ORIGINAL ARTICLE

Swimming pool attendance and respiratory symptoms and allergies among Dutch children

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ABSTRACT

Objectives To describe associations among swimming, respiratory health, allergen sensitisation and Clara cell protein 16 (CC16) levels in Dutch schoolchildren. Trichloramine levels in swimming pool air were determined to assess potential exposure levels.

Methods Respiratory health and pool attendance information was collected from 2359 children, aged 6–13 years. Serum from 419 children was tested for allergen sensitisation and CC16 levels. Trichloramine levels were assessed in nine swimming facilities.

Results Trichloramine levels ranged from 0.03 to 0.78 mg/m^3 (average 0.21 mg/m^3). Reported swimming pool attendance and trichloramine exposure were both not associated with asthma, wheezing, rhinitis or CC16 levels. Birch and house dust mite sensitisation were associated with recent indoor swimming (OR>1.86), but not after considering recent swimming frequency multiplied by trichloramine levels. Sensitisation to house dust mites was associated with frequent baby swimming (ORs=1.75; 95% CI 1.09 to 2.79). Furthermore, sensitisation was associated with lower serum CC16 levels. CC16 levels were associated with average trichloramine concentrations in pools; however, not after considering swimming frequency multiplied by trichloramine levels.

Conclusions Measured trichloramine levels were comparable with other studies but lower than in an earlier Dutch study. Swimming pool attendance was not associated with respiratory symptoms. The association between sensitisation and swimming during the first 2 years of life suggests that early-life exposures might be important, although this needs further study. The interpretation of transient and chronic changes of CC16 and other inflammatory markers in relation to the pool environment and health impacts warrants further investigation. Detailed comparisons with other studies are limited as few studies have measured trichloramine levels.

What this paper adds

- Recent concern regarding the potential effects of disinfectant by-products on children's respiratory health has initiated several studies on this topic. Available studies are conflicting, and their interpretation limited by the lack of reported quantitative levels of volatile chlorine compounds.
- Clara cell protein 16 levels were associated with sensitisation to house dust mites and to any common allergens, but not with respiratory symptoms. Associations with average trichloramine levels disappeared when swimming frequency was taken into account.
- Our results indicate that sensitisation to common allergens may be related to increased swimming, especially during pool attendance in the first 2 years of life. However, we found no associations between any swimming behaviours and respiratory symptoms among 2359 children. Thus, our study does not provide any strong evidence to dissuade children from attending chlorinated swimming pools.

INTRODUCTION

Swimming is a popular activity among children. The physical benefits are numerous and include cardiovascular conditioning, increased muscle strength, endurance, posture and flexibility. Moreover, a recent meta-analysis identified swimming as being less asthmagenic than other types of exercise and possibly beneficial with respect to disease severity.[1]

To protect swimmers, the use of disinfectants in swimming pool water is highly regulated.[2] Recent concern over the potential detrimental effects of disinfectant by-products, such as trichloramine, on children's respiratory health has sparked a series of studies on this topic. Several Belgium studies report associations between early-childhood swimming and elevated levels of respiratory biomarkers and increased occurrence of asthma.[3–6] However, an association between respiratory symptoms and swimming was not observed in a German[7] and Spanish study.[8] Quantitative exposure levels were not reported in these studies. A review by Weisel *et al*[9] concluded that evidence for the association between childhood swimming and onset of asthma is suggestive, but not conclusive. A more recent longitudinal study found no increased risk of asthma or allergic symptoms in British infant swimmers. In fact, swimming was associated with increased lung function and a lower prevalence of asthma symptoms, especially among children with pre-existing respiratory conditions.[10] Again, exposure levels were not reported.

This study aims to describe respiratory health ascertained by questionnaires, allergen-specific sensitisation from serum and levels of serum Clara cell protein 16 (CC16), a marker of lung epithelial damage, in relation to swimming pool attendance and trichloramine levels. Where previous studies have used self-reported swimming pool attendance as a

proxy for exposure, this study is unique in documenting present trichloramine levels in pools frequented by the study population. Determining the concentration of trichloramines in swimming pool air is an important step towards understanding the role played by these compounds on childhood respiratory health.

METHODS

Study design and population

This study is an extension of the collaborative project entitled 'Health Effects of Indoor Pollutants: Integrating Microbial, Toxicological and Epidemiological Approaches' (www.hitea.eu). In December 2008, we conducted a cross-sectional study in primary schools in the province of Utrecht in The Netherlands. Of the 23 schools asked to participate, only one declined. All parents of children in grades three to eight (aged 6–13 years) were invited to complete a questionnaire on behalf of their child(ren). Of the 4282 parents who were contacted, 2540 (59%) returned the completed questionnaire. Removal of children with missing information on swimming behaviour, health symptoms, gender and age yielded a sample size of 2359 children. After completing the questionnaire, parents of children enrolled in 11 schools (total 2329 students) were asked if their child was willing to provide a blood sample. Serum was collected from 501 children. Ultimately, 419 children with serum samples and complete information on swimming behaviour, gender and age were included in this analysis. Parental consent was obtained from all participants. The study protocol was approved by the Medical Ethical Committee of the Utrecht Medical Center and complied with all requirements of international regulations.

