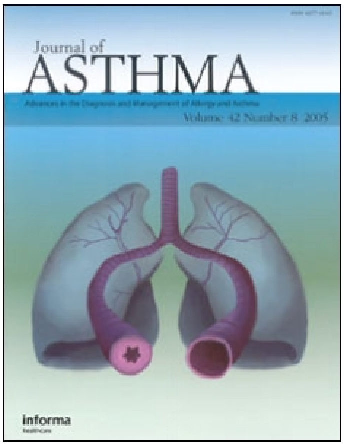

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Asthma and Swimming: A Meta-Analysis

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ORIGINAL ARTICLE

Asthma and Swimming: A Meta-Analysis

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In this meta-analysis, studies on swimming and asthma were divided into four groups: Group I compared frequency of asthma among elite swimmers to that of other athletes; Group II examined the association between asthma and swimming during childhood; Group III evaluated effects of swimming programs on asthma severity and pulmonary function; and Group IV compared immediate respiratory effects of swimming to those of other types of exercise. The summary results were expressed as meta-odds ratios (ORs) for binary endpoints such as presence of asthma, and meta-differences for continuous endpoints such as changes in post-exercise pulmonary function tests (PFTs). All summary measures of effect were calculated using random effects models accompanied by a corresponding 95% confidence interval (CI) and a test for heterogeneity. In the analysis comparing frequency of asthma among elite swimmers to that among other athletes (Group I), meta-ORs ranged from 2.3 to 2.6 with all 95% CIs excluding 1.0. The corresponding meta-ORs reflecting the association between asthma and swimming pool use during childhood (Group II) were in the 0.63–0.82 range and were not statistically significant. In comparison to swimming, running and/or cycling was associated with a statistically significant four- to six-fold increase in exercise induced bronchospasm. Although asthma is more commonly found among elite swimmers than among other high-level athletes, it is premature to draw conclusions about the causal link between swimming and asthma because most studies available to date used cross-sectional design, because the association is not confirmed among non-competitive swimmers, and because asthmatics may be more likely to select swimming as the activity of choice because of their condition.

Keywords asthma, swimming pools, chlorine, chlorine hypothesis, meta-analysis

INTRODUCTION

Surveys from the United States and Europe indicate that swimming ranks high among preferred types of physical activity in both children and adults (1, 2). For this reason increased availability of swimming pools is considered one of the most effective ways of achieving higher levels of physical activity in the general population (3).

Despite these important benefits, the potential adverse health effects of swimming pool use also require serious consideration. In recent years, public attention began to shift from well known sources of pool-related morbidity and mortality such as injuries and infections (4, 5) towards the potential link between swimming and asthma (6). According to the pool chlorine hypothesis, by-products of water chlorination may cause asthma among children (7). Conversely, several authors suggested that swimming may have beneficial effect on disease severity among asthma patients (8–10).

The concerns about the role of swimming in asthma etiology may have important public health implications as large numbers of children routinely attend recreational water venues including swimming pools (11), and an increased risk of asthma among these children could translate into a substantial burden of disease. On the other hand, if the evidence in support of the causal link between asthma and swimming pool use is weak or inconsistent, it would be important to alleviate the unwarranted concerns as they may deter children from participating in this potentially useful activity, or cause potentially harmful decreases in water disinfection (6, 7).

To address these issues, we initiated a review and meta-analysis of the available studies evaluating the effects of swimming and swimming training on asthma frequency and severity. The aims of this review were to examine the methodological issues that may affect the epidemiology of asthma in relation to swimming, and to assess the consistency of findings across studies.

METHODS

The criteria for inclusion in and exclusion from the meta-analysis are summarized in Table 1. Electronic literature databases Pub Med, Medline and EMBASE were searched using a variety of search strategies and multiple combinations of keywords such as swimming, chlorine, pool, asthma, allergies, wheezing, and epidemiology. Two independent searches produced two different lists of publications that were then consolidated into a single list. When information was missing from published reports, attempts were made to contact the authors to obtain the missing data.

In conducting this study we an effort to follow the recommendations of the current methodological literature on systematic reviews (12–18). We cross checked our study methods against a recently proposed 'assessment tool of multiple systematic reviews' (AMSTAR) (17), which represents an extension of the previously published instruments such as 'overview quality assessment questionnaire' (OQAQ) (12) and 'quality of reporting of meta-analyses' (QUOROM) (15). The AMSTAR tool includes the following 10 items:

(1) an *a priori* statement of research questions and inclusion/exclusion criteria;
(2) duplicate literature searches by two or more co-authors;
(3) the use of at least two electronic search engines followed by a supplemental search of reviews, textbooks

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TABLE 1.—Summary of methods of study selection and evaluation.

