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Swimming attendance during childhood and development of asthma: a meta-analysis

Running title: *Swimming pool and asthma in children.*

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Figure legend:

Figure 1. Flowchart representing the selection process of the present systematic review.

Figure 2. The Forest plot of the statistical analysis results.

Figure 3. The funnel plot used to examine publication bias.

Table 1. Quality criteria in this study.

Table 2. The table represents the quality score assigned to each study included in systematic review.

Table 3. Principal characteristics of the studies included in the meta-analysis.

Abstract

Background

The association between asthma and swimming pool attendance has not been demonstrated and contrasting results emerged. In order to clarify the association between asthma diagnosis in children and swimming pool attendance, and to assess the consistency of findings of the available epidemiological studies, we completed a literature analysis focusing on literature

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about the relationship between the exposure to disinfection by-products in indoor swimming pool during childhood and asthma diagnosis.

Methods

Following the MOOSE and PRISMA criteria, a systematic review and meta-analysis was performed by searching MEDLINE via PubMed, TOXNET, and Scopus databases (inception - April 20, 2015) using the key word “Asthma” together with “swimming pool”, “disinfection by-products”, “indoor air pollution” and “children”. Inclusion criteria were: English language, a complete analytic study design comprising a cohort of children (0–16 years), a well-defined definition of exposure, and the presence of data on effect and variance. Studies considering in vivo, in vitro or professional and accidental exposures were excluded.

Results

After a screening process, seven reports (n=5851 subjects) were included out of a total of 2928 references. The reported Odds Ratio (ORs) of the association between swimming pool attendance and asthma prevalence ranged from 0.58 to 2.30. The present meta-analysis failed to reveal a significant difference in asthma development between children attending swimming pools and controls (OR=1.084; 95%IC=0.89-1.31).

Conclusion

Swimming in childhood does not increase the doctor diagnosed asthma. Based on this meta-analysis review, the association of the disease with attendance of indoor pools resulted inconsistent.

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Key words: swimming pool, asthma, meta-analysis, systematic review, swimming-associated illness.

Introduction

Swimming, one of the most popular, practiced and recommended aerobic physical activity is a well-recognized exercise modality for health promotion and disease prevention¹. Indeed, the Center for Disease Control and Prevention of Atlanta highlighted that the regular practice (just two and a half hours per week) of a sport such as swimming has been associated with a decrease of the risk of chronic illness and an improvement of the health quality of people affected by cardiovascular diseases and diabetes². Besides, it has been reported that swimmers present about half the risk of death respect to inactive subjects³.

Specific positive effects for human health related to swimming were reported for children and adolescents, since it allows to prevent drowning, to improve emotional health and well-being, and to develop a healthy physical balance, flexibility, strength and stamina⁴⁻⁶.

World Health Organization (WHO) dedicated specific guidelines to the health hazards related to recreational waters, reporting risks related to drowning, injury, microbiological and chemical quality of the specific microenvironment, water and air^{7,8}. Over the years several studies reported some adverse effects occurring after swimming, such as acute gastroenteritis (from 3 to 8% of risk of gastroenteritis)⁹ and other infectious diseases¹⁰, or detrimental effects on dermal and respiratory health derived from the exposure to chemicals present in the indoor swimming pools^{9, 10}. Recent reports focused on the association between the onset of asthma and the indoor swimming pool attendance, especially in paediatric populations¹¹⁻¹⁸. The conceptual rationale for these studies is that biocides used to control the microbiological contamination of swimming pools' water and/or the disinfection by-products generated by these treatments are well-known irritants. A relationship between the exposure to these products and respiratory adverse health end points in adult swimmers, such as bronchial hyper-responsiveness or bronchial epithelial damage, was showed in several studies^{19,20}. Some authors evaluated the respiratory hazards connected with the exposure to disinfection

by-products in pool environments among children focusing on allergic diseases and asthma. The results of a review on this issue showed that the chlorinated pools attendance during childhood could be a risk factor for asthma and other allergic diseases²¹. Another review regarding the association between childhood swimming and new-onset asthma evidenced that the increase of new cases of asthma determined by the exposure to biocides and their by-products were “suggestive but not conclusive”¹¹. Further studies did not help to clarify this hypothesis. Belgian researchers found that asthma in children was associated with the exposure to the irritant environment in indoor disinfected swimming pools^{14,15}, other European studies with larger population-based sample sizes, with a longitudinal design or a more detailed semi-quantitative exposure assessment did not replicate this association^{16,17}. On the other hand, since swimming is less asthmogenic than other land based activities it is well known that this sport is practiced by atopic children and adults, or by subjects affected by asthma²². This benefit can be overcome by the respiratory hazards related to the exposure to disinfection by-products; the most recent findings raised the exigency of a more detailed investigation, focusing the attention on childhood²³.

In order to clarify the association between asthma diagnosis in children and swimming pool attendance, and to assess the consistency of available epidemiological studies, we performed a systematic review and meta-analysis.

Materials and Methods

The criteria suggested by the study group guidelines “Meta-analysis of Observational Studies in Epidemiology” (MOOSE) and “Meta-analysis by the Preferred Reporting Items for Systematic reviews and Meta-Analyses” (PRISMA) were followed to assess the studies^{24, 25}.

