A REVIEW OF THE LITERATURE ON SCREENING CHILDREN AND ADOLESCENTS FOR EXERCISE-INDUCED ASTHMA

By

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A REVIEW OF THE LITERATURE ON SCREENING CHILDREN AND ADOLESCENTS FOR EXERCISE-INDUCED ASTHMA

Abstract

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Asthma is a major cause of morbidity in children and adolescents. Exercise-induced asthma (EIA) is transient airway narrowing causing symptoms of cough and shortness of breath during and after exercise, either with or without chronic asthma. Parents and children may not recognize the symptoms of EIA as such and therefore children may lack proper treatment. Screening children for EIA will assist in identifying those at risk. A systematic review of EIA screening tests was conducted by searching PUBMED for key terms. Sixty-seven articles were identified; after abstracting the papers, seven met inclusion criteria for the focus of the review. These peer-reviewed studies screened presumably healthy children and children with known asthma or presumed EIA for EIA. The most common screening test used was the six-minute exercise challenge using a treadmill or free running test. The most common criteria for determining EIA was a decrease in FEV$_1$ by 10 or 15%. Screening for EIA in schools has the potential to identify at risk children and adolescents, but screening needs to be both time- and cost-effective in order to be implemented successfully. More research is needed to identify feasible screening. A program is suggested that, with more research, may be implemented in schools to identify children and adolescents with undiagnosed EIA.
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Dedication

This project is dedicated to my family, William, Emerson, and Lindsay, for their support and patience over the past three years.
A Review of the Literature on Screening Children and Adolescents for Exercise-Induced Asthma

Statement of the Problem

Asthma is a major source of illness and hospitalization of children under 18 years of age and is the most common chronic illness in the United States, affecting around 11.9% of children (MMWR, 2012). Asthma is a chronic respiratory disease that has no cure, but with proper diagnosis and treatment, the symptoms of wheezing, chest tightness, shortness of breath, cough, lack of energy, and feeling out of shape can be managed and exacerbations reduced (MMWR, 2011; Weiler et al., 2010). Exercise-induced asthma (EIA) is defined as transient airway narrowing which increases airway resistance during and after exercise, in either the presence or absence of underlying asthma (Weiler et al., 2010). The prevalence of EIA is unclear because most studies do not differentiate between whether the cause of airway narrowing is asthma or bronchoconstriction without asthma (Weiler et al., 2010).

Genetic factors are thought to play a role in EIA, but are not as well understood as environmental triggers. The relationship between genetics and EIA is largely unknown at this time, but environmental triggers are well understood in terms of persistence (Weiler et al., 2010). Environmental triggers are classified as either irritants or allergens. Irritants include cigarette and other smoke, microorganisms, weather changes, especially cold, dry air, exercise, and airborne chemicals (Weiler et al., 2010; Winkelman, Workman, and Hausman, 2010). Allergens, for example, include animal dander, dust mites, and pollens (Weiler et al., 2010). Exercising at an aerobic level increases rate of breathing and oxygen consumption, therefore increasing the inhalation of allergens and irritants (Winkelman, et al., 2010). Although EIA is diagnosed and treated differently than chronic asthma not exacerbated only by exercise, the pathophysiology is
the same regardless of the trigger. An inflammatory response is triggered by exposure to an irritant or allergen, causing airway obstruction and/or airway hyperresponsiveness. Both lead to bronchoconstriction, which causes the known asthma symptoms (Winkelman, et al. 2010).

Understanding the prevalence of EIA in children and adolescents will inform the need for establishing EIA screening programs in schools. Children and adolescents are sometimes treated for chronic asthma based on self-reported symptoms. However, the symptoms the child experiences may be only exercise-induced. Often children are reluctant to participate in physical activity or sports because of shortness of breath and feeling out of shape. These children may have unidentified exercise-induced asthma (Helms, 2005). Screening schoolchildren and adolescents for EIA will lead to referral for confirmatory diagnosis and ultimately proper treatment. Confirming an accurate medical diagnosis of exercise-induced asthma requires examination and testing by a diagnostician. Treating EIA in children should lead to an increased ability to perform physical activity, participate in sports, and simply play comfortably on the playground without fear of symptom exacerbation. Preliminary screening in the school setting is proposed to identify children who may be at risk.