Trichloramine measurements

Ten swimming pool facilities frequently visited at present by the study population, as reported in the questionnaire, were asked to participate; only one declined. The remaining nine facilities were visited on a regular basis by 77% of the study population. All swimming facilities were sampled in January 2010. Seven of the nine facilities were sampled on two different days, whereas two were sampled only once. The sampling schedule was designed to maximise variability in the number of swimmers and types of activities ongoing during sampling. During sampling, trichloramine measurements were collected 1.50 m above the water surface for three consecutive 2-h periods at two different types of swimming pools within one facility. Altogether, 96 trichloramine samples were taken (7 facilities×2 days+2 facilities×1 day; 6 samples per facility per measuring day). The method used for sampling was developed by Hery *et al*[11] and applied as described by Jacobs *et al*.[12] Briefly, air is passed through a sampling head loaded with quartz glass fibre filters soaked in a solution of sodium carbonate and di-arsenic tri-oxide at a rate of 1.2 l/min. After sampling, impregnated filters are desorbed, sonicated and centrifuged, chloramines are reduced to chlorides which are subsequently analysed by ion chromatography (Dionex DX500 HPLC; Dionex BV, Bavel, The Netherlands; IonPac AG14 guard and AS14 highly selective anion column with ASRS-I self-regenerating suppressor; DS3 conductivity detector), with a mobile phase of Na_2CO_3/$NaHCO_3$ (3.5 mM/1.0 mM) and a flow rate of 1.2 ml/min. Air temperature and relative humidity, pool volume, size of the space around the pool, and number of swimmers in the water were recorded during sampling. Information on water pH and temperature, free and bound chlorine concentrations is routinely measured by each swimming facility and was obtained.

Health questionnaire

Information on respiratory health, early living environment, condition of current home, level of physical activity and swimming pool attendance was collected. Recent indoor (and outdoor) swimming pool attendance was defined as a positive answer to: 'Did your child attend an indoor (outdoor) swimming pool at least once a week for at least 1 month during the last year?' The frequency of indoor past and present swimming was obtained by requesting age-specific swimming attendance for every 2 years of life (frequency: never, less than once a month, between 1 and 3 times a month, 1–3 times a week, >3 times a week; age categories: ≤2, 3–4, 5–6, 7–8, 9–10, 11–12 years). Baby swimming was defined as attending a swimming pool at least once a month between the age of 0 and 2 years (yes/no). Information on whether a child attended or avoided swimming pools due to health concerns was obtained. The respiratory health status of children was assessed using questions derived from the validated International Study of Asthma and Allergies in Childhood questionnaire.[13] Asthma was defined as: (1) ever asthma (experiencing asthmatic symptoms at any point during life), (2) current asthma (experiencing wheeze or asthmatic symptoms or using medication during the last 12 months in combination with asthma at any point during life) or (3) doctor confirmed asthma (physician diagnosis of asthma). Additionally, information on ever or current wheezing and rhinitis was requested. Finally, parents were asked whether their child had ever suffered from eczema or allergies.

Serum analysis

Aeroallergen-specific immunoglobulin E (IgE) serum concentrations were measured by enzyme immunoassay.[14] IgE levels were screened against house dust mites, cat epithelium, dog dander, birch and grass pollen mixture. A child was considered sensitised if the IgE concentration exceeded 0.050 optical density. Due to the low number of children sensitised to some allergens (dog, birch and cat), these allergens were not considered separately in all analyses. All allergens were included in the grouped analysis looking at sensitisation to any common inhalant allergen.

CC16 was measured using a Biovendor Human Clara Cell Protein ELISA kit, as described by the manufacturer (Brno, Czech Republic).

Statistical analysis

Associations between various swimming behaviours and trichloramine exposure and health outcomes were analysed with logistic regression for binominal outcomes and linear regression for continuous outcomes (CC16 levels). As children were recruited from schools, multilevel analyses were used to adjust for possible correlations between children within one school using generalized linear models and mixed-effects models (GENMOD and MIXED procedure). Covariates that might confound exposure–response associations were selected based on previous studies and whether they were significantly associated with the outcome of interest. Covariates were retained in the final model if they substantially (>10%) modified the crude OR, which included only gender and age. As recruited schools were selected based on the presence or absence of moisture, schools with dampness-related problems were oversampled. Therefore, each model was adjusted for the moisture status of a child's school. Adjusted ORs and their respective 95% CI are reported.

For exposure estimation purposes, swimming pool attendance categories were transformed into hours of pool attendance per month. Specifically, 0, 0.5, 3, 6 and 20 h of pool attendance per month correspond with a reported frequency of never, less than once a month, between 1 and 3 times a month, 1–3 times a week and >3 times a week, respectively. Pool attendance hours were multiplied by the average trichloramine levels of the swimming facility most frequently visited by each child, in order to obtain a cumulative exposure to trichloramine. When no exposure information on trichloramines was available for the pool most frequently visited, the overall average of all nine swimming facilities was used. All statistical analyses were performed in SAS V.9.1.

