Nickmilder and A Bernard

Occup. Environ. Med. 2007;64;37-46; originally published online 17 Jul 2006;
doi:10.1136/oem.2005.025452

ORIGINAL ARTICLE

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Background: It has been hypothesised that the rise in childhood asthma in the developed world could result at least in part from the increasing exposure of children to toxic chlorination products in the air of indoor swimming pools.

Objectives: Ecological study to evaluate whether this hypothesis can explain the geographical variation in the prevalence of asthma and other atopic diseases in Europe.

Methods: The relationships between the prevalences of wheezing by written or video questionnaire, of ever asthma, hay fever, rhinitis, and atopic eczema as reported by the International Study of Asthma and Allergies in Childhood (ISAAC), and the number of indoor chlorinated swimming pools per inhabitant in the studied centres were examined. Associations with geoclimatic variables, the gross domestic product (GDP) per capita, and several other lifestyle indicators were also evaluated.

Results: Among children aged 13–14 years, the prevalence of wheezing by written questionnaire, of wheezing by video questionnaire, and of ever asthma across Europe increased respectively by 3.39% (95% CI 1.96 to 4.81), 0.96% (95% CI 0.28 to 1.64), and 2.73% (95% CI 1.94 to 3.52), with an increase of one indoor chlorinated pool per 100 000 inhabitants. Similar increases were found when analysing separately centres in Western or Northern Europe and for ever asthma in Southern Europe. In children aged 6–7 years (33 centres), the prevalence of ever asthma also increased with swimming pool availability (1.47%; 95% CI 0.21 to 2.74). These consistent associations were not found with other atopic diseases and were independent of the influence of altitude, climate, and GDP per capita.

Conclusions: The prevalence of childhood asthma and availability of indoor swimming pools in Europe are linked through associations that are consistent with the hypothesis implicating pool chlorine in the rise of childhood asthma in industrialised countries.

See end of article for authors' affiliations

Correspondence to: Prof. A Bernard, Department of Public Health, Catholic University of Louvain, 30.54 Clos Chapelle-aux-Champs, B-1200 Brussels, Belgium; bernard@toxi.ucl.ac.be

Accepted 19 May 2006
Published Online First 17 July 2006

Over the last three decades, the prevalence of asthma and allergic diseases has dramatically increased in the developed world.[1–3] Although genetic factors are important, it is unlikely that they can account for such a rapid increase of all forms of atopic disease, worldwide. This has led to the suggestion that the rising prevalence of these diseases must be linked to some changes in our lifestyle or environment. Currently, the hypothesis generating the most interest is the "hygiene hypothesis", postulating that the rise in asthma and allergy is due to the decreased exposure to microbiological products and/or infectious agents, especially in early life.[4] Several studies, indeed, have shown a reduced risk of asthma, allergic rhinitis, or atopic sensitisation in situations with a presumably higher exposure to infectious agents such as large families, day care attendance, and exposure to pets or farm animals.[5 6] This protective effect of infection, however, has not been confirmed by other studies,[7–10] while some features of the childhood asthma epidemic remained unexplained by the hygiene hypothesis. For instance, asthma has also increased among inner-city children who live in very poor housing conditions, which are presumably somewhat dirty.[11] The hygiene hypothesis is also temporally inconsistent with the rise of childhood asthma, which started after the 1960s, whereas major hygienic progresses in industrialised countries were achieved well before the 1940s.[12]

Recently, a hitherto unsuspected factor, so deeply rooted in our hygienic western way of life that it was unexplored for decades, has come to light with the discovery that regular pool attendance, especially by young children, was associated with lung hyperpermeability and an increased risk of developing asthma.[13–16] These findings led to the "pool chlorine hypothesis", proposing that the childhood asthma rise in industrialised countries is caused, at least partly, by the increasing and largely uncontrolled exposure of young children to chlorination by-products contaminating the air of indoor swimming pools.[13] According to this new hypothesis, the asthma rise in children in industrialised countries would thus result less from the declining exposure to microbiological agents—the hygiene hypothesis–than to the increasing exposure to the harmful by-products of chlorination, the most commonly used method to achieve hygiene in developed countries. Of these by-products, probably the most toxic to the respiratory tract is nitrogen trichloride or trichloramine, the gas which gives indoor swimming pools their typical smell and which is released in pool air when chlorine based disinfectants destroy organic matter brought by swimmers.[13–17]

There is no doubt that swimming pool attendance by children has considerably increased in the last decades, first as part of school programmes and then as a recreational activity now being offered to increasingly younger children. This increasing attendance of swimming pools by children has in turn led to substantial changes in the swimming pool environment such as higher water temperatures, increased bathing loads, and installation of recreational equipment. All these changes have contributed to raising the levels of chlorination by-products in pool air, especially as, at the same time, energy conservation programmes reducing ventilation were implemented to face the rising cost of energy. Depending on the chlorine dosing, pool occupancy, and ventilation rate, mean levels of trichloramine in

Abbreviations: GDP, gross domestic product; ISAAC, International Study of Asthma and Allergies in Childhood the air of public indoor pools vary between 300 and 500 μg/m^3,[13 17–19] making this gas one of the most concentrated air pollutants to which children in Europe are regularly exposed (mean concentrations of other indoor or outdoor air pollutants in Europe seldom exceed 300 μg/m^3).[20]

The aim of this ecological study was to examine to what extent the prevalences of asthma and other atopic diseases in Europe correlate with the availability of indoor chlorinated swimming pools. The geographical consistency and the specificity of associations emerging between atopic diseases and swimming pool availability were assessed by analysing data at the regional level and adjusting them for the influence of geoclimatic variables and the gross domestic product (GDP) per capita.

METHODS

Prevalences of asthma, rhinitis, hay fever, and atopic eczema in children were those published by the International Study of Asthma and Allergies in Childhood (ISAAC) phase 1 study.[21–23] The ISAAC study examined a total of 189 150 children aged 13–14 years in 69 European centres representing 21 countries (three centres of the original ISAAC database—two in United Kingdom and one in rural Latvia—were excluded because the covered area could not be precisely delimited). In 33 of the above centres, the ISAAC study also examined a total of 94 549 children aged 6–7 years. Symptoms of atopic diseases in all these children were assessed by a standardised written questionnaire.[24] In 38 centres, a video questionnaire displaying the signs and symptoms of asthma was also used to examine children aged 13–14 years. Centres in the United Kingdom and the Republic of Ireland, however, did not apply this video questionnaire.