Screening is defined as “…the presumptive identification of unrecognized disease or defects by the application of tests, examinations, or other procedures that can be applied rapidly” (Friis and Bartlett, 2009, p. 410). Macha and McDonough (2012) further illustrate the difference between screening and diagnosis, noting that the more sensitive test yields greater false-positive rates, which lowers its specificity. A test with more specificity often has a higher false-negative rate, though less sensitive. Therefore, a more sensitive test is used for screening purposes and a more specific test is used to confirm diagnosis.
EIA is objectively diagnosed by direct challenge and/or indirect challenge. The direct challenge uses pharmaceutical agents that act directly on airway smooth muscle to invoke bronchoconstriction; therefore invoking a decrease in expiratory airflow (Weiler et al., 2010). According to the Joint Task Force for Practice Parameters for Allergies and Immunology (Task Force), the criteria for EIA diagnosis is a 10% decrease in FEV₁ with the direct or indirect challenge (Weiler et al., 2010). The indirect challenge involves exercise, or a surrogate such as eucapnic voluntary hyperventilation (EVH), to invoke a response. The latter is preferred as it is more closely reproduces bronchial hyperresponsiveness and more closely reproduces the effects of exercise (Weiler et al., 2010). This paper will focus on the indirect methods of diagnosing EIA.

The simplest indirect method of diagnosing EIA involves an exercise challenge in which the participant exercises for a six-minute period. The testing is most accurate if the environment is controlled for temperature and humidity, factors that can affect respiratory response to exercise. The patient must exercise for six to eight minutes at 80-90% of their maximum heart rate (HRmax) (Weiler et al., 2010) using the formula of 208 – 0.7 X age (Weiler et al., 2010; Mahon, Marjerrison, Lee, Woodruff & Hanna, 2010). Spirometry, or a lung function test, is performed at baseline and at 5, 10, 15, and 30 minutes post exercise challenge (Weiler et al., 2010). Ideally, the exercise challenge is performed on a treadmill in a laboratory setting in order to monitor heart rate and exertion, as well as provide rescue medications in the event of an acute asthma attack. A decrease in FEV₁ (forced expiratory volume in the first second of exhalation) is noted for a positive EIA test. Experts differ regarding the percentage of decrease in FEV₁ required to be indicative of EIA, but the Joint Task Force for Practice Parameters for Allergies
The purpose of this paper is to identify a simple, inexpensive, rapid, and accurate method to screen school age children and adolescents for EIA. Findings will be synthesized alongside Task Force recommendations to present a feasible program for implementation in the school setting. Children aged 6-12 and adolescents aged 13-18 are the focus of this review since children five and under are unable to adequately perform spirometry (Stonham, 2011), and PUBMED categorizes children from ages 6-12 and adolescents from 13-18.

Search Strategies

The PubMed database was searched using the MeSH major topics of 1) Asthma, Exercise-Induced, and 2) Asthma, Exercise-Induced/Diagnosis. Filters were added to limit articles to those written in English, addressing children aged 6 to 12, and adolescents aged 13 to 18, published within the last ten years, and based on human subjects only. Sixty-seven articles were found. Abstracts were reviewed, and data collected on a data abstraction form with the following fields: author, screening test used for diagnosis, age of subjects, sample size, and diagnostic criteria. These fields were chosen to allow comparison of the screening methods. After an initial review of article abstracts, seven primary studies fit the inclusion criteria and are discussed in this paper. See Figure 1 for the literature flow diagram. Eleven papers that did not meet the focus of this paper were included as references due to their inclusion of data relevant to EIA screening in children and adolescents.