Search strategy

The search strategy was developed according to the knowledge of the authors and the findings of previous reviews or original articles on regular indoor swimming pool attendance and asthma¹⁸. Relevant literature focusing on exposure to disinfection by-products present in indoor swimming pool and asthma during childhood was collected through a systematic search of the following electronic databases (from inception to April 20, 2015): MEDLINE via PubMed, TOXNET, and Scopus. The combination of the key word “Asthma” with any of the following terms was used for the search in the databases listed above: “swimming pool”, “disinfection by-products”, “indoor air pollution” and “children”. The references of each article included in this review were examined in order to achieve additional relevant citations.

Eligibility criteria and study selection

Several inclusion criteria were considered to identify the eligible studies for this meta-analysis. Each included study: (1) was written in English; (2) had a complete analytic study design with an appropriate control group; (3) had similar outcomes of interest with other studies included in meta-analysis (e.g., asthma diagnosis, PFT or measures of asthma severity); (4) presented a well-defined definition of exposure as swimming or swimming pool use, and used well-defined methods for exposure evaluation (including personal monitoring, use of questionnaire designed on the basis of the International Study of Asthma and Allergies in Childhood and/or estimation from environmental levels) (5) measured the effect and variance, or they could be calculated using data reported in the original articles; (6) comprised a cohort of children and pre-adolescents aged 0–16 years; (7) we considered the results related to asthma, that were defined a physician-diagnosed asthma²⁶.

Studies considering in vivo, in vitro or professional and accidental exposures were excluded because the aim of this review was just to evaluate the possible adverse effects on health in

term of asthma in children population determined by the attendance of a swimming pool. Case reports, studies without a control group, studies with incomplete design (e.g. ecological studies) and studies that evaluate workers and professional swimmers were also excluded.

Study selection was performed through the following multi-step exclusion process: two reviewers independently investigated the titles and the abstracts; then, the full text of any potentially includable study (when it seemed to meet the inclusion criteria or when the title and the abstract did not present sufficient data for a clear decision) was obtained. The authors of the studies for which it was not possible to find the full text were directly contacted. During this multi-step exclusion process, all of the reviewers' divergences were discussed and a consensus was reached.

In Appendix 1 are reported in detail the methods used for electronic search strategy and the PUBMED full electronic search strategy.

Study quality and evaluation

The study quality was assessed using the criteria described in Table 1. In brief, the bias assessment tool was based on the risk of different types of biases, including study design, sample selection, outcomes and exposure evaluation, adequate adjustment for confounders, analytical issues, and attrition bias. Each criterion was classified assigning a score from 0 to 2. This score was used to assess the quality and the selection criteria of each study, in line with previous meta-analysis¹⁸. All of the selected studies were summarised according to the year of publication, study design, outcomes, exposure assessment, and results.

Statistical analysis

Statistical elaboration and meta-analysis were performed with Comprehensive Meta Analysis 3.0 (Englewood, USA) software. Meta-analysis was conducted to compare two groups according to the level of exposure to disinfection by-products, based on the intensity of the swimming practice (e.g. cumulated pool attendance, CPA $\leq$ or >100 hours, attendance of swimming pool $<$ or ≥ 1 /week, swimmers versus activities not practiced in swimming pools). The two groups were coded respectively as “low exposure” and “high exposure”. The outcome variables selected for the meta-analysis were “doctor diagnosed asthma” or “doctor diagnosed ever asthma”.

Odds Ratio (OR) and 95% Confidence Interval (95% CI) were extracted for each study. OR >1 with 95% CI that did not span the null value indicated that swimming pool attendance was associated with a significant increase of doctor diagnosed asthma. When study data were presented in alternative formats (e.g. discontinuous data, p-value comparisons with group sizes, or as correlations), appropriate transformations were conducted. ORs for asthma were combined across the included studies by using the Der Simonian and Laird random effects method²⁷ with heterogeneity among studies assessed using the Cochrane Q and I_2 statistic^{28, 29}. The I_2 statistic is a measure of the percentage of variability in the effect estimate that is due to heterogeneity rather than due to chance. The thresholds used for the interpretation of I_2 were: $<25\%$ low heterogeneity, $<50\%$ moderate heterogeneity, and $>75\%$ high heterogeneity, as suggested previously²⁸.

Results

Selection process and study quality evaluation

Figure 1 shows the steps of the study selection process. After the review of titles and abstracts, 2366 articles were excluded. The main reasons for removal included: experimental or occupational studies, reviews or book chapters, or studies regarding other matrices (water,

soil, etc) rather than air. In total, the full texts of 22 epidemiologic studies about the association between asthma and swimming pool attendance during childhood were revised. The quality score obtained after the review of the full text evaluation are summarised in Table 2. Ten papers^{12, 15, 16, 30-36} were excluded from meta-analysis because had a cross sectional design of study and/or the methodology of exposure assessment was based only on self-reports. Two studies were excluded because they had an incomplete study design³⁷ or a lack of relevant quantifiable measures of association³⁸. The quality of the articles was evaluated using the bias assessment tool, and one study³⁹ was excluded because it showed a high risk of bias in more than three domains (exposure assessment, outcome ascertainment and adjustment for extraneous factors). Another article was removed because it was more focused on bronchiolitis and on wheezing associated with human rhinovirus species⁴⁰. The last excluded article was considered unfit to meta-analysis stage because it was focused on the effect of exposure to trihalomethanes during pregnancy and it was not possible to compare its results with those reported by the other included articles⁴¹.

Finally, seven papers were included in meta-analysis.