RESULTS

Trichloramine exposure

Facility and measurement characteristics are summarised in online supplementary appendix 1 (see supplementary file). The average trichloramine level across all measurements was 0.21 mg/m^3. The highest average day level within one pool was 0.44 mg/m^3, while the highest single measurement was 0.78 mg/m^3. Approximately 90% of the measurements were below 0.50 mg/m^3. As found in our previous study,[12] trichloramine levels were significantly associated with the number of bathers during sampling, the volume of air above the pool and the free chlorine concentration in the water (online supplementary appendix 2). The largest part of the variability in trichloramine levels was explained by variation between measuring days (56%), while 13% was explained by variation between swimming facilities. Swimming time (estimated from reported pool attendance frequency in the questionnaire) multiplied by pool average trichloramine levels ranged from 0 to 8.24 mg/m^3×hours per month for recent swimming (online supplementary appendix 1) and 0 to 5.19 mg/m^3× hours per month for baby swimming (not shown).

Reported pool attendance and symptoms

Population characteristics, prevalence of health outcomes and swimming behaviours for all children and for the subset of children with serology information are summarised in table 1. There were no significant differences in pool attendance or health symptoms between those who provided serum and those who did not, with the exception of 'ever wheezing', which was more frequently reported among children who provided blood (OR=1.37; 95% CI 1.10 to 1.71). Of the 260 (11%) children who ever had asthma within the whole population, 55% reported currently suffering from symptoms. Overall, 28%, 27% and 34% of the children reported ever wheezing, rhinitis and eczema, respectively.

Asthma occurred more often in older children and boys. Children of higher birth weight had a significantly lower risk of asthma, wheezing and rhinitis. Symptoms were more frequently reported among children living in houses with water damage and mould. Parental asthma and parental skin and nasal allergies were positively associated with all health outcomes investigated (ORs ranged between 1.38 and 4.82; data not shown). There was no association between pool attendance frequency and indoor air quality in schools, which was characterised by the presence of moisture or mould. All but three children reported swimming at least once a month at some point during life. Within the study population, 71% of children had attended a pool before the age of 2 and 32% reported swimming at least once a month between the ages of 0 and 2 years (baby swimming). Swimming at least once a week for at least 1 month during the past 12 months in an indoor and outdoor pool was reported by 54% and 21% of the children, respectively. These children will be referred to as recent swimmers. Recent indoor swimmers tended to be younger, have lower body mass indexes, higher housing densities and were less likely to currently own a pet. Recent outdoor swimmers were more likely to have had farm animal contact early on in life and to be exposed to smoke in the home. Parents of recent indoor and outdoor swimmers were less likely to have postsecondary education compared with parents of non-swimmers. Except for age and gender, inclusion of these potential confounders did not substantially (>10%) change the crude OR.

Associations between swimming pool attendance and respiratory health are depicted in figure 1A. Overall, the ORs associated with recent indoor swimming (yes/no) tended to be greater than 1.0, but none reached statistical significance. Similar results were obtained for recent outdoor swimming, although the prevalence of eczema was significantly lower in recent outdoor swimmers (OR=0.73; 95% CI 0.60 to 0.90). In general, respiratory symptoms were not associated with swimming at any age (data not shown), although asthma prevalence was lower in baby swimmers (figure 1A). In addition, the frequency of recent or baby swimming was not associated with increased symptom risk (figure 2-1). Only baby swimmers attending a pool between one and three times a month reported less current asthma symptoms than non-baby swimmers (OR=0.45; 95% CI 0.24 to 0.82). Stratification by physical exercise (less or more often than once a week), pool type, parental allergies or parental education did not modify the results, nor did excluding baby swimmers and recent outdoor swimmers from the analyses.

Reported pool attendance and allergen sensitisation

Among the 419 children with available serum and questionnaire information, 29% were sensitised to at least one of the five allergens investigated. Being female, having older siblings, living with pets indoors or early-life farm animal contact reduced the risk of sensitisation. In contrast, day care attendance increased the risk of sensitisation. Sensitisation was positively associated with all respiratory health outcomes investigated (ORs between 1.59 and 9.74; data not shown). Among those who gave blood, 51% recently swam indoors, 20% recently swam outdoors and 31% swam regularly (at least once a month) before the age of 2 years.

Recent pool attendance tended to be associated with allergen-specific sensitisation (figure 1B). However, associations were only statistically significant between indoor swimming (yes/no) and birch sensitisation (OR=5.63; 95% CI 1.16 to 27.29), and indoor swimming (yes/no) and house dust mite sensitisation (OR=1.86; 95% CI 1.00 to 3.45). Baby swimming (yes/no) was associated with sensitisation to house dust mites (OR=3.03; 95% CI 1.96 to 4.69). Swimming frequency tended to increase the risk of sensitisation to at least one of the common allergens (figure 2-2). Children who visited a pool at least once a week before the age of 2 years were more often sensitised to house dust mites (OR=6.29; 95% CI 3.51 to 11.29), grass pollen (OR=2.07; 95% CI 1.00 to 4.30) and to at least one common allergen (OR=4.11; 95% CI 2.48 to 6.83), compared with those who did not. Because of the lack of cat sensitised children among those who did not swim before the age of 2 years, calculation of cat-specific ORs was only possible after imputing one case in the non-swimmers (OR>9.66; 95% CI 1.17 to 79.78; OR>8.13; 95% CI 1.24 to 53.44; OR>11.25; 95% CI 0.87 to 144.80 for increasing swimming frequency).