Inclusion criteria
1. A complete analytic study design with an appropriate control group
2. Data non-overlapping with other studies
3. Similar endpoints of interest (e.g., asthma diagnosis, PFT or measures of asthma severity) reported by at least 3 independent studies
4. Exposure defined as swimming or swimming pool use
5. Measures of effect and variance reported by the authors, or could be calculated using the data from the original articles
Exclusion criteria
1. Case reports, descriptive studies (without a control group)
2. Studies of incomplete design (e.g., ecologic studies)
3. Studies of respiratory conditions other than asthma
4. Studies that evaluated swimming pool workers, but not swimmers
Quality criteria
1. Overall study design: Cross-sectional studies - 0 points cohort & case-control 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 or crude PFTs (e.g., PEF) -1 point Documented asthma, or more accurate PFTs (e.g., FEV_1) - 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.

PFT = pulmonary function test; FEV_1 = forced expiratory volume exhaled in 1 second; PEF = peak expiratory flow.

and secondary references with keywords and MESH statements reported in the methods section;
(4) a list of studies excluded from the review;
(5) a summary of study characteristics that met the inclusion criteria;
(6) a formal assessment of the individual study quality;
(7) consideration of study quality in drawing conclusions;
(8) whenever possible pooling of study results in a quantitative meta-analysis accompanied by a test for heterogeneity;
(9) assessment of publication bias; and,
(10) a statement of sources of support (17).

For studies that used binary endpoint variables (e.g., presence of asthma), information extracted for the purposes of the meta-analysis included a relevant odds ratio (OR) and the corresponding 95% confidence interval (CI). For studies that used continuous endpoint variables, such as measures of asthma severity or pulmonary function test (PFT) results, the effect size was determined using a two-step procedure. In the first step, we ascertained the before-and-after percent change in swimmers and controls expressed as $\frac{\mu_1-\mu_2}{\mu_1} \times 100\%$, where μ_1 and μ_2 represent the mean values of the parameter of interest before and after exposure, respectively.

A positive percent change in all of these analyses was made to be reflective of a post-exposure improvement whereas a negative change represented worsening of symptoms or test results. In the second step the measure of association for each individual study was calculated as the difference between the percent changes observed in the swimming and non swimming groups, where a positive difference is interpreted as a better outcome among swimmers compared to controls.

For those studies that did not report effect estimates or variance, the appropriate measures were calculated from the data provided in the articles. For example, some studies did not report the results in terms of ORs, but did provide information necessary to reconstruct the two-by-two tables. In those instances the ORs and 95% CIs were calculated using OpenEpi software (19). Similarly, in some studies the information needed to calculate variance of the continuous measures of effect was not provided. However, we were able to calculate variance based on the p-values, or based on the authors' statement that the difference was statistically significant, in which case the p-value was conservatively assumed to be 0.05. Unless specified otherwise, the comparison of distributions for continuous variables was conducted assuming equal variance and independence of samples.

All relevant studies underwent a formal evaluation and received a quality score according to five parameters: overall design, selection of participants, exposure assessment, outcome ascertainment and control for extraneous factors. Each of these parameters received 0, 1, or 2 points using the scoring scheme also summarized in Table 1. The total score represented the sum of all points with the possible values ranging from 0 to 10. This score was used as the relative measure of the data quality.

The summary results (meta-ORs for binary endpoints, or meta-differences for continuous endpoints) were calculated using random effects models accompanied by a corresponding 95% CI, and a test for heterogeneity (18). The test for heterogeneity of the X studies examines the hypothesis that the X underlying ORs (or any other effect estimates) are equal, and is based on the chi-square distribution with X-1 df as described by Fleiss and Gross (20).

To explore the impact of different outcome definitions (e.g. asthma severity versus PFT results), different exposure comparisons (e.g., swimming compared to cycling versus swimming compared to running), and different populations (e.g., children versus adults) we conducted series of sensitivity analyses using appropriate subcategories of studies. In addition, whenever possible, a subset of three studies with the highest quality score was analyzed separately to evaluate the impact of variable study quality on meta-estimates. All meta-analyses were performed using EPISHEET, a spreadsheet-based analytical package (21).

Whenever meta-analysis results were significantly different from the null, we evaluated the potential role of publication bias by calculating the weighted fail-safe N (FSN) as described by Rosenberg (22). The FSN is equivalent to the number of studies of null effect and mean weight necessary to change the observed type I error from <0.05 to 0.05. These calculations were performed using the Fail Safe Number Calculator software (Arizona State University, Tempe, AZ).

RESULTS

Overview

Our search identified 36 potentially relevant studies of which eleven did not meet the criteria for inclusion in the meta-analysis (9, 23-32). As shown in Table 2 the reasons for exclusion were redundant data, incomplete study design, lack of relevant quantifiable measures of association or

TABLE 2.—Summary of studies excluded from the meta-analysis.