Theoretical Framework

The Theory of Ecological Development (Bronfenbrenner, 1979) was chosen to help guide
this study of current EIA screening methods for children and adolescents. According to Bronfenbrenner’s theory, many levels of the child’s environment play into EIA. The theory helped identify factors important to consider in the review. For example, a child’s environment influences exposure to EIA screening. Factors associated with screening include support from the school system, funding for school health programs, obtaining parental consent and buy-in for a program, and support from the health care community. Health outcomes in children and adolescents with EIA are complex and include the child’s relationship with family, school, neighborhood, and societal influences.

Bronfenbrenner (1979) sought to explain how processes of growth and development are shown in context to the individual in relationship to their environment. By approaching the proposal of school-based screenings for EIA through this framework, it is noted that these complex interactions are all stages at which the child or adolescent is a risk for alterations in growth and development. The Theory of Ecological Development provides rationale for the importance of screening and diagnosis of EIA among children and adolescents, investigating each level of complexity and its opportunity to identify and treat EIA (Jeong and Arriaga, 2009; Tudge, Mokrova, Hatfield, and Karnik, 2009; Celano, 2001; Crowley, 2001). This theory regards the whole system surrounding the person, and the interaction between the factors involved with the individual’s system. The complexity of EIA and the influence of the child’s environment are acknowledged through the Ecological Theory of Development framework. The theory is relevant to building partnerships with schools, parents, and communities to develop screening programs. Such screening programs will lead to diagnosis, treatment, and minimal interruption in children’s growth and development. See Figure 2 for diagram of the Ecological Theory as related to children and adolescents with EIA.
This adaptation of the ecological theory finds the child or adolescent at its inner core, with all surrounding levels interacting symbiotically. The first level, the microsystem includes the family, home, and school. The next level is the mesosystem, which involves the interaction between the child’s closest environments of home, school, and clinic. For example, a child with EIA may perform poorly in physical education class at school. Without diagnosis, parents and teachers may assume that the child is simply not in good physical condition or not making enough of an effort at the physical activity. The exosystem surrounds the mesosystem and involves an influential environment in which the child is not directly involved, such as the school district’s policy (or lack thereof) on EIA and treatment at school (Pitsios, 2010). The outer level of this model is the macrosystem, which includes society’s values, norms, and expectations (Tudge, et al. 2009). For example, a child with EIA may exhibit signs and symptoms of dyspnea during physical activity and use albuterol to treat the exacerbation. Sports authorities such as coaches, physical education teachers, and athletic recruiters may frown on the use of medications as perceived as being “performance enhancing” (Ogston and Butcher, 2002). While not envisioned as another circle around the macrosystem, the chronosystem is viewed as the continuity of the model over time. The chronosystem looks at the child’s development and the other systems’ contributions to this development over time. If EIA has gone undiagnosed, over time, the child may avoid physical activity; develop obesity and perhaps a low self-esteem.

**Literature Review**

The literature was organized into two categories: Studies screening random, presumably healthy children, and studies screening children with an asthma diagnosis suspected of having EIA. Each study will be discussed in detail and then overall findings will be synthesized. See Table 1 for comparative data.
Studies Screening Random or Presumably Healthy Children

DeBaets, et al. (2005) sought to determine EIA prevalence in a large cohort of urban and rural Belgian children. The traditional six-minute FRAST (free running asthma screening test) was employed to screen 15,241 children ages 9 to 13. A 15% decrease in peak expiratory flow rate (PEFR) was used as criteria for identifying EIA. Overall, 7.4% of children were positive for EIA.

In a study of healthy high school cross-country skiers in Minnesota, Ogston and Butcher (2002) studied one hundred healthy adolescents, ages 13 to 18. These skiers participated in a 15-minute free ski on groomed trails at “race pace”. A 10% fall in FEV₁ was the criteria for EIA. Twenty-two percent of these athletes tested positive for EIA.