Table 1 General characteristics, prevalence of health outcomes and swimming pool behaviour of the study population

	Total population	Serology available
	n=2359*	n=419*
General characteristics		
Males (n, %)	1128 (48)	195 (47)
Age (years, SD)	9.1 (1.8)	9.0 (1.8)
BMI (kg/m^2, SD)	16.5 (2.4)	16.7 (2.4)
No. of older siblings (median, IQR)†	1.0 (1–2)	1.0 (0–1)
Parental education (n, %)		
Primary	25 (1.1)	2 (0.5)
Secondary	939 (42.0)	180 (44.4)
Postsecondary	1272 (56.9)	223 (55.1)
Smoking in home (n, %)		
Current	314 (13.4)	63 (15.0)
During 1st year	298 (12.7)	59 (14.2)
During pregnancy	200 (8.6)	45 (10.8)
Birth weight (n, %)		
<2.5 kg	165 (7.2)	32 (7.7)
2.5–4 kg	1798 (78.2)	325 (78.5)
>4 kg	338 (14.7)	57 (13.8)
Day care attendance (n, %)	763 (32.5)	144 (34.4)
Parental asthma (n, %)	505 (21.7)	96 (23.3)
Parental allergies (n, %)	1703 (72.8)	314 (75.6)
Farm animal contact 1st year (n, %)	267 (11.4)	51 (12.2)
Pets present in home (n, %)		
Current	1153 (49.4)	213 (51.3)
During 1st year	1025 (44.3)	181 (44.0)
Mould spots/odour at home (n, %)		
Ever	477 (20.5)	115 (27.8)
During last 12 months	346 (14.9)	81 (19.6)
Water damage at home (n, %)		
Ever	526 (22.7)	120 (29.1)
During last 12 months	200 (8.6)	45 (10.9)
Physical activity‡		
During last 12 months	1660 (70.4)	302 (72.1)
Health outcomes (questionnaire-based)		
Asthma (n, %)		
Ever	253 (10.7)	46 (11.0)
Doctor confirmed	244 (10.3)	45 (10.7)
Current	139 (5.9)	24 (5.7)
Wheezing (n, %)		
Ever	655 (27.8)	142 (34.1)
During last 12 months	222 (9.4)	35 (8.4)
Nasal symptoms (no cold) (n, %)		
Ever	638 (27.1)	118 (28.6)
During last 12 months	559 (23.7)	103 (24.9)
Allergies (positive skin prick test SPT/serum) (n, %)	301 (12.8)	52 (12.7)
Eczema ever (n, %)	801 (34.0)	162 (38.9)
Serology		
Allergen-specific sensitisation (n, %)		
House dust mite		79 (18.9)
Dog		1 (0.2)
Cat		26 (6.2)
Grass		65 (15.5)
Birch		12 (2.9)
Any common allergen		120 (28.6)
Serum pneumoprotein CC16 (μg/l, SD)		7.1 (2.5)
Swimming behaviour		
Recent indoor swimming (n, %)	1272 (53.9)	216 (51.6)
Recent outdoor swimming (n, %)	486 (20.6)	84 (20.1)
Baby swimming (n, %)	664 (30.5)	124 (31.3)
Present level of swimming (n, %)		
No swimming last year	100 (4.7)	19 (4.9)
Less than once a month	765 (36.3)	143 (37.1)
1–4 times a month	714 (33.9)	119 (30.8)
1 or more times a week	529 (25.1)	105 (27.2)
Children *attending* a swimming pool because of respiratory allergies/skin problems	0	0
Children *avoiding* a swimming pool in the past 12 months because of respiratory allergies/skin problems	17 (0.8)	4 (1.0)

Recent indoor/outdoor swimming: swimming pool attendance at least once a week for at least 1 month during the last year; baby swimming: swimming pool attendance at least once a month between the age of 0 and 2 years.
*Not all categories add to the total sample size due to missing information.
†Because the distribution is skewed to the right, the median is reported instead of the mean.
‡Exercise outside school hours more than once a week.
BMI, body mass index; CC16, Clara cell protein 16.

Trichloramine exposure and respiratory health

No significant associations were found between visiting a pool with higher trichloramine levels or average trichloramine levels multiplied by recent attendance (in hours per month) and sensitisation or respiratory symptoms (table 2). Trichloramine exposure during baby swimming, under the assumption that the currently visited pool is the same as that visited during baby swimming, was significantly and positively associated with mite sensitisation (OR=1.80; 95% CI 1.25 to 2.60) as well as sensitisation to at least one of the common allergens (OR=1.62; 95% CI 1.21 to 2.18). Trichloramine exposure during baby swimming was not associated with the presence of respiratory symptoms (data not shown). The results remained unchanged after mutually adjusting for baby swimming and present swimming, respectively (data not shown).