Authors (reference)	Exposure	Endpoint(s)	Reason for exclusion	Findings
Seligman et al. 1970 (27)	Training program that included swimming and other exercise	PFT results	Lack of control group	Improvement
Anderson et al. 1975 (23)	Swimming compared to running/cycling	Post-exercise change in PEF	No measures of variance available	Swimming less asthmagenic
Szentagothai et al. 1987 (28)	Swimming training program	Asthma severity	Lack of control group	Improvement
Olivia et al. 1990 (25)	Swimming training program	Post-exercise change in FEV_1	Lack of control group	Improvement
Zwick et al. 1990 (30)	Competitive swimming	Symptoms of rhinitis, laryngitis or bronchitis	Not an asthma study	More symptoms in swimmers
Engstrom et al. 1991 (24)	Training program that included swimming and other exercise	Asthma severity PFT results Measures of self-esteem	Lack of control group Lack of control group Lack of control group	Improvement Improvement Improvement
Varray et al. 1991 (29)	Swimming training program	Asthma severity Aerobic capacity	Qualitative results only Lack of other similar studies	No improvement Improvement
Potts 1996 (26)	Competitive swimming	Asthma prevalence	Lack of control group	Asthma in 13.4% of swimmers
Wardell & Isbiste 2000 (9)	Swimming training program	Asthma severity	Lack of control group	Improvement
Bernard et al. 2003 (31)	Swimming among school children	Prevalence of EIB or asthma medication use	Outcome definition does not satisfy inclusion criteria	Increased prevalence among swimmers
Nickmilder et al. 2007 (32)	Areas with high swimming pool availability	Asthma prevalence	Incomplete design (ecologic study)	Increased prevalence in areas with more pools

PFT = pulmonary function test; FEV_1 = forced expiratory volume exhaled in 1 second; PEF = peak expiratory flow.

variance, and absence of similar studies. Thirteen (48%) of the 25 studies that met the inclusion criteria came from Europe, six (26%) from North America, four (17%) from Australia and the remaining two studies were conducted in Israel and Japan. The earliest study was published in December, 1971 (33) and the most recent is still considered in press (34). The study populations ranged in size between 1,309 (35) and 8 (10, 36) subjects.

With respect to the main research question, the relevant studies can be divided into four groups: Group I studies compared frequency of asthma among elite swimmers to that of other elite athletes; Group II studies examined the association between asthma and swimming pool attendance during childhood; Group III studies evaluated effects of swimming training programs on asthma severity and pulmonary function of children with asthma; and finally, Group IV studies compared immediate (within minutes) respiratory effects of swimming among asthmatics to those of other types of exercise. The results of the meta-analysis are presented separately for each of the four groups

Group I: Studies of Asthma in Elite Athletes

Six studies in Group I compared the prevalence of current or lifetime asthma among elite (e.g., Olympic or collegiate) swimmers to that of other high level athletes in the United States, Canada, Great Britain, Australia, Finland, and Ireland (37-42). All six studies used cross-sectional design. Three of those studies (37, 39, 41) were able to recruit over 80% of the target population. Five studies relied on questionnaires and one study (37) used review of medical records to ascertain the presence of asthma diagnosis. None of the studies were able to adequately adjust for potential confounders; and the overall study quality scores ranged between 2 and 5 points. All but one study demonstrated a significant increase in asthma prevalence among swimmers compared to all other sports combined (Table 3). The meta-OR estimates was 2.29 (95% CI: 1.57, 3.34) for all studies combined and 2.57 (95% CI: 1.87, 3.54) for a subset of studies (37, 39, 41) with the highest quality score.

Group II: Studies of Asthma and Swimming During Childhood

Group II included six relevant epidemiologic studies of the association between asthma and swimming pool attendance during childhood (Table 4). Five of these studies evaluated frequency of asthma among children and adolescents, (34, 43–46) and one study examined prevalence of asthma among adults comparing those who did and did not attend swimming pools during school age (35). All but one study (34) used cross sectional design. Only one study appeared to have achieved

TABLE 3.—Summary of Group I observational studies evaluating the association between asthma diagnosis and swimming among elite athletes.