Descriptive analysis of the included studies

The main characteristics observed in each study included in the meta-analysis were outcomes and exposure assessment, potential confounders, and the principal results. All of the included studies were recent (published from 2006 to 2015), and they were conducted in several countries: five researches were carried out in Europe (three studies in Germany, and one in Belgium, Spain and Sweden, respectively), and one in Canada. Only two studies achieved a participation rate >80%^{42, 43}, three studies had a rate between 50 and 80%⁴⁴⁻⁴⁶, two studies had a rate <50%^{47, 48}. Outcomes assessment was performed in all the reviewed studies by a questionnaire, reporting the main symptoms as wheezing, asthma, eczema, hay fever and the

use of medications. Six questionnaires included questions based on the questionnaire validated and used by the International Study of Asthma and Allergies in Children⁴⁹. Some studies reported also information regarding laboratory results of studied children. The children check includes: spirometric parameters such as Forced Expiratory Volume in 1 second (FEV1), Forced Vital Capacity (FVC) and forced mid-expiratory flow⁴⁴, exercise-induced bronchoconstriction⁴⁸, the measurement of exhaled breath of nitride oxide, serum Clara cell protein (CC16), surfactant-associated protein D (SP-D) and some markers of the deep lung epithelium integrity⁴⁸ screening for respiratory allergies, as specific immunoglobulin and skin prick test⁴⁷. Exposure assessment was performed with different approaches by each study, mainly through the calculation of the swimming pool attendance or CPA⁴⁸. In some cases, the swimming pool attendance was also correlated to some environmental parameters, such as the levels of active and combined chloride in water and concentration of trichloramine in indoor pool air⁴⁸. In all works, some potential confounders were considered. Main confounders were socio-demographic characteristics, parental education, and environmental tobacco smoke exposure, parental history of asthma, current residence area and contact with domestic animals.

The principal characteristics (outcome groups, exposure groups and ORs) of each study included in the meta-analysis are synthesized in Table 3. Six studies evaluated the prevalence of asthma and allergic symptoms at different periods during early childhood⁴³⁻⁴⁸ and one study examined the prevalence of asthma among adults comparing those who attended or not swimming pools during school age⁴². The reported ORs of the association between swimming pool attendance and asthma prevalence ranged from 0.58 to 2.30. In three of the included studies, swimming frequency did not increase the risk of any evaluated symptom, either overall or wheeze, sensitization, rhinitis or eczema⁴²⁻⁴⁴.

Meta-analysis

The independent study effects are presented in the forest plot (Fig. 2). A total of 5851 subjects were included in the analysis (3265 children in the exposure group and 2586 children in the control group). The combined effect expressed as OR for asthma through all studies included in the analysis was equal to 1.08 (95% CI = 0.898–1.307), $p = 0.4$. The effects of the individual studies presented a moderate level of heterogeneity ($Q = 12.571$, d.f. = 6, $p = 0.050$, $I^2 = 52.271\%$), which is supported by the significance of Q . The weight studies used various severity measures of exposure and outcome ascertainment. The contour enhanced funnel plot did not appear to be asymmetrical, except for a two small positive studies (Figure 3), and Egger's regression method confirmed the lack of association between $\log(e)$ OR and standard error of $\log(e)$ OR.

Discussion

The association between asthma and swimming pool attendance during childhood has not been demonstrated and, in recent years, contrasting results emerged¹²⁻¹⁴. In order to study in depth this association, we performed a systematic review and meta-analysis. Combining univariate findings from seven independent studies, swimming pool attendance in paediatric age resulted not significantly associated with an increase of asthma diagnosis during childhood or later; our results are in agree with those reported by Goodman and Hays¹⁸. In our study, the papers that reported a positive association between asthma and exposure to the irritant environment in indoor chlorinated disinfected swimming pools have a structure of the study based especially on self-report⁴⁷ or not have larger population-based sample sizes, and no have adopted a longitudinal design or a more detailed semi-quantitative exposure assessment. In fact, the recruitment of an appropriate study population and an adequate evaluation of the selection criteria and the confounding factors are very significant variables

in order to minimize biases⁵⁰. In addition, the analysis of included papers has shown an opposed results in the association between swimming infant attendance and physician-diagnosed asthma. The swimming pool attendance in the first childhood seem be protective for asthma (OR= 0.76, 0.58)^{42, 44}, but in one work is reported a strong positive association (OR=2.3)⁴⁸. The results of the meta-regression might partly to explain this heterogeneity. In fact, the study of Bernard et al.⁴⁸ involves a small size of children that present a cumulative exposure to cigarette smoke. This aspect might partly to explain the observed differences and suggest that the sum of infant swimming activity and passive smoking could do to increase the risk of asthma.

Moreover, more attention should probably be given to studies aimed to evaluate the association between swimming and asthma occurrence in the general population (both children and adults) since, traditionally, studies pointed out that the agonist swimmers were more susceptible to respiratory syndromes¹⁸. Our data show that this association is slightly plausible and that swimmers can have more symptoms than other physical exercise⁴⁶. Indeed, scientific literature shows several epidemiological studies on respiratory irritation induced by swimming, but they were focused to professional athletes and workers^{51,52}. Elite swimmers are not necessarily the most exposed group in swimming pools, but also lifeguards and others workers spending many hours a day near the water were checked for health status⁵¹. In contrast, few epidemiological studies have been carried out on this topic for recreational bathers, reported an independent association and emphasized that the conditions of disinfection and exposure times can, however, affect the association⁵³. Moreover, recent studies are providing further evidence that children with asthma may even benefit from swimming training^{55, 56}.