In a sensitivity analysis, limited to the population attending the nine pools with available exposure measurements, similar results were found (data not shown).

Pool attendance, trichloramine exposure and CC16

The mean CC16 serum concentration in the population was 7.1 μg/l. CC16 levels were higher in girls and children having older siblings. Other determinants such as day care attendance, exposure to moisture or environmental tobacco smoke ETS, parental education and allergies, body mass index or physical exercise were not associated with CC16 levels. CC16 levels, adjusted for age, gender and school moisture status, were significantly lower in children sensitised to house dust mites (β=−0.77; p=0.02) and to any of the common allergens (β=−0.69; p=0.01). However, CC16 levels were not associated with cat, birch or grass pollen sensitisation or with any respiratory symptoms (data not shown).

Although CC16 levels were slightly lower in children frequently attending pools, CC16 levels were not significantly associated with reported pool attendance (table 3). However, higher CC16 levels in serum were significantly associated with present trichloramine levels in swimming pools visited by

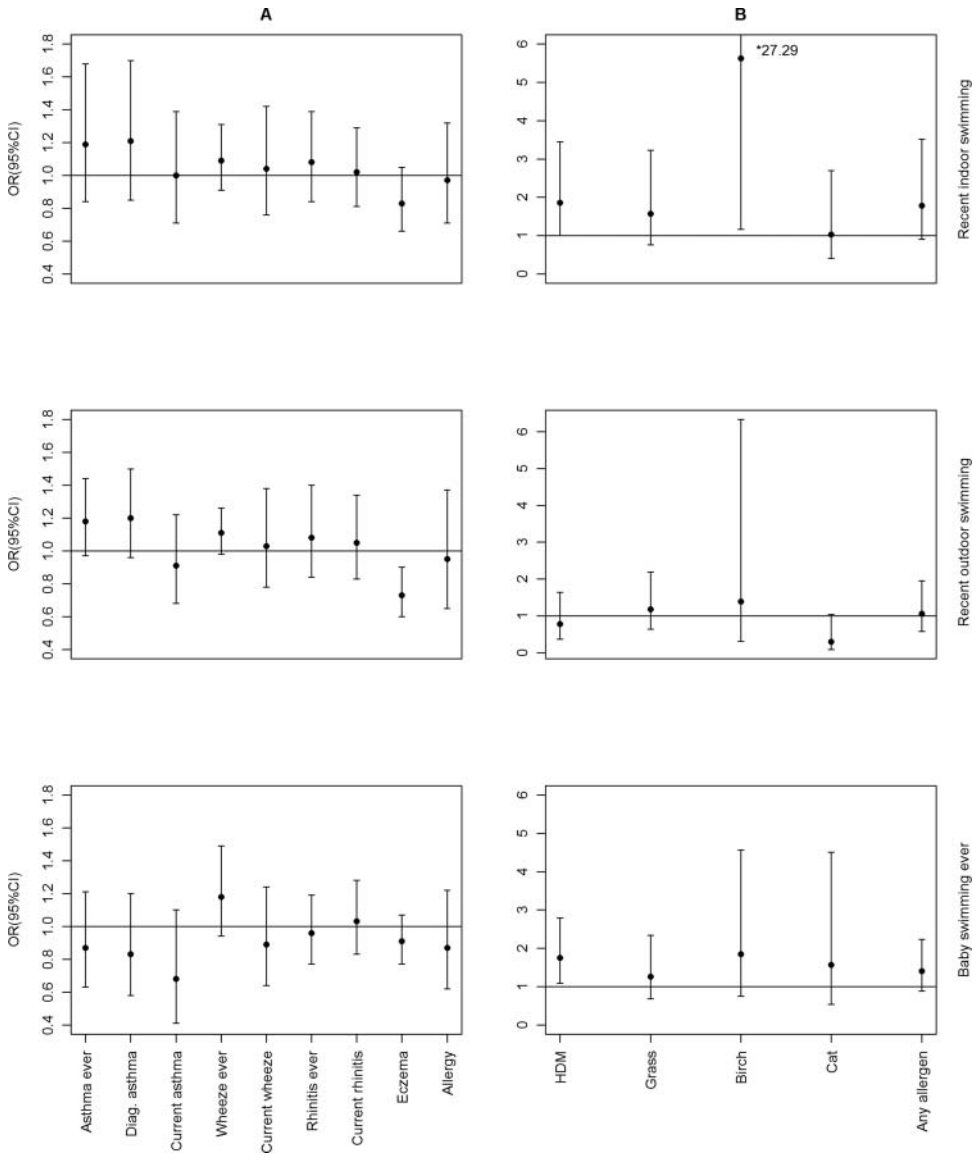

Figure 1 ORs and corresponding 95% CIs for the association among recent indoor and outdoor swimming, baby swimming and respiratory health symptoms (A) and sensitisation (B) (yes/no; adjusted for age, gender and school moisture status). HDM, house dust mites.

children but the association disappeared when swimming frequency was also considered.