Although most ISAAC publications defined asthma as wheezing or whistling symptoms during the last 12 months (current wheezing) reported in a written questionnaire,[24] we used two additional asthma outcomes, one called ‘‘ever asthma’’ based on the answer to the question ‘‘have you ever had asthma?’’, and the other based on current wheezing but ascertained by video questionnaire. The reason for this choice is that the prevalences of wheezing by written and by video questionnaire in the ISAAC European database (38 centres) were poorly correlated (Pearson’s $r = 0.39$, $p = 0.01$) whereas prevalences of wheezing by video questionnaire and of ever asthma were much more closely related (Pearson’s $r = 0.80$, $p < 0.001$). Such a poor agreement between video and written questionnaire in the ISAAC database, reported by others,[25] raises the question of what has exactly been measured in either type of questionnaire. Given this concern recently expressed by the ISAAC group,[26] we have decided to reinforce our analysis by using also the prevalence of ever asthma, a less subjective indicator presumably more linked to medical diagnosis.

The number of indoor chlorinated swimming pools accessible to the public in each centre was obtained by consulting the international swimmer guide directory (http://www.swimmers-guide.com/) and cross-checking the collected information with that from sport services on web pages of the studied cities or areas. For the three centres located in Estonia, Georgia, or Uzbekistan where no public swimming pool could be identified from these sources, we interrogated the consulate and the tourist office in Belgium who confirmed there was indeed no public pool in those centres. For each swimming pool, we checked that it was well an indoor pool using a chlorine based disinfectant (hypochlorite or chlorine gas). Swimming pools using an alternative disinfection method such as ozonation (one centre in Greece and three centres in Finland) were not considered. Pool availability in each centre was then estimated by dividing the number of indoor swimming pools by the number of inhabitants in the area obtained from the population web pages (http://www.citypopulation.de/).

Information on altitude, rainfall, and temperature in each centre was extracted from the world climate statistics (http://www.worldweather.org/). Mean rainfall and temperature over the three years of the fieldwork of ISAAC phase 1 study (1994–96) were used. The gross domestic product (GDP) per capita and the mean number of children born per woman (a surrogate marker of family size) were obtained on a country basis from the Index Mundi (http://www.indexmundi.com/). Data concerning other lifestyle indicators for the year 1996 or for the nearest year were extracted on a country basis from Eurostat (http://www.europa.eu.int/comm/eurostat/). The following indicators were studied: the proportion of food sales by non-specialised stores (hypermarket and supermarket) versus specialised ones (available for 62 centres), the expenditure for tobacco in percent of the total household expenditure (60 centres), and the number of passenger cars per 1000 inhabitants (63 centres).

In order to assess the geographical consistency of the associations while taking into account the possible influence of climatic and cultural variables, analyses were done at the level of the whole of Europe and at the regional level by dividing centres between Western and Eastern Europe or between Northern and Southern Europe. The limit between Northern and Southern Europe was set at latitude of 47.2°, corresponding to the Loire River in France.[26] We considered as Western countries the 15 ISAAC countries who were already members of the European Union on 1 May 2004, to which we added Malta because of its western lifestyle. The geographical consistency was further assessed by excluding centres from the United Kingdom and Republic of Ireland, two English speaking countries with some of the highest prevalences of wheezing or asthma in Europe.

We used the Pearson correlation to compare the different asthma outcomes. Associations between the other variables were assessed by simple linear regression analyses. Associations emerging between atopic diseases and swimming pool availability across the whole of Europe and Western Europe were further assessed by multiple linear regression analyses, testing as predictors the number of swimming pools per inhabitant together with GDP per capita, altitude, and mean annual temperature, three variables that have been found to correlate with asthma prevalence in Europe.[27–29] The geoclimatic variables and GDP per capita were normalised by log transformation. To enable log transformation, we set the minimum altitude at 1 metre (instead of zero) and the minimum mean annual temperature at 1℃ (instead of −1.0℃). Prevalences of ever asthma and wheeze were adjusted on the geometric mean of covariates. The level of statistical significance was set at $p < 0.05$.

RESULTS

Figure 1 shows that the availability of indoor swimming pools widely varies across Europe along a marked East–West gradient. The number of indoor swimming pools per inhabitant differed by more than 20-fold between centres in the top decile of swimming pool availability, all in Western Europe, and those in the lowest decile situated in Eastern countries (4.04 versus 0.18 per 100 000 inhabitants). In Western Europe, there was on average one indoor swimming pool per 50 000 inhabitants compared to one per 300 000 inhabitants in Eastern Europe. The number of swimming pools per inhabitant also widely varied within the same country, with up to a fivefold difference between some centres in Italy, Spain, or the United Kingdom. Centres having no indoor chlorinated swimming pool were

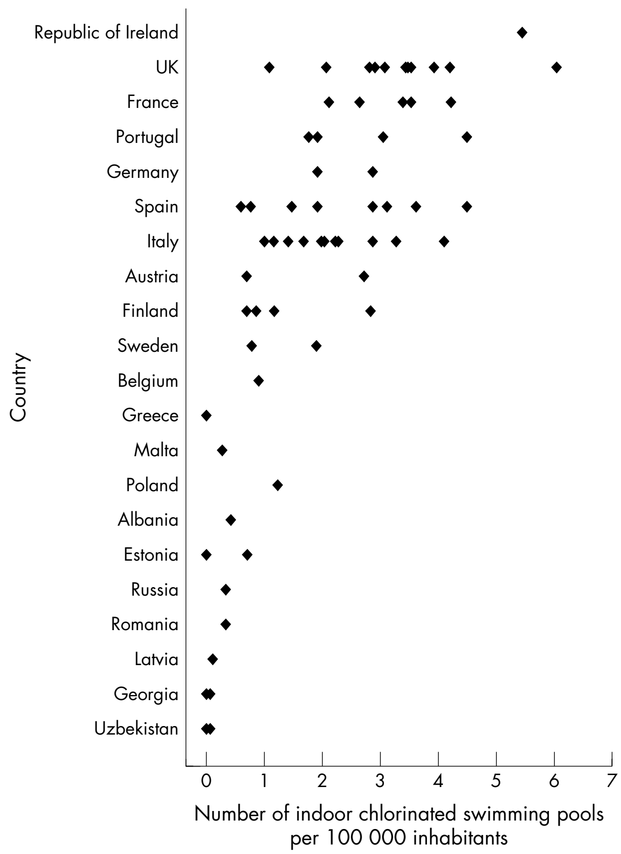

Figure 1 Geographical variation of the availability of indoor chlorinated swimming pools in Europe.

those having either no indoor public pool at all (e.g. Kutaisi in Georgia, Narva in Estonia, Samarkand in Uzbekistan) or having indoor pools that were not sanitised with chlorine (e.g. ozone in Athens).