Authors	Quality Score	Exposed group	Comparison group	OR (95% CI)
Weiler et al. 1998 (41)	4	54 U.S. Olympic swimmers	645 other Olympic athletes	2.27 (1.13, 4.35)*
Helenius et al. 1998 (38)	2	42 Finnish elite swimmers	120 runners and speed & power athletes	1.42 (0.49, 3.86)*
Langdeau et al. 2000 (42)	2	25 Canadian high level swimmers	75 other high-level athletes	0.38 (0.08, 1.80)*
Smith et al. 2002(40)	2	50 Irish college swimmers	203 other college athletes	3.25 (1.57, 6.62)*
Dickinson et al. 2005 (37)	5	41 British Olympic swimmers	233 other British Olympic athletes	3.32 (1.52, 7.08)*¶
Katelaris et al. 2006 (39)	4	Australian Olympic swimmers (N not reported)	Non-swimmers (N not reported)	2.50 (1.70, 3.80)
META-ANALYSIS				
All studies combined ; $P_{heterogeneity} = 0.16$				2.29 (1.57, 3.34); FSN= 83
Subset of studies with the highest score (37, 39, 41); $P_{heterogeneity} = 0.74$				2.57 (1.87, 3.54)

*Unadjusted results calculated from data in tables.
¶Limited to data for the 2000 Olympic team in which presence of asthma was extracted from medical forms.

TABLE 4.—Summary of Group II observational studies evaluating the association between asthma diagnosis and swimming pool attendance during childhood.

Authors (reference)	Quality Score	Exposed group	Age range	Comparison group	OR (95% CI)
Bernard et al. 2006 (43)	3	157 Belgian children with >100 hr cumulative pool attendance (CPA), age 10–13	10–13	184 children with <100 hrs CPA	1.63 (0.75, 3.55)*
Carraro et al. 2006 (45)	2	100 Italian swimming pool (SP) attendees, age 7–10	7–10	141 non-SP children	0.54 (0.16, 1.54)**
Kohlhammer et al. 2006 (35)	6	1035 German adults who attended swimming pool at school age, age 35–74	35–74	274 persons who never attended pool at school age	0.89 (0.56, 1.41)
Levesque et al. 2006 (46)	5	305 Canadian swimmers, age <12–16+	<12–16+	499 soccer players	1.00 (0.60, 1.80)
Bernard et al. 2007 (44)	3	43 former swimming babies in Belgium, mean age 11.5	10–13	298 other children	2.20 (0.77, 6.50)
Schoefer et al. 2007 (34)	5	660 German children who attended pools since infancy followed from birth to age 6		191 children who started attending pool after age 3 or never	0.42 (0.22–0.82)
META-ANALYSIS					
All studies using results of Bernard et al. 2006; $P_{heterogeneity} = 0.09$					0.82 (0.54, 1.25)
All studies using results of Bernard et al. 2007; $P_{heterogeneity} = 0.09$					0.82 (0.52, 1.28)
Subset of studies with the highest score (34, 35, 46); $P_{heterogeneity} = 0.17$					0.63 (0.38, 1.06)

*Unadjusted results calculated from data reported in Table 1 and Figures 2 and 3 (published results use CPA as a continuous variable).
**Unadjusted results calculated from data provided by the authors (personal communication).

>80% participation, (35) two studies had participation of over 50% but less than 80% (34, 47), two studies had less than 50% participation (43, 44) and in one study (45) the proportion of the target population that was included in the analysis was not reported.

Four studies made an attempt to control for extraneous factors; however only three of those studies (34, 35, 44) allowed inclusion of adjusted estimates in the meta-analysis. One study presented results without adjustment for potential confounders and reported prevalence of asthmatic symptoms instead of asthma diagnosis (45). In this case the data on self-reported asthma diagnosis were obtained after contacting the authors (e-mail communication with Dr. Eugenio Baraldi). None of the studies confirmed asthma diagnosis using medical records; and the overall study quality scores in Group II ranged between 2 and 6 points.

The reported ORs of the association between swimming pool attendance and asthma prevalence ranged between 0.42 and 2.20 but none of the individual point estimates demonstrated a significant increase in asthma prevalence among the exposed. Two of the five studies were published by the same group of researchers and were based on the same data, (43, 44) and thus could not be included in the meta-analysis at the same time. As shown in Table 3 the meta-ORs were 0.82 regardless of which of the two overlapping studies was included in the analysis. When the meta-analysis was limited to studies with the highest quality scores the meta-OR was 0.63 (95% CI: 0.38, 1.06).

Group III: Studies of the Effect of Swimming Training on Asthma Patients

Eight studies in Group III compared before-and-after changes in asthma severity, or PFT results among pediatric asthma patients participating in swimming programs to those among non-swimming controls (Table 5). Two studies used randomized clinical trial design, (10, 36) however only one of those studies (36) analyzed the data on the entire study population without any loss to follow up. The reported duration of swimming intervention ranged from 5 weeks (10) to 6 months (48), and in one instance the duration of the intervention was not reported (49). Three studies specified that swimming lessons took place in indoor pools, (36, 49, 50) and in other studies the location of the pool was not reported. One study indicated that the pool used natural warm water without chlorination (48). With respect to control for extraneous factors two studies matched participants and controls (50, 51), and one study used randomization (36), which in theory should achieve comparability of the two groups. The quality scores in Group III ranged for a minimum of four points to a maximum of 10 points.