The studies included in our meta-analysis are all Europeans except one (Canadian), suggesting that in European countries there is a high attention on to this issue. This is

probably due to the fact that the International Study of Asthma and Allergies in Childhood, a unique worldwide epidemiological research program established in 1991, born from the initiative of New Zealand and Germany, represent a milestone in this field¹⁶.

Our review has several strengths. First, we conducted an extensive searching in key electronic databases. Data extraction was conducted by two independent researchers; findings were then compared to ensure the reliability of the results. Moreover, in this work the studies were rated using a quality scoring system, which categorized the selected researches according to the number of 'weak' characteristics displayed within each paper. The main advantage of this approach is represented by the possibility to conduct sensitivity analyses for investigating the impact of quality on the observed effects related to the studied association. On the contrary, a limit emerges: the number of the included papers is quite small, leading to a not very high statistical power of the meta-analysis. As in previous review have done reliant on peer-reviewed published data, rather than including grey literature. While this will ensure a focused, and therefore manageable, number of studies is reviewed, it does make the review vulnerable to publication bias. In fact, there may be publication bias, since studies with positive findings are more likely to be published than studies with null results.

Finally, it is possible that if other statistical methods such as fixed models were used, results would have shown more differences, although, due to the heterogeneity of the included studies, a most prudent model was chosen.

Conclusion

Swimming pool attendance in childhood does not increase doctor diagnosis rate for childhood asthma and any association resulted insubstantial after meta-analysis revision. Swimming can be a safe sport for children, when environmental hygiene conditions are respected.

Conflicts of interest: none

Author contribution: FV and CP were involved in acquisition and analysis of data and wrote the paper. MV and VRS were involved in design and supervising of the research and edited the present manuscript. All authors read and approved the final version of this manuscript.

References

1. Tanaka H. Swimming exercise: impact of aquatic exercise on cardiovascular health. *Sports Med.* 2009; 39(5):377-387.
2. Center for Disease Control and Prevention. CDC 24/7: Saving lives, protecting people. Health benefits of water-based exercise. Available at link: http://www.cdc.gov/healthywater/swimming/health_benefits_water_exercise.html#one.
3. Chase NL, Sui X, Blair SN. Swimming and all-cause mortality risk compared with running, walking, and sedentary habits in men. *Int J of Aquatic Res and Educ.* 2008; 2(3):213-223.
4. Karen Moyse Promoting Health in Children and Young People: The Role of the Nurse. John Wiley & Sons. 2009.
5. U.S. Department of Health and Human Services. Physical Activity Guidelines for Americans: Be active, healthy, and happy! In Chapter 2: Physical Activity Has Many Health Benefits. 2008
6. Protano C, Valeriani F, Macedonio A, Cammarota F, Romano Spica V, Orsi GB, Vitali M. Family-based social determinants and child health: a cross-sectional study Social determinants and child health. *Pediatr Int.* 2016; doi: 10.1111/ped.13097. [Epub ahead of print]

7. World Health Organization. Guidelines for safe recreational water environments. Issue 2 Swimming pools and similar environments. World Health Organization; 2006. Available at link: http://www.who.int/water_sanitation_health/bathing/srwe2full.pdf.
8. Giampaoli S, Romano Spica V. Health and safety in recreational waters. Bull World Health Organ. 2014;92(2):79.
9. Sanborn M, Takaro T. Recreational water-related illness: office management and prevention. Can Fam Physician. 2013; 59(5):491-495.
10. Barna Z, Kádár M. The risk of contracting infectious diseases in public swimming pools. A review. Ann Ist Super Sanita. 2012; 48(4):374-386.
11. Uyan ZS, Carraro S, Piacentini G, Baraldi E. Swimming pool, respiratory health, and childhood asthma: should we change our beliefs? Pediatr Pulmonol. 2009; 44(1):31-37.
12. Font-Ribera L, Villanueva CM, Gràcia-Lavedan E, Borràs-Santos A, Kogevinas M, Zock JP. Indoor swimming pool attendance and respiratory and dermal health in schoolchildren--HITEA Catalonia. Respir Med. 2014; 108(7):1056-1059.
13. Weisel CP, Richardson SD, Nemery B, Aggazzotti G, Baraldi E, Blatchley ER 3rd, Blount BC, Carlsen KH, Eggleston PA, Frimmel FH, Goodman M, Gordon G, Grinshpun SA, Heederik D, Kogevinas M, LaKind JS, Nieuwenhuijsen MJ, Piper FC, Sattar SA. Childhood asthma and environmental exposures at swimming pools: state of the science and research recommendations. Environ Health Perspect. 2009; 117(4):500-507.
14. Voisin C, Sardella A, Bernard A. Risks of new-onset allergic sensitization and airway inflammation after early age swimming in chlorinated pools. Int J Hyg Environ Health. 2014; 217(1):38-45.
15. Voisin C, Sardella A, Marcucci F, Bernard A. Infant swimming in chlorinated pools and the risks of bronchiolitis, asthma and allergy. Eur Respir J. 2010; 36(1):41-47.