The number of swimming pools per inhabitant was positively related to the GDP per capita across centres over the whole of Europe (regression coefficient 2.93; 95% CI 1.79 to 4.08) but not across centres situated in Western Europe (regression coefficient 0.68; 95% CI −5.42 to 6.78). The number of indoor swimming pools per inhabitant was associated with tobacco expenditure, across both the whole of Europe (regression coefficient 0.80; 95% CI 0.08 to 1.52) and Western Europe (regression coefficient 0.79; 95% CI 0.02 to 1.55). By contrast, swimming pool availability was not related to the number of cars per inhabitant nor to the ratio of hypermarket to traditional food sales, both across the whole of Europe and Western Europe (all $p > 0.08$). As expected from fig 1, the availability of swimming pools decreased with the longitude (whole of Europe, regression coefficient −0.054; 95% CI −0.07 to −0.037; Western Europe, regression coefficient −0.058; 95% CI −0.089 to −0.027) but did not vary with the latitude ($p > 0.20$), nor with the mean annual temperature ($p > 0.60$). Swimming pool availability, however, showed a weak positive association with the annual rainfall over the whole of Europe (regression coefficient 2.49, 95% CI 0.050 to 4.93), that tended to persist in Western Europe (regression coefficient 2.41, 95% CI −0.16 to 4.97).

Prevalences of wheezing by written questionnaire, wheezing by video questionnaire, and ever asthma along the East–West European gradient are shown in fig 2. There was no real East–West gradient in the prevalence of wheezing by written questionnaire since only centres in the United Kingdom and the Republic of Ireland had prevalence values clearly higher than in Eastern Europe. If one excludes data from these two countries, the prevalence of wheezing by written questionnaire shows little difference between Western and Eastern countries. By contrast, both the prevalence of wheezing by video questionnaire and the prevalence of ever asthma showed a strong East–West gradient that was not solely driven by centres in the United Kingdom and Republic of Ireland (where video questionnaire was not used).

When considering all European centres, the prevalences of all atopic diseases were positively related to the number of swimming pools per inhabitant (table 1). Prevalences of all atopic diseases also showed a positive relationship with GDP per capita. No association was seen with the other lifestyle indicators studied, except for the number of cars per inhabitant, which showed a modest relationship with hay fever (data not shown in the table). Interestingly, when centres in Western Europe were analysed separately, the prevalences of wheeze by written questionnaire and of ever asthma remained significantly associated with swimming pool availability, whereas the association of these two indicators with GDP per capita completely disappeared. The association between ever asthma and swimming pool availability persisted in Western Europe after exclusion of centres from the United Kingdom and Republic of Ireland (regression coefficient 0.81; 95% CI 0.09 to 1.53), whereas the association between wheezing by written questionnaire and swimming pool availability was abolished by the exclusion of centres in these two countries (regression coefficient −0.01; 95% CI −0.11 to 0.26). Pursuing the analysis at the country level (six countries had between 4 and 13 centres), we found no significant association between asthma and swimming pool availability. In Eastern Europe, none of the atopic diseases were related to swimming pool availability or GDP per capita. Concerning the influence of geoclimatic variables, the prevalence of wheezing by written questionnaire was inversely related to altitude, both in Western Europe and over the whole of Europe, while the prevalences of ever asthma, rhinitis, and hay fever decreased with altitude across all European centres. Mean annual temperature showed no consistent association with any asthma indicator but was inversely related to the prevalence of hay fever and atopic eczema in Western Europe and over the whole of Europe.

Multiple regression analyses confirmed that the associations of wheezing and ever asthma with swimming pool availability were independent of the influence of GDP per capita, altitude, and mean annual temperature. When analysing all European centres, the prevalence of wheezing by written questionnaire remained strongly associated with the availability of swimming pools (partial $r = 0.46$, $p < 0.001$), while decreasing with the altitude (partial $r = -0.26$, $p = 0.01$). The prevalence of ever asthma also remained strongly associated with the number of swimming pools per inhabitant (partial $r = 0.49$, $p < 0.001$) independently of the positive influence of GDP (partial $r = 0.29$, $p = 0.006$). When only centres in Western Europe are analysed, the prevalence of wheezing by written questionnaire across Western Europe was positively associated with swimming pool availability (partial $r = 0.39$, $p < 0.001$) and GDP per capita (partial $r = 0.29$, $p = 0.002$), while correlating negatively with altitude (partial $r = -0.33$, $p = 0.001$). Across Western Europe, the availability of indoor swimming pools emerged as the only factor significantly influencing the prevalence of ever asthma (partial $r = 0.48$, $p < 0.001$).

The prevalences of wheezing and ever asthma adjusted for covariates do not increase with swimming pool availability to the same extent in Western, Northern, and Southern Europe. As shown in fig 3, the prevalence of wheezing by written