Studies Screening Children with Asthma or Presumed EIA

Kaslovsky, Sondike, and Cummings (2010) invited obese children between the ages of 6 to 18 who experienced exertional dyspnea but not diagnosed with asthma to participate in a trial. Twenty children were tested with spirometry at baseline. Those with decreased airflow, as defined by FEV₁ less than 80% of predicted, were treated with albuterol and testing was repeated. Four children (20%) were diagnosed with asthma based on spirometry and not enrolled in the exercise challenge test. If there was no significant improvement in airflow (among those not diagnosed with asthma), or baseline testing was normal, the children were invited to proceed with the exercise testing part of the study. Fifteen children, ages 8 to 16, met those criteria and exercise testing was done using a standard treadmill protocol using the FRAST for six minutes. Spirometry was performed at 5, 10, 15, and 20 minutes post exercise. A 12% drop in FEV₁ was considered positive. Five of the 15 children, or 33%, met the criteria for EIA. The findings in this study indicate that asthma, either chronic or exercise-induced, may impede a child’s ability to
exercise. In total, nine of the 20 obese children in this study (45%) had clinically diagnosed asthma or EIA.

In Greece, Pitsios, Del Giacco, and Grigoreas (2010) evaluated the use of the FRAST compared to a symptom questionnaire to diagnose EIA in rural children. Among a cohort of 268 children, ranging in age from 8 to 12, one percent claimed to have a history of prior asthma when queried on history of asthma. The FRAST was completed by using a treadmill for six minutes exercising at 80-90% maximum heart rate. A 15% drop in PEFR was used as criteria for EIA. A total of 11 children, or 4.1%, tested positive for EIA. The researchers found that the FRAST is a useful test in diagnosing EIA and that it is more specific than a historical questionnaire.

Abu Hasan, Tannous, and Weinberger (2005) studied 142 children between the ages of six and 21 (mean age 14) with exercise-induced dyspnea. A standard six-minute exercise FRAST was done using a treadmill while monitoring heart rate, oxygen saturation, and carbon dioxide. Children were challenged to exercise at 85% of maximum heart rate. A 15% decline in FEV₁ was the criteria for EIA. The majority of children had normal physiologic exercise limitations and no other restrictive abnormalities such as vocal cord dysfunction or laryngomalacia. Sixty-nine percent of the children were diagnosed with chronic asthma, while 71% were already being treated for asthma without a definitive diagnosis. Of the 142 children completing the exercise challenge, 11 (7%) were positive for EIA.

Seear, Wensley, and West (2005) studied 52 children (mean age of 11.5 years) with poorly controlled EIA compared to eight healthy children without symptoms or history of asthma. The children were challenged with a ten-minute treadmill exercise test at 80 to 90% of maximum heart rate. A 10% decrease in FEV₁ was considered positive for EIA. Among this
cohort, 15.4% had EIA, 23.1% were unfit, 26.9% had vocal cord dysfunction, 21.1% had no abnormality, and 13.5% had habitual cough.

Tancredi, et al. (2004) compared the traditional six-minute exercise test using a treadmill with a three-minute step test using a 30-centimeter box. Children with asthma (N=154) with a pre-exercise FEV$_1$ of $\geq 80\%$ performed baseline spirometry, followed by the six-minute treadmill test exercising at 80\% of maximum heart rate. At least 24 hours later, the same children performed the three-minute step test at 80\% of maximum heart rate, stepping at a rate of 30 steps per minute. A 15\% drop in FEV$_1$ was the criteria used to diagnose EIA. The treadmill test yielded a 14.9\% rate of EIA, while the step test yielded an 11.6\% rate of EIA.

**Discussion**

This systematic review identified seven primary articles focusing on screening methods to identify EIA in children and adolescents. Authors varied in the methods used to assess EIA and cutpoints used to diagnose EIA. Researchers varied in the method of exercise challenge, from free running, controlled treadmill running, to a step test. Most researchers utilized a six-minute running test, using either a treadmill or a free running exercise. The treadmill method is not suitable for in-school screening.