16. Font-Ribera L, Villanueva CM, Ballester F, Santa Marina L, Tardón A, Espejo-Herrera N, Esplugues A, Rodríguez Dehli C, Basterrechea M, Sunyer J. Swimming pool attendance, respiratory symptoms and infections in the first year of life. *Eur J Pediatr*. 2013; 172(7):977-985.
17. Villanueva CM, Font-Ribera L. Health impact of disinfection by-products in swimming pools. *Ann Ist Super Sanita*. 2012; 48(4):387-396.
18. Goodman M, Hays S. Asthma and swimming: a meta-analysis. *J Asthma*. 2008; 45(8):639-647.
19. Belda J, Ricart S, Casan P, Giner J, Bellido-Casado J, Torrejon M, Margarit G, Drobnic F. Airway inflammation in the elite athlete and type of sport. *Br J Sports Med*. 2008; 42(4):244-248.
20. Bougault V, Turmel J, St-Laurent J, Bertrand M, Boulet LP. Asthma, airway inflammation and epithelial damage in swimmers and cold-air athletes. *Eur Respir J*. 2009; 33(4):740-746.
21. Kohlhammer Y, Heinrich J. Chlorine, chlorination by-products and their allergic and respiratory health effects. *Curr Resp Med Rev*. 2007; 3:39–47.
22. Bar-Or O, Inbar O. Swimming and asthma. Benefits and deleterious effects. *Sports Med*. 1992; 14(6):397-405.
23. Gomez-Bruton A, Montero-Marín J, González-Agüero A, García-Campayo J, Moreno LA, Casajús JA, Vicente-Rodríguez G. The Effect of Swimming During Childhood and Adolescence on Bone Mineral Density: A Systematic Review and Meta-Analysis. *Sports Med*. 2015. Epub ahead of print.

24. Biondi-Zoccai G, Lotrionte M, Landoni G, Modena MG. The rough guide to systematic reviews and meta-analyses. *HSR Proceedings in Intensive Care & Cardiovascular Anesthesia*. 2011; 3(3):161-173.
25. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*; 2009:339.
26. Ronmark E, Bjerg A, Perzanowski M, Platts-Mills T, Lundback B. Major increase in allergic sensitization in schoolchildren from 1996 to 2006 in northern Sweden. *J Allergy Clin Immunol*. 2009; 124:357–363.
27. Egger M, Davey SG, Altman DG. *Systematic reviews in health care: meta-analysis in context*. London: BMJ Publishing. 2001.
28. Higgins JP, Thomson SG, Deeks JJ, Altman DG. Measuring inconsistency in metaanalysis. *BMJ*. 2003; 327:557–60.
29. Moreno S, Sutton A, Ades A, Stanley T, Abrams K, Peters J, et al. Assessment of regression-based methods to adjust for publication bias through a comprehensive simulation study. *BMC Med Res Methodol*. 2009:9.
30. Bernard A, Nickmilder M, Dumont X. Chlorinated pool attendance, airway epithelium defects and the risks of allergic diseases in adolescents: Interrelationships revealed by circulating biomarkers. *Environ Res*. 2015; 140:119-126.
31. Voisin C, Sardella A, Bernard A. Allergic sensitization and airway inflammation after early swimming. *Am J Respir Crit Care Med*. 2013; 187(12):1392-1394.
32. Jacobs JH, Fuertes E, Krop EJ, Spithoven J, Tromp P, Heederik DJ. Swimming pool attendance and respiratory symptoms and allergies among Dutch children. *Occup Environ Med*. 2012; 69(11):823-830.

33. Font-Ribera L, Kogevinas M, Zock JP, Nieuwenhuijsen MJ, Heederik D, Villanueva CM. Swimming pool attendance and risk of asthma and allergic symptoms in children. *Eur Respir J*. 2009; 34(6):1304-1310.
34. Cotter A, Ryan CA. The pool chlorine hypothesis and asthma among boys. *Ir Med J*. 2009; 102(3):79-82.
35. Nystad W, Njå F, Magnus P, Nafstad P. Baby swimming increases the risk of recurrent respiratory tract infections and otitis media. *Acta Paediatr*. 2003; 92(8):905-909.
36. Bernard A, Carbonnelle S, Michel O, Higuët S, De Burbure C, Buchet JP, Hermans C, Dumont X, Doyle I. Lung hyperpermeability and asthma prevalence in schoolchildren: unexpected associations with the attendance at indoor chlorinated swimming pools. *Occup Environ Med*. 2003; 60(6):385-394.
37. Nickmilder M, Bernard A. Ecological association between childhood asthma and availability of indoor chlorinated swimming pools in Europe. *Occup Environ Med*. 2007; 64(1):37-46.
38. Clearie KL, Vaidyanathan S, Williamson PA, Goudie A, Short P, Schembri S, Lipworth BJ. Effects of chlorine and exercise on the unified airway in adolescent elite Scottish swimmers. *Allergy*. 2010; 65(2):269-273.
- 39.
40. Schuez-Havupalo L, Karppinen S, Toivonen L, Kaljonen A, Jartti T, Waris M, Peltola V. Association between infant swimming and rhinovirus-induced wheezing. *Acta Paediatr*. 2014; 103(11):1153-1158.
41. Villanueva CM, Gracia-Lavedán E, Ibarluzea J, Santa Marina L, Ballester F, Llop S, Tardón A, Fernández MF, Freire C, Goñi F, Basagaña X, Kogevinas M, Grimalt JO, Sunyer J; INMA (Infancia y Medio Ambiente) Project. Exposure to trihalomethanes through

different water uses and birth weight, small for gestational age, and preterm delivery in Spain. *Environ Health Perspect.* 2011; 119(12):1824-1830.