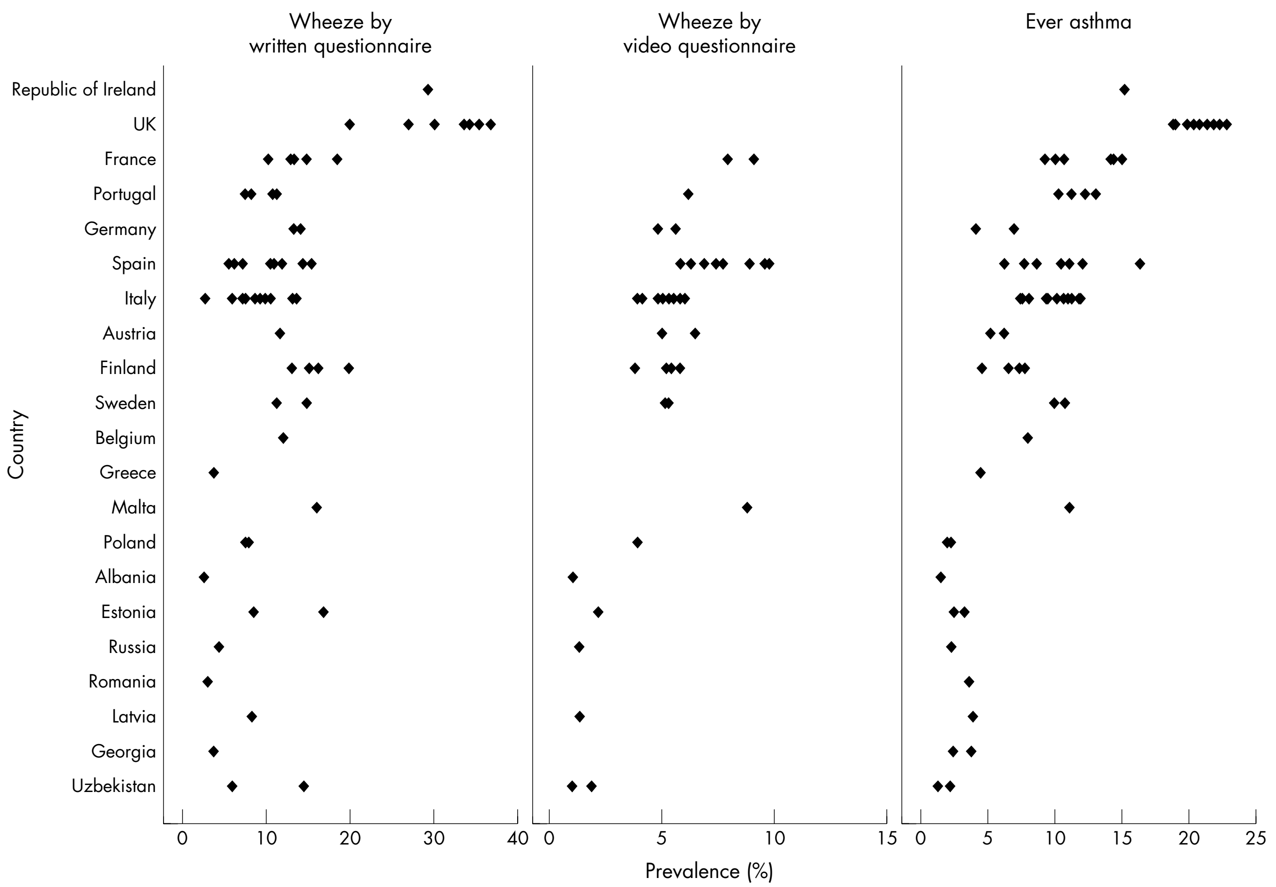

Figure 2 Prevalences of wheezing by written questionnaire, wheezing by video questionnaire, and of ever asthma along the East–West gradient in Europe. Data are those published by the ISAAC phase 1 study.[21]

questionnaire increases with swimming pool availability across centres in Western and Northern Europe but not across those in Southern Europe. Similarly, while the association between wheezing by video questionnaire and swimming pool availability did not persist across Western Europe (table 1), the analysis of this indicator along the North–South gradient reveals a strong association in Northern Europe (fig 4), despite the absence of data from the United Kingdom and the Republic of Ireland. As illustrated in fig 5, the associations between ever asthma and swimming pool availability were the most outstanding since they were consistently observed across Western, Northern, and Southern Europe and even persisted after exclusion of centres in the United Kingdom and the Republic of Ireland. It is interesting to note that when centres from these two countries were excluded, the prevalences of ever asthma in Northern and Southern Europe showed a similar increase with the number of indoor pools per inhabitant.

Among children aged 6–7 years, the prevalence of ever asthma was also associated with swimming pool availability, but the relationship was noticeably weaker than in children aged 13–14 years who were examined in the same centres (fig 6). Remarkably, the difference in ever asthma prevalence between the two age groups, positive in most centres, also correlated with swimming pool availability. In these younger children, the prevalence of wheezing (by written questionnaire only) was not related to swimming pool availability, nor was there any association between ever asthma or wheezing and the GDP per capita and other lifestyle variables ($p > 0.10$).

DISCUSSION

The present study shows that the prevalence of childhood asthma is consistently associated with the number of indoor swimming pools per inhabitant across Europe. The strongest and more consistent associations were found with the prevalence of ever asthma and of wheezing by video questionnaire, the indicators that also showed the strongest East–West gradients across Europe. The reason why associations were less consistent with the prevalence of wheezing by written questionnaire, the asthma outcome used in the ISAAC study, is still unclear. One explanation could be that ever asthma and wheezing by video questionnaire would capture more severe cases of asthma than the written questionnaire,[30] implicating that swimming pool attendance would be more closely related to persistent asthma symptoms. Another possibility, more likely in our view, would be that ever asthma and wheezing by video questionnaire are more reliable indicators to study variations in asthma prevalence between countries with different languages and cultures. As acknowledged by ISAAC investigators,[30] a written questionnaire describing the asthma symptoms is likely to provide a less accurate recognition of clinical asthma than a video based questionnaire displaying these symptoms. A written questionnaire is probably also a less accurate indicator than ever asthma, an outcome presumably linked to a medical diagnosis. The poor agreement of wheezing by written questionnaire with wheezing by video questionnaire reported by recent ISAAC studies[25 26] or with ever asthma as noted by us argue strongly in favour of this second interpretation.

Table 1 Regression coefficients (95% CI) between the prevalences of atopic diseases in 13–14 year old children and the number of indoor chlorinated swimming pools per inhabitant, gross domestic product per capita, altitude, and mean annual temperature in Western Europe and the whole of Europe.

	Swimming pool per inhabitant (n/100 000)		Log gross domestic product per capita (US$)		Log altitude (m)		Log mean annual temperature (°C)	
	Western Europe	Europe	Western Europe	Europe	Western Europe	Europe	Western Europe	Europe
Wheeze (written questionnaire)	3.08 (1.22 to 4.93)	3.39 (1.96 to 4.81)	37.8 (−7.1 to 82.6)	13.9 (5.40 to 22.4)	−3.14 (−6.16 to −0.12)	−3.88 (−6.56 to −1.19)	−10.3 (−22.0 to 1.33)	−7.34 (−18.0 to 3.34)
Wheeze (video questionnaire)	0.29 (−0.31 to 0.88)	1.08 (0.49 to 1.67)	−17.2 (−26.4 to −8.0)	5.45 (3.18 to 7.73)	−0.17 (−0.85 to 0.50)	−0.55 (−1.41 to 0.30)	2.41 (0.40 to 4.42)	2.73 (−0.01 to 5.47)
Ever asthma	1.94 (0.97 to 2.91)	2.73 (1.94 to 3.52)	1.65 (−23.2 to 26.6)	12.9 (8.12 to 17.7)	−0.90 (−2.58 to 0.79)	−1.89 (−3.61 to −0.16)	2.49 (−3.97 to 8.95)	4.60 (−2.1 to 11.3)
Rhinitis	1.26 (−0.63 to 3.15)	3.86 (2.11 to 5.61)	31.5 (−11.1 to 74.1)	29.5 (21.1 to 37.8)	−1.52 (−4.45 to 1.41)	−4.14 (−7.41 to −0.86)	−4.70 (−16.0 to 6.6)	−0.42 (−13.5 to 12.6)
Hay fever	1.09 (−1.04 to 3.21)	2.88 (1.17 to 4.60)	68.0 (23.1 to 112.8)	21.7 (12.9 to 30.5)	−1.39 (−4.68 to 1.89)	−2.67 (−5.81 to 0.47)	−18.3 (−29.9 to −6.7)	−12.6 (−24.4 to −0.80)
Atopic eczema	0.78 (−0.26 to 1.81)	1.32 (0.52 to 2.12)	35.5 (13.7 to 57.4)	8.91 (4.7 to 13.2)	−1.13 (−2.73 to 0.47)	−1.60 (−3.03 to −0.16)	−13.6 (−18.6 to −8.6)	−10.7 (−15.7 to −5.69)

Prevalences of atopic diseases were those published by the ISAAC phase 1 study.