Five studies examined changes in asthma severity expressed as either frequency of asthma attacks (50, 51), or an asthma severity score, which was used to measure the frequency of wheezing episodes and medication use (10, 52, 53). The before-and-after improvement in asthma severity among the swimming intervention groups ranged from 8.7% to 78%, and the corresponding differences between swimmers and controls ranged from 21% to 67%. The meta-analysis of all five studies combined showed that improvement among swimmers was higher than a similar improvement among controls by 42.3% (95% CI: 19.0, 66.3). A sub-analysis limited to three studies (10, 50, 51) with relatively high quality scores (range 6–7) demonstrated a somewhat stronger effect, 46.8% (95% CI: 14.8, 78.8).

In contrast to studies focusing on clinical measures of asthma severity, studies that evaluated the impact of swimming interventions on resting PFT results generally demonstrated no discernable difference between swimmers and controls. None of the individual study results was significantly different from the null (Table 5). The meta-analysis of the five studies evaluating effect of swimming training on resting forced expiratory volume exhaled in 1 second or FEV_1 showed a meta-difference of 2.9% between intervention and control groups (95% CI: −5.6, 11.3). A similar meta-analysis evaluating the long term effect of swimming training on post-exertion fall in PFTs expressed as either change in FEV_1 or change in peak expiratory flow (PEF) produced a comparable null result (difference 4.7%; 95% CI: −4.2, 13.6).

TABLE 5.—Summary of Group III studies evaluating the effect of swimming training programs on respiratory function and disease severity among asthma patients.

Authors (reference)	Quality Score	Participants, Location	Intervention	Control	Endpoints (% change in swimmers)	Difference between groups (95% CI)
Sly et al. 1972 (50)	7	12 children, age 9–12, New Orleans, US	Swimming & other exercise for 3-months	No exercise (N = 12, age 9–13)	Frequency of wheezing (49.8) FEV_1 at rest (14.3)	52.8 (−12.6, 118.2) 7.3 (−10.3, 25.0)
Fitch 1977 (52)	5	32 children, age 9–16, Perth Australia	Swimming training at least 50 km in 5 mo.	Swimming <50 km in 5 months (N = 14, age NS)	Asthma severity score (51.2)	37.0 (0.0, 74.0)*
Schnall et al. 1982 (53)	4	11 children, mean age 9.2, Parkville, Australia	Swimming pool program for 10 weeks	Dry land exercise, (N = 12, mean age 9.7)	Asthma severity score (43.7) FEV_1 at rest (−5.6) Post-exercise fall in PEF (2.5)	43.7 (−68.2, 155.6)* 6.2 (−136.8, 149.2) 2.0 (−19.1, 23.1)
Svenonius et al. 1983 (49)	5	15 children, age 9–16, Malmö, Sweden	Swimming and other exercise, duration unclear	No exercise (N = 10, age 9–17)	FEV_1 at rest (2.1) Post-exercise fall in FEV_1 (8.8)	−0.1 (−24.2, 24.1) 5.2 (−4.8, 15.2)
Huang et al. 1989 (51)	7	45 children, age 6–12, Baltimore, US	Swimming pool lessons for 2 months	No exercise (N = 45) matched on age, sex & asthma severity	Frequency of asthma attacks (78)	67.0 (16.1, 117.9)*
Matsumoto et al. 1999 (36)	10	8 children, age 9–11, Fukuoka, Japan	Swimming program for six weeks	No exercise (N = 8, age 8–11)	Post-swimming fall in FEV_1 (6.6) Post-cycling fall in FEV_1 (22.6)	5.3 (−58.9, 69.5) 10.6 (−71.7, 93.0)
Weisgerber et al. 2003 (10)	6	5 children, age 7–12, Augusta, US	Swimming pool lessons for 5–6 weeks	No exercise (N = 3, age 7–8)	Asthma severity score (8.7) FEV_1 at rest (5.3)	21.0 (−32.1, 74.0) 2.2 (−15.5, 19.9)
Arandelovič et al. 2007 (48)	6	45 adults, (mean age 33.1), Niš, Serbia	Swimming program for 6 months	No exercise (n = 45, mean age 33.5	FEV_1 at rest (2.8)	1.6 (−11.5, 14.7)
META-ANALYSIS						
Studies (10, 50–53) evaluating effect of swimming training on clinical asthma severity, $P_{heterogeneity} = 0.79$						42.3% (19.0, 66.3); FSN = 18
Subset of studies with the highest score (10, 50, 51) evaluating effect of swimming training on clinical asthma severity; $P_{heterogeneity} = 0.46$						46.8% (14.8, 78.8)
Studies (10, 48–50, 53) evaluating effect of swimming training on FEV_1 at rest; $P_{heterogeneity} = 0.99$						2.9% (−5.6, 11.3)
Subset of studies with the highest score (10, 48, 50) evaluating effect of swimming training on FEV_1 at rest; $P_{heterogeneity} = 0.87$						3.2% (−5.8, 12.3)
Studies (36, 49, 53) evaluating effect of swimming training on post-exercise fall in PFTs; $P_{heterogeneity} = 0.45$						4.7% (−4.2, 13.6)