42. Kohlhammer Y, Döring A, Schäfer T, Wichmann HE, Heinrich J; KORA Study Group. Swimming pool attendance and hay fever rates later in life. *Allergy.* 2006; 61(11):1305-1309.

43. Schoefer Y1, Zutavern A, Brockow I, Schäfer T, Krämer U, Schaaf B, Herbarth O, von Berg A, Wichmann HE, Heinrich J; LISA study group. Health risks of early swimming pool attendance. *Int J Hyg Environ Health.* 2008; 211(3-4):367-373.

44. Font-Ribera L, Villanueva CM, Nieuwenhuijsen MJ, Zock JP, Kogevinas M, Henderson J. Swimming pool attendance, asthma, allergies, and lung function in the Avon Longitudinal Study of Parents and Children cohort. *Am J Respir Crit Care Med.* 2011; 183(5):582-588.

45. Andersson M, Hedman L, Nordberg G, Forsberg B, Eriksson K, Rönmark E. Swimming pool attendance is related to asthma among atopic school children: a population-based study. *Environ Health.* 2015; 14:37.

46. Lévesque B, Duchesne JF, Gingras S, Lavoie R, Prud'Homme D, Bernard E, Boulet LP, Ernst P. The determinants of prevalence of health complaints among young competitive swimmers. *Int Arch Occup Environ Health.* 2006; 80(1):32-39.

47. Bernard A, Carbonnelle S, de Burbure C, Michel O, Nickmilder M. Chlorinated Pool Attendance, Atopy, and the Risk of Asthma during Childhood. *Environmental Health Perspectives.* 2006; 114(10):1567-1573.

48. Bernard A, Carbonnelle S, Dumont X, Nickmilder M. Infant swimming practice, pulmonary epithelium integrity, and the risk of allergic and respiratory diseases later in childhood. *Pediatrics.* 2007; 119(6):1095-1103.

49. ISAAC. Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. The International Study of Asthma and Allergies in Childhood (ISAAC) Steering Committee. *Lancet*. 1998; 351:1225–1232.
50. Wacholder S, McLaughlin JK, Silverman DT, Mandel JS. Selection of controls in case-control studies. I. Principles. *Am J Epidemiol*. 1992; 135(9):1019-1028.
51. Rosenman KD, Millerick-May M, Reilly MJ, Flattery J, Weinberg J, Harrison R, Lumia M, Stephens AC, Borjan M. Swimming facilities and work-related asthma. *J Asthma*. 2015; 52(1):52-58.
52. Jacobs, J.H., Spaan, S., van Rooy, G.B., Meliefste, C., Zaat, V.A., Rooyackers, J.M., Heederik, D. Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers. *Eur. Respir. J*. 2007; 29(4):690–698.
53. Helenius, I., Ryttilä, P., Sarna, S., Lumme, A., Helenius, M., Remes, V., Haahtela, T. Effect of continuing or finishing high-level sports on airway inflammation, bronchial hyperresponsiveness, and asthma: a 5-year prospective follow-up study of 42 highly trained swimmers. *J. Allergy Clin. Immunol*. 2002; 109(6):962–968.
54. Ferrari M, Schenk K, Mantovani W, Papadopoulou C, Posenato C, Ferrari P, Poli A, Tardivo S. Attendance at chlorinated indoor pools and risk of asthma in adult recreational swimmers. *J Sci Med Sport*. 2011; 14(3):184-189.
55. Wang JS, Hung WP. The effects of a swimming intervention for children with asthma. *Respirology* 2009; 14:838–842.
56. Weisgerber M, Webber K, Meurer J, Danduran M, Berger S, Flores G. Moderate and vigorous exercise programs in children with asthma: safety, parental satisfaction, and asthma outcomes. *Pediatr Pulmonol* 2008; 43:1175–1182.

Figure legend:

Figure 1. Flowchart representing the selection process of the present systematic review.

Figure 2. The Forest plot of the statistical analysis results.

Figure 3. The funnel plot used to examine publication bias.

Table 1. Quality criteria in this study.

Table 2. The table represents the quality score assigned to each study included in systematic review.

Table 3. Principal characteristics of the studies included in the meta-analysis.

Table 1.

<i>Quality criteria</i>	
1. Overall study design	Cross-sectional studies - 0 points Retrospective studies, longitudinal studies, non-randomized experiments - 1 point Randomized trials or crossover experiments - 2 points
2. Participant selection	<50% participation, or evidence of selection bias - 0 points 50–80% participation, but no clear evidence of selection bias - 1 point Trials with complete follow up, or studies with ≥80% participation & no evidence of bias - 2 points
3. Exposure Assessment	Self-reports of swimming - 0 points Documented evidence and/or quantitative assessment of swimming - 1 point Direct observation of swimming exposure (e.g., in experimental conditions) - 2 points
4. Outcome ascertainment	Self-reports of asthma - 0 points Unconfirmed diagnoses from questionnaires -1 point Documented asthma, or more accurate - 2 points
5. Adjustment of results for extraneous factors	No adjustment - 0 points Some adjustment - 1 point Detailed multivariate modeling, randomization or cross-over design - 2 points

Table 2.