Associations emerging between asthma and swimming pool availability were independent of the influence of altitude and mean annual temperature, two factors inversely related to the prevalence of ever asthma or wheezing as already reported.[27 28] Nor can these associations be explained solely by differences in wealth between European countries since asthma prevalence and swimming pool availability did not correlate with GDP per capita except when grouping centres from Western and Eastern Europe. Asthma prevalence or swimming pool availability were also not related to the other Westernisation factors such as tobacco expenditure, number of cars per inhabitant, number of children per woman, or the proportion of food sales in hypermarket versus traditional market.

Our study of course is not exempt from the risks of bias and misclassification inherent to any ecological study. Although we cannot formally exclude the possibility that swimming pool availability would be merely the reflection of a lifestyle causing asthma, this remains a very speculative possibility. Such a possibility, indeed, would imply the existence of a mysterious risk factor that would be closely linked to swimming pool availability across Europe while being independent of climate, wealth of the country, and other Westernisation indicators. Risk of misclassification with respect to exposure is another possibility since a retrospective evaluation of pool attendance by ISAAC participants was of course impossible. As proxy indicator of pool attendance by ISAAC children, we used the number of swimming pools per inhabitant in each centre. Two elements suggest that this surrogate indicator reliably reflects the pool attendance of schoolchildren at the population level. The first is the high representativity of the ISAAC data, which were based on an average of about 3000 children recruited from all or a random sample of schools in each centre. The second element is the limited capacity of public swimming pools that on average can welcome a maximum of 3000–4000 persons per week. Clearly therefore, in those areas having less than one public swimming pool per 100 000 inhabitants, not all children can regularly attend the pool. A regular pool attendance (e.g. at least once a week) by all children requires a minimum of two to three large pools per 100 000 inhabitants, a threshold that was attained in about 50% of the ISAAC centres in Western Europe but in none of the centres in Eastern Europe.

The main difficulty in our study was to ensure the completeness of the database of public indoor chlorinated swimming pools in the ISAAC centres. To reduce the risk of error, we first excluded three centres for which we could not precisely delineate the covered area on the basis of published information. We then constructed our database by collecting data from the international swimmer guide directory. We completed the information provided by this directory by adding swimming pools that could be retrieved from the web pages of the main cities in the studied centres. In this search, we considered only indoor chlorinated pools that can be used for swimming training of schoolchildren, excluding outdoor pools, indoor pools not sanitised with chlorine, as well as indoor pools in hotels that usually are not attended by schools. Of course, we cannot formally exclude the possibility that the sources we consulted did not contain all swimming pools in the studied centres or included some swimming pools that were not built or in activity in the 1990s, when phase 1 of ISAAC study was conducted. However, the swimming pool availability in Europe as assessed from our database cannot be very different from that existing in the late 1980s since the vast majority of public swimming pools in Europe were built in the 1960s and 1970s. Even if one assumes that some swimming pools were missing in our database or were not built or operational during the ISAAC study, we think it unlikely that this could have distorted our analysis. It is difficult to conceive indeed that some missing