Confidence intervals approximated based on p-values reported by authors. FEV_1 = forced expiratory volume exhaled in 1 second; PEF = peak expiratory flow.

Group IV: Studies Comparing Asthmagenicity of Swimming and Dry Land Exercises

Table 6 summarizes the results of six studies comparing immediate (within minutes) respiratory effects of swimming to those of running and/or cycling among asthma patients. Three of the six studies were conducted among children (36, 54, 55), one study was conducted among adults (56), and in two studies the participants included both adults and children (33, 57). All swimming challenge tests took place in indoor pools; however in two instances (54, 56) the participants were breathing air supplied via a mouthpiece or a mask and thus the experimental conditions in those two studies differed from the usual swimming pool environment. The endpoints of interest were expressed as a post-exercise percent change in either FEV_1 or PEF with an average range from 0% to −28.7% after swimming, and from −14.4% to −47.6% after dry land exercises. All but one study used an experimental cross-over design and thus the results were less likely to be affected by extraneous factors. For all of the above reasons, the studies in Group IV tended to have higher-quality scores compared to other groups (Table 6).

The meta-analysis results demonstrated that the difference between swimming and running was more pronounced (20.1; 95% CI: 12.9, 27.3) than the difference between swimming and cycling (8.3; 95% CI: 3.0, 13.5). The results also appeared to be stronger in children (difference 18.9; 95% CI: 9.1, 28.7) than in all age groups combined (difference 12.9; 95% CI: 6.2, 19.7). When the sub-analyses were limited to studies with relatively high quality scores the results remained generally unchanged (Table 6).

Figure 1 presents the results of analyses evaluating the association between swimming and the risk of exercise-induced bronchospasm (EIB) defined as significant (e.g., >15%, >20%, or >25%) post-exercise decrease in PFT results. Because different studies use different definitions of clinically significant EIB we conducted our analyses using two alternative cutoff points. The meta-ORs in these analyses were 0.16 (95% CI: 0.07, 0.39) using the cutoff of 15% and 0.28 (95% CI: 0.12, 0.63) using the cutoff of 25%. These results indicate that in comparison to swimming, running and/or cycling is associated with a 4- to 6-fold increase in the EIB risk; however, this observation is based on a relatively small number of studies.