Exploration of possible reverse causation

None of the children reported swimming because of respiratory allergies and/or skin problems, and only 17 children (0.8%) avoided swimming during the last 12 months because of respiratory allergies and/or skin problems. Associations between swimming and health remained the same after removing these children from the analyses. As such, reverse causation is unlikely to have affected our results.

DISCUSSION

Our findings indicate that no strong associations exist among recent trichloramine exposure, self-reported swimming pool attendance and reported respiratory symptoms among Dutch children. Allergen-specific sensitisation was increased among baby swimmers and recent indoor swimmers, although associations with recent swimming disappeared when reported swimming pool attendance was multiplied by measured trichloramine levels. This association with sensitisation may be indicative of an inflammatory response, but CC16 levels did not clearly confirm this hypothesis. The association between baby swimming and atopy may also indicate that early-life exposures may be relevant. Future studies which include detailed exposure assessments during early-life swimming are required to further elucidate our findings.

Respiratory health symptoms were not associated with recent indoor and outdoor swimming in our study. Swimming pool attendance before the age of 2 years was associated with a lower prevalence of asthma ever and rhinitis ever and a higher prevalence of wheezing ever. However, only the association between current asthma and visiting a pool 1–3 times a month reached statistical significance. These findings are consistent with other studies performed in Spain, Germany, the UK and Italy which have also found no clear associations between swimming pool attendance and respiratory health,[7 8 10 15 16] but are in contrast to studies from Belgium,[3 4 17 18] which suggests that swimmers are at an increased risk of asthma and recurrent respiratory tract infections. Our study found a

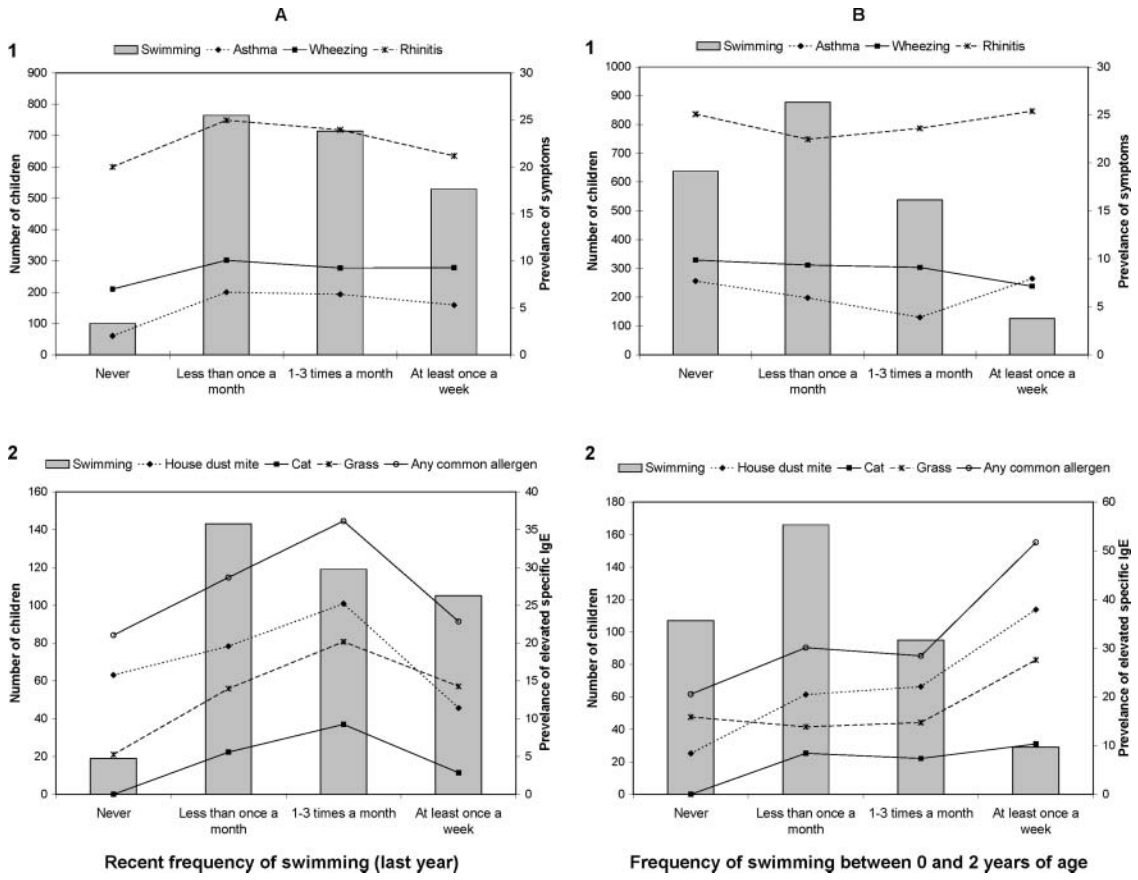

Figure 2 Frequency of recent indoor swimming pool attendance (A) and baby swimming (0–2 years of age) (B) and prevalence of symptoms last year (1) and sensitisation (2).

reduced risk of eczema associated with predominantly recent outdoor swimming. We caution against overinterpretation of this result as it is in contrast to other reports.[8] Also, although we found no evidence for reverse causation in our population, we cannot completely exclude the possibility that children with skin symptoms may avoid attending outdoor pools. However, this seems unlikely as associations with symptoms suggest otherwise and very few children reported pool avoidance because of allergies during the last 12 months (N=17 children, <1%). Furthermore, associations between swimming and health remained the same after removing these 17 children from the analyses (data not shown).