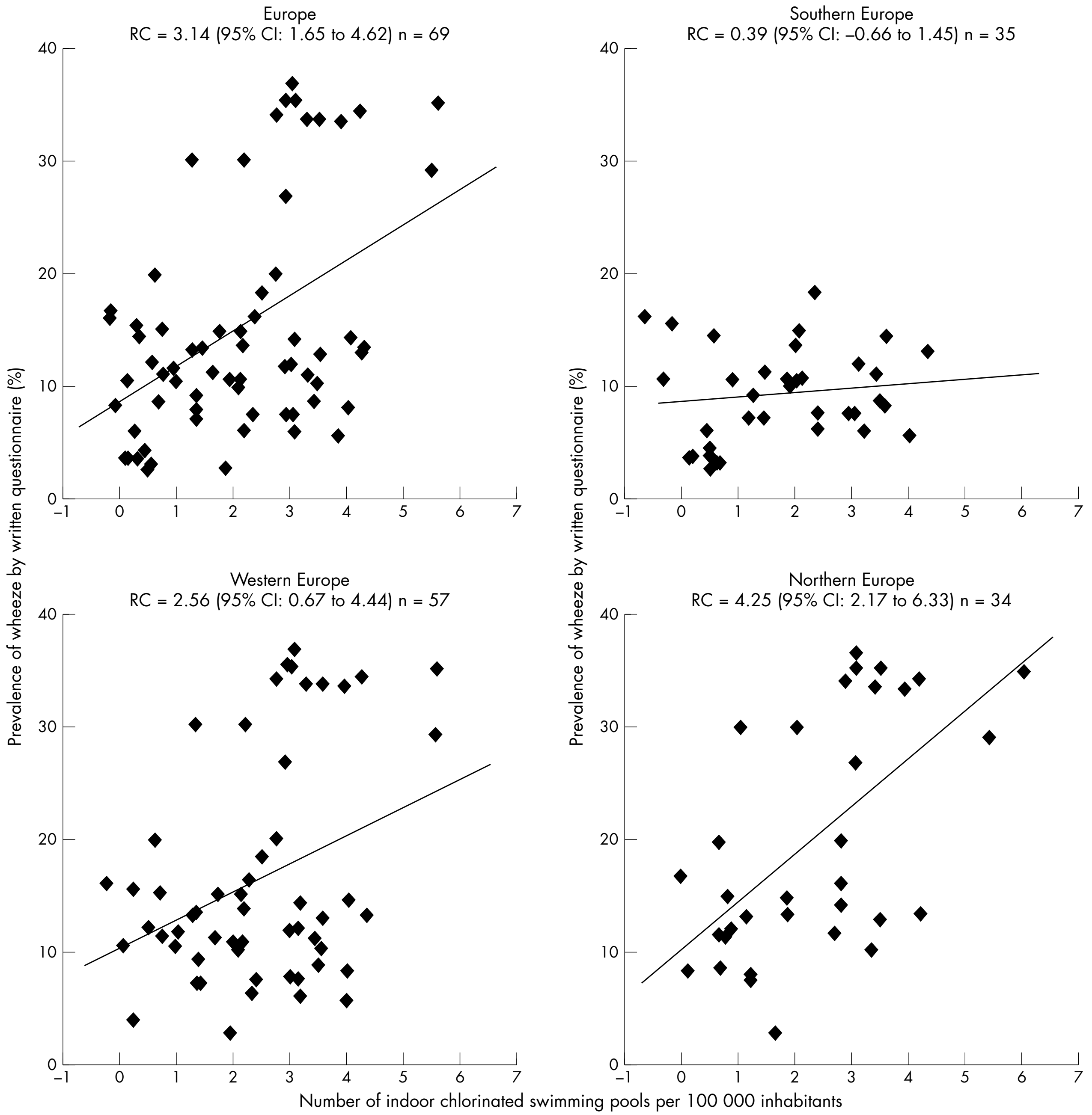

Figure 3 Associations between the prevalence of wheezing by written questionnaire in children aged 13–14 years and indoor swimming pool availability across the whole of Europe and across Western, Northern, and Southern Europe. Prevalences of wheezing have been adjusted for GDP per capita (Western Europe) or altitude (whole of Europe, Western and Southern Europe). Western Europe includes the 15 European Union member states before May 2004 plus Malta. Northern Europe includes the centres located above latitude 47.2° in Austria, Belgium, Estonia, Finland, France (three centres), Germany, Italy (one centre), Latvia, Poland, Republic of Ireland, Sweden, and the United Kingdom. Southern Europe includes centres located below a latitude of 47.2° in Albania, France (two centres), Georgia, Greece, Italy (12 centres), Malta, Portugal, Romania, Russia, Spain, and Uzbekistan. Prevalences of wheezing were those published by the ISAAC phase 1 study.[21] RC, regression coefficient; CI, confidence interval.

or inaccurate data in our database could have generated associations that would be both consistent across Northern, Western, and Southern Europe, while being specific of the most objective measures of asthma.

In contrast to epidemiological studies on ambient air pollution which have access to a wealth of environmental measures, there are very few data available about historical levels of trichloramine in indoor swimming pools in Europe. The survey of this gas in the air of indoor swimming pools in Europe, as in the rest of the world, has indeed started recently and in a few countries only (France, Belgium, and Germany). Although mean trichloramine levels reported in these countries since the late 1980s fluctuate in the same range (300–500 µg/m^3),[13 17] these levels might not be representative of those prevailing in the rest of Europe, in particular in countries with a colder climate or in countries having no code for swimming pools or having established such a code very recently (e.g. United Kingdom[31]). Differences in pool ventilation rate

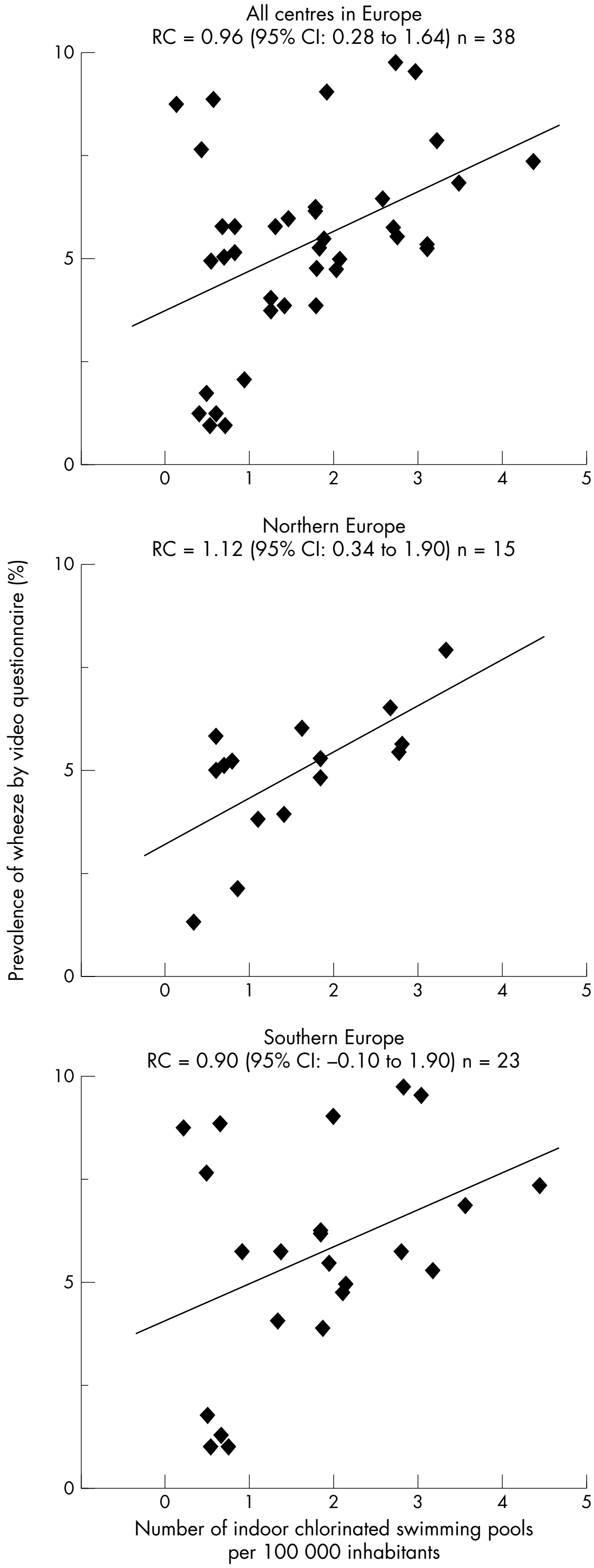

Figure 4 Associations between the prevalence of wheezing by video questionnaire in children aged 13–14 years and indoor swimming pool availability over the whole of Europe and across Northern and Southern Europe. Prevalences of wheezing have been adjusted for GDP per capita and altitude. This analysis does not include centres in the United Kingdom and Ireland, which did not measure the prevalence of wheezing by video questionnaire. Prevalences of wheezing by video questionnaire were those published by the ISAAC phase 1 study.[21] See the legend of fig 3 for countries included in the different parts of Europe. RC, regression coefficient; CI, confidence interval.

according to the climate might, for instance, explain why the relationships between asthma and pool availability appear steeper in Northern Europe compared to Southern Europe.

Another factor that we could not take into account is the possible exposure to chlorine used in backyard pools or in drinking water. Since backyard pools are usually outdoors, they have at their surface very little trichloramine owing to their natural ventilation. Outdoor pools, however, usually have higher levels of active chlorine in water than indoor pools. As a result of exposure to heat and light, active chlorine (hypochlorite) is transformed into chlorine gas, which being heavier than air tends to accumulate at the surface of outdoor pools, giving them their chlorine smell. Although we cannot exclude the possibility that chlorination products in outdoor pools can also cause deleterious effects on the respiratory tracts of children, we do not think that our findings could have been distorted by chlorine exposure in backyard pools since the association between swimming pool availability and asthma or wheezing was strongest in Northern Europe, where backyard pools are uncommon compared to Southern Europe.