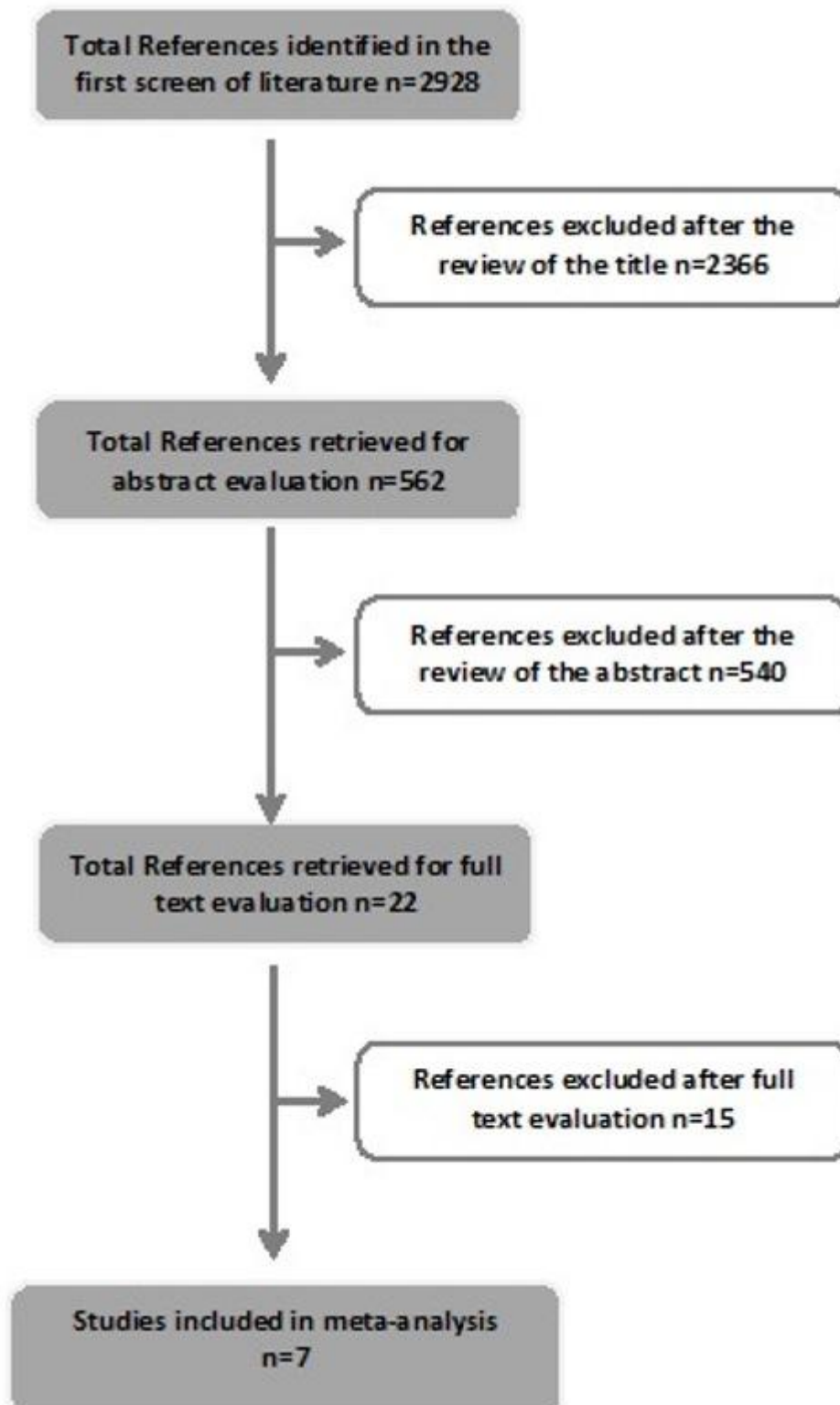
References	Overall study design	Participant selection	Exposure Assessment	Outcome ascertainment	Adjustment of results for extraneous factors
Andersson, 2015 [45]	1 (Longitudinal study)	1 (>50% participation rate)	0 (Self report)	2 (Documented asthma, skin prick testing)	2 (Multivariate analyses)
Bernard, 2003 [36]	1 (Retrospective study)	1 (>50% participation rate)	0 (Self report)	0 (self report)	0 (No adjustment)
Bernard, 2006 [47]	1 (Retrospective study)	1 (<50% participation rate)	0 (Self report, public analysis report)	1 (Unconfirmed diagnoses from questionnaire, EIB, eNO, IgE)	1 (Some adjustment)
Bernard, 2007 [48]	1 (Retrospective study)	1 (<50% participation rate)	0 (Self report)	2 (IgE serum concentration, Clara cell protein)	1 (Some adjustment)
Bernard, 2009 [39]	1 (Retrospective study)	1 (>70% participation rate)	0 (Self report)	2 (Documented asthma, EIB, FEV ₁ , IgE)	1 (Some adjustment)
Bernard, 2015 [30]	0 (Cross sectional study)	1 (78% participation rate)	0 (Self report)	2 (Documented asthma, IgE serum concentration, CC16)	1 (ANOVA)
Clearie, 2010 [38]	0 (Pilot study)	0 (<50 % participation rate)	1 (TNO, NNO, exhaled NO and PNIF)	2 (Documented asthma, FEV ₁ , EIB)	0 (No adjustment)
Cotter, 2009 [34]	0 (Cross sectional study)	1 (>50% participation rate)	0 (Self report)	0 (Self report)	1 (Some adjustment)
Fon-Ribera, 2009 [33]	0 (Cross sectional study)	1 (58% participation rate)	0 (Self report)	2 (Documented asthma)	1 (Multivariate logistic regression analysis)
Font-Ribera, 2011 [44]	1 (Longitudinal study)	1 (50.7% participation rate)	0 (Self report)	2 (Documented asthma, FEV ₁ , FVC, CC16)	1 (Confunders)
Font-Ribera, 2013 [16]	0 (Cross sectional study)	1 (>50% participation rate)	0 (Self report)	2 (Documented asthma, FEV ₁ , FVC)	1 (Some adjustment)
Font-Ribera, 2014 [12]	0 (Cross sectional study)	1 (54% participation rate)	0 (Self report)	2 (Documented asthma)	1 (Multivariate mixed model)
Jacobs, 2012 [32]	0 (Cross sectional study)	1 (59% participation rate)	2 (THM exposure)	2 (Documented asthma, IgE serum concentration, CC16)	1 (Linear regression for continuous outcomes, covariates, ORs)