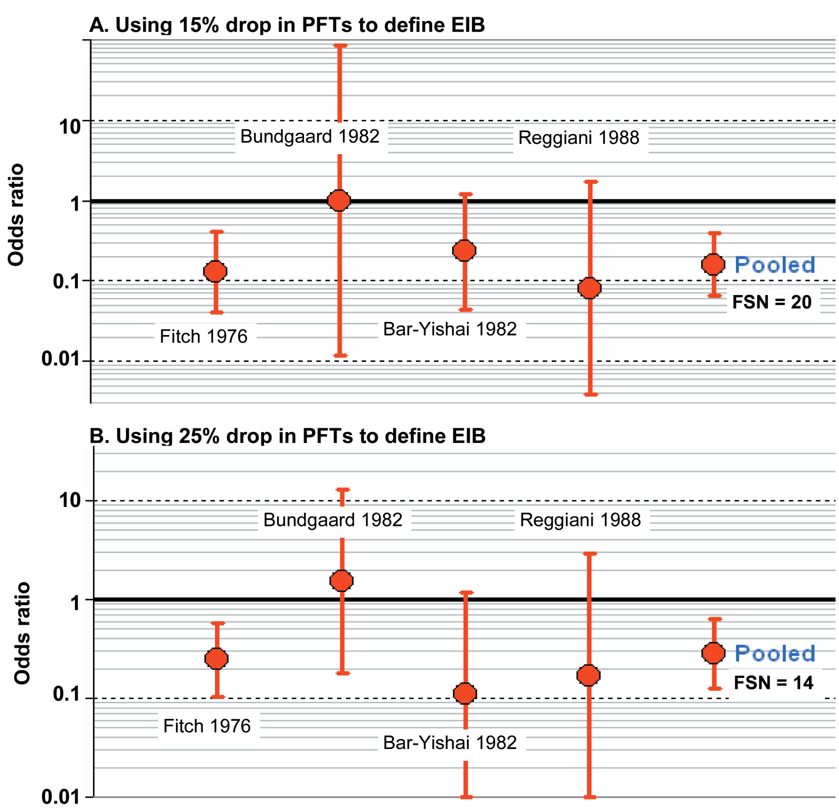
DISCUSSION

In evaluating the association between swimming and asthma frequency we used asthma diagnosis as the endpoint of interest. It is important to keep in mind that reported asthma diagnosis is not an optimal outcome definition because it may result a moderate, but appreciable proportion of false positive and false negative cases (58, 59). Similar degree of misclassification was found in studies comparing parental reporting and self-reporting of asthma among children and adolescents (60, 61). Several studies included in this review reported the

TABLE 6.—Summary of Group IV experimental studies comparing post-exercise effects of swimming to those of running and cycling among asthma patients.

Authors (reference)	Quality Score	Participants, Location	Endpoints (% change after swimming)	Comparison exercise	Difference between exercises (95% CI)
Fitch & Morton 1971 (33)	10	40 children & adults age 10–51, Perth, Australia	Post-exercise change in FEV_1 (−20.2)	Running Cycling	14.5% (3.5, 25.5) 10.7% (2.6, 18.8)
Godfrey et al. 1973 (57)	3	10 children & young adults, age not specified, London, UK	Post-exercise change in PEF (−14.7)	Running (N = 100) Cycling (N = 16)	26.6 (13.5, 39.7) 8.7% (−5.3, 22.7)
Bar-Yishai et al. 1982 (54)	9	13 children, age 9–17, Jerusalem Israel	Post-exercise change in FEV_1 (−13.0)	Running	19.2% (−4.3, 42.7)
Bundgaard et al. 1982 (56)	8	11 adults, age 17–46, Copenhagen, Denmark	Post-exercise change in PEF (−28.7)	Cycling	1.6% (−7.3, 10.5)
Reggiani et al. 1988 (55)	9	9 children, average age 15.1 years, Genoa, Italy	Post-exercise fall in FEV_1 (0.0)	Running Cycling	23.2% (6.0, 40.5) 14.4% (−0.1, 29.1)
Matsumoto et al. 1999 (36)	10	8 children, age 9–11, Fukuoka, Japan	Post-exercise fall in FEV_1 (−14.6)	Cycling	24.1% (2.7, 56.5)
META-ANALYSIS					
All studies comparing swimming to all other exercises combined; $P_{heterogeneity} = 0.12$					12.9% (6.2, 19.7); FSN = 61
Subset of studies with the highest score (33, 36, 54, 55) comparing swimming to all other exercises combined; $P_{heterogeneity} = 0.73$					14.4% (8.8, 20.0)
Studies comparing swimming to running (33, 54, 55, 57); $P_{heterogeneity} = 0.56$					20.1% (12.9, 27.3); FSN= 43
Subset of studies with the highest score (33, 54, 55) comparing swimming to running; $P_{heterogeneity} = 0.69$					17.3% (8.7, 25.9)
Studies comparing swimming to cycling (33, 36, 55–57); $P_{heterogeneity} = 0.39$					8.3% (3.0, 13.5); FSN= 11
Subset of studies with the highest score (33, 36, 55) comparing swimming to cycling; $P_{heterogeneity} = 0.69$					12.2% (5.2, 19.1)

*Confidence intervals approximated based on *p*-values reported by authors.
FEV_1 = forced expiratory volume exhaled in 1 second; PEF = peak expiratory flow.



PFTs= pulmonary function tests.
EIB = exercise-induced bronchospasm.

FIGURE 1.—Meta-analysis of the association between exercise-induced bronchospasm and swimming among asthmatics using cycling and/or running as reference.

use of biomarkers of pulmonary damage or various challenge tests as surrogate measures of asthma prevalence; however only diagnosed asthma was used consistently to allow meaningful comparisons and pooling of results.

In this study we found that that the association between asthma frequency and swimming depends on the population of interest. On the one hand asthma diagnosis is clearly more likely to be found among elite swimmers than among similarly high-level participants in other competitive sports events (Group I). On the other hand, there appears to be no consistent association between the prevalence of asthma and swimming pool use during childhood (Group II). The observed discrepancy between two groups could be explained by higher frequency, intensity and duration of swimming (and therefore swimming pool exposures) among elite athletes. However, it is also plausible that asthmatics are more likely to be attracted to and excel in swimming compared to other sports, and thus, some asthmatics identified in cross-sectional studies of swimmers may have selected swimming as the activity of choice because of their condition.