Concerning drinking water, very little trichloramine is released because tap water is normally not in contact with urine, saliva, or other nitrogenous substances that contaminate swimming pool water and lead to the formation of chloramines. Even if some chlorine gas can be released from drinking water with high levels of chlorine, the impact on indoor air quality is usually very limited. Nonetheless, when used for bathing or washing, drinking water can be a significant source of skin exposure to chlorination products. In countries where swimming pools are rare, drinking water is probably the major source of skin exposure to chlorine. Interestingly, a recent ecological study in Japan[32] has shown that the chlorine levels in water supply correlated with the prevalence of atopic eczema but not with that of wheezing. These findings, exactly the opposite of those in our study, suggest that if chlorine in drinking water could have confounded our observations, it is only for those observations that concerned atopic eczema.

Despite the limitations inherent to the methodological design of our study and the lack of data about trichloramine levels in pool air, we think it would not be reasonable to dismiss our observations as simply arising from chance or bias without taking into consideration the arguments suggesting causality. The first argument for causality is the remarkable strength and consistency of associations emerging between swimming pool availability and the prevalence of ever asthma and of wheezing by video questionnaire, two outcomes which are assumed rather robust measures of asthma prevalence and which were also the only ones to show a clear East–West gradient across Europe. The biological plausibility of our findings and their coherence with other data also argue in favour of causality. Not only is trichloramine accumulating in the air of indoor swimming pools one of the most concentrated lung toxicants to which children of developed countries are regularly exposed, but recent studies have also suggested that this gas can cause occupational asthma[33] and promote the development of asthma in atopic children.[13 16] Engineers have also known for a long time that the atmosphere of indoor swimming pools is one of the most aggressive to be found in the building environment. The discovery that this chlorine laden atmosphere can be deleterious to the lungs of young children exercising in it is not surprising. The pattern of associations between atopic diseases and swimming pool, shifted to ever asthma and wheezing, also

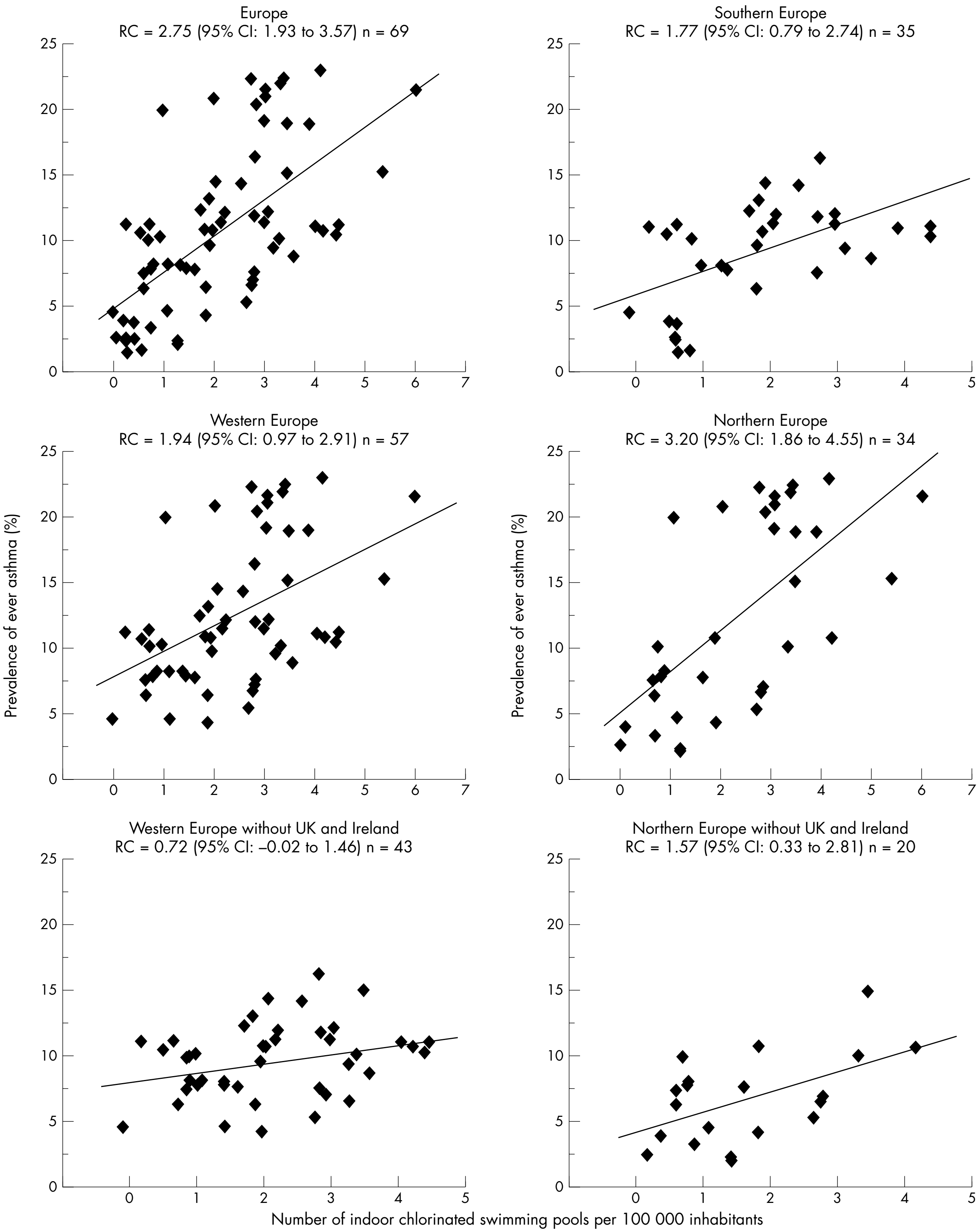

Figure 5 Associations between the prevalence of ever asthma in children aged 13–14 years and indoor swimming pool availability across the whole of Europe and across Western, Northern, and Southern Europe. For Western and Northern Europe, associations are also shown after excluding centres in the UK and Republic of Ireland. Prevalences of ever asthma have been adjusted for GDP per capita (Europe, Southern Europe, and Northern Europe without UK and Ireland) and mean annual temperature (Southern Europe and Western Europe without UK and Ireland). Prevalences of ever asthma were those published by the ISAAC phase 1 study.[21] RC, regression coefficient; CI, confidence interval.