Babies and young children are especially sensitive to inhalant irritants because they are still undergoing lung development.[19] Additionally, they are often restricted to small, hot and more heavily polluted swimming environments than older children and adults.[5] Earlier studies have observed, although not consistently, associations between atopy and swimming pool attendance. For example, pool attendance during school-age was

Table 2 Associations between present exposure to trichloramines and health outcomes

	Trichloramine exposure: pool average	Present exposure: pool average×present swimming frequency
Health outcome	**OR (95% CI)***	**OR (95% CI)***
Sensitised to:		
Any allergen	2.85 (0.45 to 17.88)	0.86 (0.64 to 1.16)
House dust mite	3.88 (0.84 to 17.91)	0.82 (0.54 to 1.23)
Cat	4.30 (0.28 to 67.05)	0.72 (0.48 to 1.07)
Asthma current	0.34 (0.06 to 2.07)	0.96 (0.71 to 1.3)
Wheeze current	0.37 (0.08 to 1.8)	0.93 (0.8 to 1.09)
Rhinitis current	0.58 (0.15 to 2.19)	0.94 (0.71 to 1.26)

*Adjusted for age, gender and school moisture status.

Table 3 Associations between Clara cell protein 16 levels (μg/l) in serum and swimming (adjusted for gender, age and school moisture status)

	Intercept	β	p Value
Swimming behaviour			
Recent indoor swimming			
(no/yes)	8.504	−0.474	0.08
Recent outdoor swimming			
(no/yes)	7.559	−0.304	0.32
Baby swimming			
(no/yes)	7.975	−0.501	0.06
Present frequency of swimming			
No swimming last year	7.807	Reference	
Less than once a month		−0.307	0.62
1–4 times a month		−0.501	0.41
1 or more times a week		−0.503	0.41
Estimated trichloramine exposure			
Present exposure: pool average (mg/m^3)	6.352	4.263	<0.01
Present exposure: pool average (mg/m^3) adjusted for baby swimming	6.976	4.745	<0.01
Present exposure: pool average×swimming frequency (mg/m^3×hours/month)	7.384	−0.108	0.51

associated with higher hay fever rates later in life.[15] However, others have found no effect on atopy among early swimmers.[7 10] Atopy might also act as an effect-modifier in the association between swimming and asthma; higher pool attendance during childhood was associated with childhood asthma in atopics.[4] However, others have found no evidence to suggest effect-modification by atopy.[10] Due to a limited sample size, a stratified analysis based on atopic status was not possible in our population. However, analyses stratified by parental allergies indicate that atopy was not an effect-modifier in our study population.

Allergen sensitisation may reflect an increased sensitivity of the lung epithelium before the onset of respiratory symptoms. Our finding that swimming, particularly during the first 2 years of life, is associated with sensitisation might indicate that early-life exposure to trichloramines in swimming pool air increases the permeability of the lung epithelium resulting in a higher risk of being sensitised, as has been suggested by others.[20] However, as our study was not designed to specifically assess this hypothesis (ie, we did not collect information on indicators of lung epithelium permeability during infancy), we are unable to conclusively comment on the factors driving this association. Future studies which collect biomarker data at younger ages are warranted.

It has been suggested that irritant exposure may result in transient or permanent changes in serum CC16 levels, a frequently used biomarker for lung permeability. Acute exposure to certain environmental irritants might cause a transient increase in serum CC16, reflecting a disruption of the epithelial barrier which increases protein leakage. Conversely, a chronic decrease in serum CC16 is a result of the destruction of Clara cells.[21] Information on 'normal' physiological levels in humans is lacking. The CC16 levels we found are of the same magnitude as those reported in earlier studies on school-aged children.[3 6 10 22 23] However, whereas others found significantly lower (>20%) CC16 levels in recent and baby swimmers,[6 22] we found no significant differences in CC16 levels between swimmers and non-swimmers. Studies on short-term changes in CC16 in relation to swimming show conflicting results. Some studies find no changes in serum CC16 levels in children[3 24] and adults[25] after swimming, whereas others detected a transient increase in adult swimmers.[3 23] Interestingly, Carbonnelle *et al*[24] found a decrease in protein levels in adult swimmers after attending an indoor chlorinated pool. In our population, present trichloramine levels in pools were positively associated with CC16. However, swimming pool attendance was not associated with CC16 levels (CC16 levels were slightly lower in frequent swimmers). There was also no association between CC16 and trichloramine levels multiplied by swimming frequency. This primarily null result is in contrast with earlier findings which suggest that chronic irritant exposure may decrease CC16 in serum.