Our meta-analyses provides some evidence that asthmatics may benefit from swimming training as reflected in the clinical measures of disease severity, although not in PFT results (Group III). Perhaps more consistently the data indicate that swimming produces significantly less airway resistance than other types of vigorous physical activity (Group IV). Although beyond the scope of this meta-analysis, it is worth noting that similar studies comparing respiratory effects of swimming and running among persons without asthma found no discernable difference (33, 62). These findings lend additional support to the position statement by the American Academy of Pediatrics (AAP), which recommends that children whose asthma is not optimally controlled with medication "*should be encouraged to participate in sports with less potential for exercise-induced asthma*," and specifically identifies swimming as a sport that is *"conducted in environments which are less apt to induce asthma"* (63).

The relatively small number of relevant publications available for some analyses in this review warrants caution given the possibility of publication bias. Publication bias, often referred to as the "file drawer problem" (64), is a type of error that may affect the results of a meta-analysis because studies with statistically significant positive findings are more likely to be published than studies with null results (65). A review of publications excluded from this meta-analysis indicated that most studies that failed to meet the inclusion criteria were generally in agreement with our findings. Furthermore, our fail-safe N calculations indicate that the "file drawer problem" is unlikely to explain the observed meta-results as the FSN values were generally high, ranging from 14 to 83.

We evaluated the quality of individual studies included in the meta-analysis by using a 10 point score. Our review indicates that quality of the studies in Groups I and II tended to have lower scores due to inadequate design, poor participation rates, self-reported exposure and outcome ascertainment and inability to adequately control for extraneous factors. By contrast, studies comprising Group III and particularly those in Group IV had the advantage of using experimental design, direct observations of exposure and outcome, and as a result received higher quality scores.

The appropriateness of formal quality scores in systematic literature reviews remains the focus of debate. Several authors recommend formalizing such evaluations by using quantitative scoring of individual studies (66, 67). Others view the use of scoring schemes as somewhat arbitrary and advise against using them (68). We previously discussed that both points of view may have merit (69).

Using a quality score as a method of weighting study results or as a variable in a regression model may introduce a subjective element into an analysis (70). On the other hand, it is important to take into account methodological strengths and weaknesses that are likely to affect the overall conclusions. For these reasons, we feel that the use of sub-analyses as presented here is justified as long as the methodology of assigning quality scores is explained. The particular scoring method used in this study reflects the consensus of its authors, but we realize that other approaches may also exist.

With respect to the merits of the pool chlorine hypothesis, it is important to emphasize that nearly all Group I and group II studies used cross-sectional design and thus cannot address the temporal relationship between asthma onset and swimming pool exposure in their study populations (71). Moreover, even studies that specifically claimed to have tested the pool chlorine hypothesis focused primarily on swimming rather than measured chlorine exposure (31, 43, 44). In the absence of prospective data that would allow direct testing of the pool chlorine hypothesis it might be useful to evaluate the evidence regarding the frequency of asthma among persons who use chlorinated pools, but are not engaged in competitive swimming.

Although the data are scarce, some information is available. In a study of the U.S. participants in the 1996 Olympic Games, Weiler and colleagues examined prevalence of asthma in swimmers separately from that in divers (41). Although divers in these analyses were combined with weight lifters, it is notable that none of the athletes in this category reported having asthma at the time of the survey. In a similar study of Australian Olympic athletes (39), the odds of asthma were much higher among swimmers (OR = 2.5, 95% CI 1.7–3.0) than among all aquatic sports participants (e.g., divers, water polo players, etc.) combined (OR = 1.5, 95% CI: 1.1–2.1). It is therefore expected that a corresponding analysis comparing aquatic athletes other than swimmers to all other non-aquatic athletes would have produced a null result.

In addition to studies of swimmers our literature search identified two cross-sectional studies of swimming pool workers. In a 1998 French study of lifeguards, the prevalence of asthma appeared to be higher in the group with the lowest cumulative exposure than in the group with the highest cumulative exposure (72). In a more recent Dutch cross-sectional study comparing chlorine byproduct-exposed individuals to non-exposed pool workers (management, catering and reception), the prevalence of asthma was elevated among swimming pool cleaners, but not among pool attendants, swimming instructors and technicians (73). There appeared to be no association between asthma and cumulative chloramine exposure levels. In a separate analysis, the prevalence of asthma among all pool workers combined was higher than that found in an earlier general population survey (74), but the data for the two surveys seemed to have been collected more than a decade apart raising concerns about the appropriateness of a side-by-side comparison.

In summary, although asthma is more commonly found among elite swimmers than among other high-level athletes, it is premature to draw conclusions about the causal link between swimming and asthma because most studies available to date used cross-sectional design and because the association is not confirmed among non-competitive swimmers. In addition, our meta-analysis indicates that asthmatics may tolerate swimming better than other sports.

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