Kohlhammer, 2006 [42]	1 (Retrospective study)	2 (>80% participation & no evidence of bias)	0 (Self report)	0 (Self report)	2 (Logist regression models)
Lévesque, 2006 [46]	1 (Longitudinal study)	1 (>50% participation rate)	2 (Questionnaire, PEF)	0 (Self report)	2 (Multivariate analyses)
Nickmilder, 2007 [37]	0 (Ecological study)	0 (<50 % participation rate)	0 (Self report)	0 (Self report)	1 (Some adjustment)
Nystad, 2003 [35]	0 (Cross sectional study)	1 (>50% participation rate)	0 (Self report)	0 (Self report)	1 (Some adjustment)
Schoefer, 2008 [43]	1 (Longitudinal study)	2 (>80% participation & no evidence of bias)	0 (Self report)	0 (Self report)	1 (Some adjustment)
Schuez-Havupalo, 2014 [40]	1 (Longitudinal study)	2 (>80% participation rate, follow-up)	2 (Diary, Questionnaires Nurse-led study)	2 (Documented asthma)	1 (Some adjustment)
Villanueva, 2011 [41]	1 (Longitudinal study)	1 (>50% participation rate)	2 (THM exposure)	2 (Birth weight)	1 (Some adjustment)
Voisin, 2010 [15]	1 (Retrospective study)	1 (50.3 % participation rate)	1 (quality water)	2 (Documented asthma, IgE)	2 (Logist regression models)
Voisin, 2013 [31]	0 (Cross sectional study)	1 (>50% participation rate)	0 (Self report)	0 (Self report)	1 (Some adjustment)

Abbreviations: NO—nitric oxide, eNO—exhaled nitric oxide, EIB—exercise-induced bronchoconstriction, FEV1—forced expiratory volume in 1 second, CC16 —Clara cell protein, SP-D—surfactant-associated protein D, IgE—immunoglobulin E, OR—odds ratio, PEF-peak expiratory flow

Table 3.

First Author (Year) [Ref]	Age range (years)	Outcomes	Exposure group (Number of children)	Control group (Number of children)	Values
Andersson (2015) [45]	7-8	Doctor Diagnosed Asthma	Attendance of swimming pool of ≥ 1 for week (N=659)	Attendance of swimming pool of < 1 for week (N=993)	OR= 1.49 (1.02-2.18, 95%)
Bernard (2006) [47]	10-13	Doctor Diagnosed Asthma (<i>ad/or screened with EIB test</i>)	CPA 100 hours (N=157)	CPA < 100 hours or never (N=184)	OR= 1.63 (0.75-3.55, 95%)
Bernard (2007) [48]	10-13	Doctor Diagnosed Asthma	Swimming infants (N=43)	Other Children (N=298)	OR= 2.3 (0.9-5.8, 95%)
Font-Ribera (2011) [44]	7-10	Doctor Diagnosed Asthma (<i>ever asthma</i>)	Swimming Highest (N=406)	Swimming Lowest- (N=147)	OR= 0.83 (0.55-1.25, 95%)
Kohlhammer (2006) [42]	35-74	Doctor Diagnosed Asthma (<i>during life-time</i>)	Attendance of swimming pool during school age (N=1035)	Attendance of swimming pool never during school age (N=274)	OR= 0.76 (0.50-1.16, 95%)
Lévesque (2006) [46]	$< 12-16+$	Doctor Diagnosed Asthma (<i>lifetime asthma</i>)	Swimmers (N=305)	Soccer players (N=499)	OR= 1.2 (0.8-1.8, 95%)
Schoefer (2008) [43]	0-6	Doctor Diagnosed Asthma	Attendance 1 st year baby swimming (N=660)	Children with attendance of swimming pool Later or never (N=191)	OR=0.58 (0.2-1.45, 95%)



Meta Analysis

Study name	Statistics for each study					Odds ratio and 95% CI
	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value	
Andersson (2015)	1,490	1,019	2,178	2,058	0,040	
Bernard (2006)	1,630	0,729	3,645	1,190	0,234	
Bernard (2007)	2,300	0,906	5,839	1,752	0,080	
Font-Ribera (2011)	0,830	0,551	1,251	-0,890	0,374	
Kohlhammer (2006)	0,760	0,499	1,158	-1,278	0,201	
Lévesque (2006)	1,200	0,800	1,800	0,881	0,378	
Schoefer (2008)	0,579	0,230	1,454	-1,163	0,245	
	1,084	0,898	1,307	0,841	0,401	