It is possible that trichloramine levels in the air of the swimming pools measured in this study may be too low to cause respiratory symptoms. Average levels in this study were lower than in our previous Dutch study conducted in 2007[12] and approximately 90% of the measurements were below the tentative exposure limit value of 0.50 mg/m^3 proposed by Hery *et al*.[11] Nevertheless, the range of exposure levels we recorded is consistent with those documented in other studies.[3 4 8 26] Furthermore, the same characteristics predicted trichloramine air levels in this study as in our earlier study,[12] which suggests that our predictors are robust.

The reasons for the conflicting results in the literature remain elusive. It has been suggested that methodological aspects of the studies may be responsible.[10] Effects are mainly found in 'small scale' studies,[4 6 27] whereas in larger population-based studies, no association was found between pool attendance and health.[7 8 10 15] This may suggest that the studies with positive outcomes are not based on a representative sample of the total population. The sample size of our questionnaire study (n>2000) was comparable with the sample size of the Spanish and German studies. The positive associations between allergen-specific sensitisation in relation to pool attendance found in our study were however derived from a smaller subsample of 419 children. Regardless, this smaller subsample did not differ from the total population with respect to respiratory symptoms and demographic characteristics (data not shown).

A second methodological issue of concern is that the sampling unit for two studies is the school or pool visited by the children.[3 17] This may lead to ecological fallacies when aggregated rather than individual-level exposure data are used, especially when the subjects are not equally 'exposed' to an environmental factor.[28] Also in this study, present exposure levels showed a strong positive association with CC16 levels, but not when attendance frequency was considered. This emphasises the importance of improving exposure assessment by characterisation of the indoor pool environment and human exposure levels in future studies.

This study is complicated by the absence of a true 'non-swimming' reference population; only four children had never visited a pool. However, this number is representative of a Dutch population, as children in The Netherlands often start taking swimming lessons at the age of five. By the age of 12, 97% have a swimming certificate. In our population, 94% of children start attending pools on a regular basis (>once a month) at age 6 or earlier. To address our lack of a 'true' reference group, present swimming patterns and baby swimming were mutually adjusted for in multiple regression models.

Retrospective questionnaire data are subject to recall bias. However, as the main aim of the HITEA project was to study indoor air quality in schools, information on many environmental and lifestyle factors was requested. Moreover, parents were blinded to the hypothesis of this study. Thus, recall bias with respect to over-reporting of respiratory symptoms in relation to swimming pool attendance is likely minimal. Furthermore, there was no association between air quality on schools and swimming pool attendance. Exposure misclassification, especially during the first 2 years of life, may be a more important concern. Accurate exposure and health measurements conducted during the first years of life are needed to confirm our results.

As the response rate of our study was 59%, selection bias may be a concern when parents of symptomatic children may have been more likely to complete the questionnaire or participate in the serum study than those with healthy children. Background information on non-participants is not available. However, pool attendance, respiratory symptoms and covariates were comparable between children who provided a questionnaire and those who also chose to donate a serum sample.

A major strength of this study is that we are among the first to report quantitative trichloramine exposure levels, and link them to individual health information in children. Additional exposure measurements are needed to confirm whether these levels are accurate and representative of long-term exposure. Exploratory 'selected-ion flow-tube mass spectrometry' measurements in one swimming pool suggest that the method used to measure trichloramines in our study,[11] which is also

commonly used in other studies, actually measures total chloramines.[29] Furthermore, the composition of different types of chloramines may differ between different sampling heights and location (above the water surface compared with at the side of the pool). At present, it is not feasible to use these sample techniques in large population surveys. Although, these observations clearly indicate the need for improved analytical techniques to better characterise trichloramine levels in swimming pool air. However, we expect that we should still be able to detect systematic differences in trichloramine levels between pools using our current approach.

Our results suggest that swimming pool attendance does not increase the risk of respiratory symptoms among children, which is consistent with previous population-based studies. The interpretation of transient and chronic changes of serum CC16 and other inflammatory markers in relation to the pool environment and health impacts needs further investigation. Measured trichloramine levels in air were comparable with other studies, but lower than in an earlier Dutch study. The association between sensitisation and swimming during the first 2 years of life suggests that early-life exposures might be important, although this hypothesis warrants further investigation. In conclusion, the results of this study do not suggest that swimming during childhood should be reduced at any age in order to prevent the onset of respiratory symptoms or allergies.

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Competing interests On behalf of the authors of this paper, I JH hereby certify that all actual or potential competing financial interests have been declared and that the authors' freedom to design, conduct, interpret and publish research is not compromised by any controlling sponsor as a condition of review and publication. DH was paid a fee for participating in a workshop on asthma in children and swimming pool associated exposures. DH, JJ and EF were paid to present results from this study to industry sponsored conferences on swimming pool exposures and asthma.

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