Measures of respiratory function to assess for EIA also varied between studies. Some authors used peak expiratory flow rate (PEFR) using a simple peak flow meter, whereas other authors used forced expiratory volume in the first second (FEV$_1$) measured during spirometry testing which is the standard practice recommended by the Task Force (Weiler et al., 2010). The cutpoints used to define EIA also differed between authors, from 10\%, 12\%, to 15\% decrease in either PEFR or FEV$_1$. 
Data from this literature review noted different prevalence rates of EIA in children and adolescents due to the variations in population and criteria used to determine positive EIA. The number of participants screened in each study varied from 19 to over 15,000. Three studies were conducted in the U.S., one in Canada, and three in Europe. DeBaets, et al. (2005) provided the best prevalence data by studying a large cohort of over 15,000 healthy children and finding a prevalence rate of 7.4-16.9%, depending on the FEV₁ value used as the cutpoint for a positive test. If the prevalence rate of EIA is this high in the U.S., screening programs will identify a significant number of children and refer for diagnostic confirmation.

Preliminary screening done in the schools should employ a sensitive spirometry test, while diagnosis of EIA can be obtained through specific pulmonary function testing and exercise challenge in a laboratory setting (Weiler et al., 2010). With an estimated 3-16% rate of new identification of EIA in children and adolescents, measures must be in place to maximize the expenditure and time associated with a screening program. A quick, reliable, and inexpensive program must be developed to provide benefit to school systems and the communities.

The Joint Task Force for Practice Parameters for Allergies and Immunology (Task Force) considers a 10% decrease of FEV₁ to be indicative of EIA (Weiler et al., 2010). It is likely that the prevalence of EIA would be higher if 10% decrease in FEV₁ were used in all screenings for EIA versus 15% (Weiler et al., 2010). Standard screening criteria must be employed to have a successful screening program in schools.

A sensitive and efficient method of testing for EIA is necessary in order to implement such a program in the school systems. Tancredi, et al. (2004) compared a traditional six-minute exercise challenge using a treadmill with a three minute step test using a 30 centimeter step. Both showed produced positive results although the six-minute test identified a larger number of
children with EIA. Using a three-minute step test would be a more efficient method of screening large numbers of children by decreasing the time of exercise by 50%. The protocol for an EIA screening program in schools must consider adverse events that could occur, such as bronchospasm and shortness of breath. Oxygen and bronchodilators should be on hand in the event of an adverse reaction. Parents must be informed of the screening program and give written consent for their child to participate.

Although it is significant that Seear (2005) found 15% of children studied to have EIA, many children were being treated with presumptive EIA unnecessarily. Misdiagnosing EIA may complicate asthma diagnosis and lead to sequelae of untreated illness. On the other hand, treating with inhaled steroids by assuming a child has chronic asthma is unnecessary and carries risk such as potential growth suppression (Deglin and Vallerand, 2009). This suggests that many children may be improperly treated for EIA with chronic inhaled steroids; while this may be necessary for some, the majority may suffice with bronchodilators prior to exercise (Abu Hasan, 2005). In the Tancredi study (2004), the researchers found that the step test yielded a lesser decrease in FEV₁, possibly indicating a lesser physical exertion than the treadmill. This method was economical, quick, and portable, all aspects necessary for screening. Further research is needed on the step test in children in order to validate its accuracy compared to the Task Force recommended six-minute exercise challenge test using a treadmill or free running activity.

**Significance to Nursing**

Data from the literature review support the clinical notion that EIA is present in children with and without known asthma. Obese and normal weight children with exercise-induced dyspnea may have EIA but must be properly diagnosed in order to avoid over treating, or misdiagnosing.
Nurses focusing on advanced population health are poised to bring innovative ideas and actions to the public. By recognizing that somewhere between 4 and 33% of children and adolescents are suffering from EIA, nurses should take action to educate families, schools, and healthcare providers of the need to research screening techniques and eventually implement in-school screening for EIA. With accurate diagnosis, proper treatment can occur. With proper treatment, children and adolescents may be encouraged to participate in sports or other physical activity. The incidence of undiagnosed EIA in children and adolescents pose a significant burden to the family if the child or adolescent becomes discouraged and thus inactive. The health outcomes of children with EIA may be negatively affected with limited exercise and this can lead to obesity, diabetes, and a host of other illnesses resulting from overweight or obesity (Winkelstein et al., 2006).