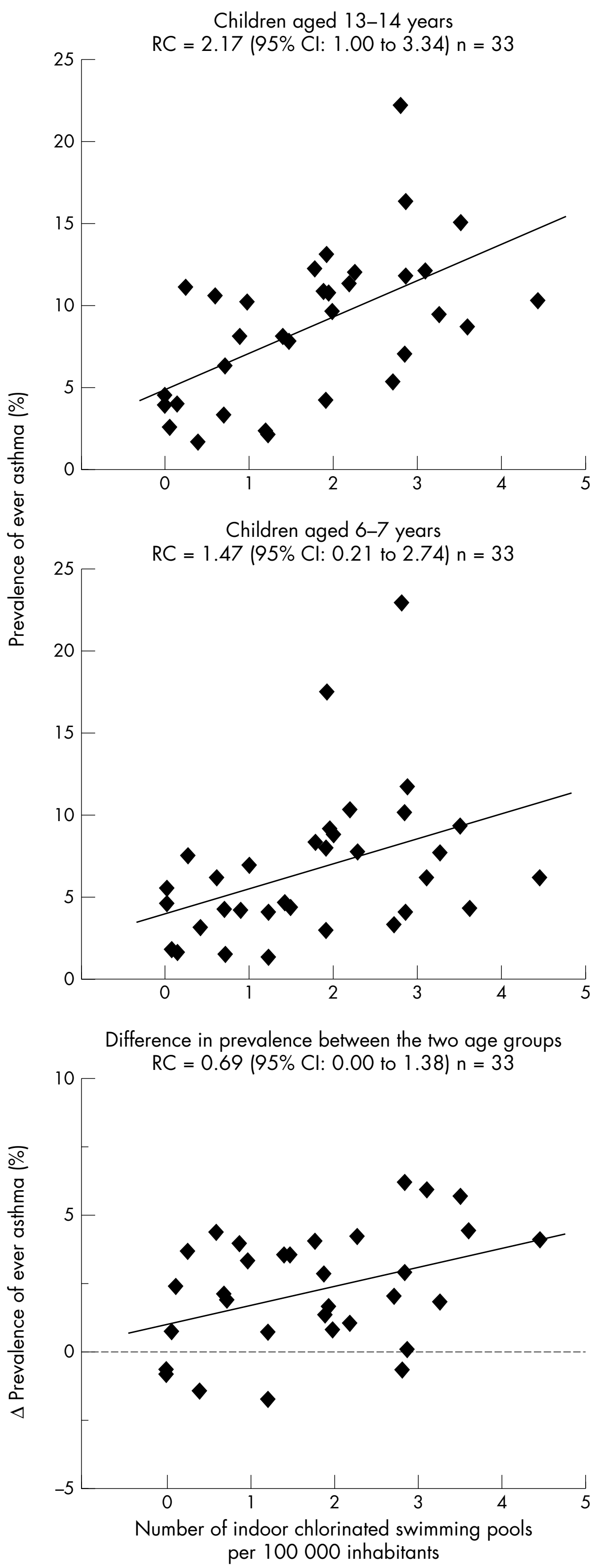

Figure 6 Prevalence of ever asthma in children aged 13–14 and 6–7 years and the difference in ever asthma prevalence between the two age groups in relation to the availability of indoor swimming pools in Europe. Prevalences of ever asthma were those published by the ISAAC phase 1 study.[21] RC, regression coefficient; CI, confidence interval.

ties in with the properties of trichloramine, an irritant and water insoluble gas affecting predominantly the lower respiratory tract. Lastly, the causality of associations between asthma and swimming pool is supported by their temporal coherence. The association between ever asthma and swimming pool availability was indeed both stronger and steeper in children aged 13–14 years than in those aged 6–7 years. The increase in ever asthma prevalence between these two groups was also proportional to the swimming pool availability in each centre. These findings are temporally consistent with pool attendance by children, which usually starts at the end of kindergarten or somewhat earlier, depending on swimming pool availability, and lasts until the end of primary school.

Our findings might appear paradoxical since swimming in the hot and humid air of an indoor pool is generally a healthy exercise well tolerated by asthmatics. However, the deeply rooted belief that the swimming pool environment is beneficial for asthmatics has been challenged by a recent study showing an increase in airways reactivity in asthmatics after only a 12 minute immersion in a chlorinated whirlpool bath.[34] This study thus provides further evidence that chlorine used to sanitise whirlpool baths, like swimming pools, may cause detrimental effects on airways of pool attendees, including asthmatics. Clearly, the benefits of swimming as a sport should not be confounded with the safety of chlorine used as biocide, nor should one confound the respiratory effects of the warm and humid air of an indoor pool with those of the chemicals polluting this air.

Intriguingly, our study suggests that the relationship between asthma and swimming pools in the United Kingdom and Republic of Ireland is different from that in other European

Main messages

- The prevalences of childhood asthma and the number of indoor chlorinated swimming pools in Europe are linked through associations that are geographically consistent and independent of climate, altitude, and the socio-economic status of the country.
- The strongest associations were found with ever asthma, which was also the asthma outcome showing the strongest East–West gradient in Europe.
- These findings accord with the ''pool chlorine'' hypothesis postulating that the rise of childhood asthma could result, at least partly, from the increasing exposure of young children to chlorination products contaminating the air and water of indoor swimming pools.

Policy implications

- Attendance at chlorinated swimming pools should be included among possible risk factors of childhood asthma and allergy in future epidemiological studies.
- There is a need to evaluate the long term respiratory effects of chlorination products that children inhale as gases or aerosols when attending swimming pools.
- Given the recent evidence that trichloramine building up in the air of indoor swimming pools can be detrimental to the lung and promote the development of asthma, there is a need to regulate the concentrations of this irritant and to ensure that indoor swimming pools are properly ventilated.

countries, since including data from these two countries noticeably increased the steepness of the relationships between asthma prevalence and swimming pool availability. The origin for this phenomenon is unclear. An overestimation of asthma prevalence in these countries appears unlikely as ISAAC data were collected using carefully standardised questionnaires.[24] We rather suspect that our study, based on public accessible swimming pools, has underestimated the swimming pool availability for children in the United Kingdom and perhaps also in the Republic of Ireland. The reason for this is that in the United Kingdom there are many more pools in schools and colleges than there are municipal pools (according to the Institute of Sport and Recreation Management, the United Kingdom has about 2300 school versus 1700 community indoor pools; http://www.isrm.co.uk/). This situation clearly contrasts with that in other countries where most schoolchildren attend only municipal indoor swimming pools.

In summary, our study shows that the prevalence of wheezing and of ever asthma across Europe is associated with the availability of indoor chlorinated swimming pools. These observations reinforce the need to pursue research in this area and to examine the relationships between the childhood asthma epidemic affecting industrialised countries and the exposure of children to chlorination products of swimming pools.

ACKNOWLEDGEMENTS

Alfred Bernard is Research Director of the National Fund for Scientific Research, Belgium.

Authors' affiliations

M Nickmilder, A Bernard, Department of Public Health, Catholic University of Louvain, Brussels, Belgium

Competing interests: none declared

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