Home, school, and healthcare environments influence children (Bronfenbrenner, 1979). The home life and school life also interact and influence the child’s development. School systems are aware of their role in managing children with asthma as evidenced by Washington State’s Asthma Plan 2011-2015 (Washington State Department of Health, 2011). Since schools are collaborating with the health care system to manage asthma, they are well positioned to be involved in the screening process to identify children and adolescents with EIA.

A program developed by advanced practice nurses to screen children for EIA in schools would fit into the exosystem level. Providing education about EIA to the community may change societal norms lead to society’s acceptance of the presence of EIA in some children and dispel the stereotype that some children are lazy or simply out of shape. Identifying those children and adolescents with EIA will lead to education for the parents, children, school, and community to help overcome perceived or real barriers to quality treatment. The chronosystem in the
theoretical model will provide data in the future regarding the effects of a screening program to identify EIA.

A simple, economical screening program can be implemented in school systems once a consensus on testing methods and cutpoints is reached. Further research is needed to first develop a valid questionnaire that will screen out children and adolescents without any signs or symptoms of EIA, thus decrease the burden of screening all schoolchildren. More research is needed to compare the screening potential of the three-minute step test with the six-minute FRAST. This could be accomplished by future studies comparing EIA diagnostic outcomes following screening of the three-minute and six-minute FRAST utilizing a cutpoint of a 10% decline in FEV. Receiver operating characteristic (ROC) is an analysis procedure that could be utilized in this type of further work to establish specificity and sensitivity levels of each test (van Leeuwen et al., 2007). ROC curves provide a graphical method for studying the effects of different cutpoints on the performance (sensitivity and specificity) of a screening test and provide a method for comparing competing screening tests.

Until further trials are completed, the author suggests utilizing the three-minute step test while monitoring heart rate to achieve appropriate exertion level, and referring all children and adolescents with a 10% decrease in FEV1 after exercise challenge to a health care provider for definitive diagnosis of EIA. Definitive diagnosing methods may include eucapnic voluntary hyperpnea, body plethesmography, and Mannitol challenge (Weiler, et al., et al. 2010).

Incorporating an efficient and safe screening program into physical activity or science class, while utilizing school nurses, nursing students, teachers, and parent volunteers, may lead to identification of children with unknown EIA. This will lead to the education of all students and
families on the importance of proper identification and treatment of EIA as well as chronic asthma (Seear, 2005).

**Recommendations**

Future studies are needed in order to determine the prevalence of EIA in children and adolescents. Standard criteria for preliminary screening, as well as testing measures that are feasible, economical, and mobile will empower schools to screen children as part of physical education class and refer students for diagnosis and treatment. Bridging the research community of nursing and medical scientists, school systems, healthcare providers, and families illustrates Bronfenbrenner’s theory regarding children and adolescents with EIA.

The Joint Task Force of Practice Parameters suggest using a six minute exercise challenge, noting 10% decrease in FEV$_1$ at two consecutive time points (at three and six minutes of exercise) as a positive indicator of EIA (Weiler, et al., Anderson & Randolph, 2010). More research is needed in utilizing the 3-minute step test, maintaining a rate of 30 steps per minute, while monitoring heart rate in the participants throughout the exercise challenge. Evaluating for a change in FEV$_1$ is suggested. Three studies used the criteria of a 10% decrease in FEV$_1$ yielding an average of 18% positive for EIA (De Baets, et al. 2005; Ogston and Butcher 2002; Seear, et al. 2005). Kaslovsky, et al. (2005) used the cutpoint of 12% decrease in FEV$_1$ and saw a 33% prevalence of EIA. A study using the 3-minute step test and the criteria of a 10% decrease in FEV$_1$ provides a simple and inclusive method for the initial screening of children and adolescents. Schools are an ideal setting in which to conduct screening for EIA, much as the current screenings for hearing and vision occur. In order to implement such a program in schools, the program design must be simple, feasible, and economical. The 3-minute step test is
proposed after more research is conducted, as it is inexpensive, portable, and more time efficient as a primary screening tool than the 6-minute exercise challenge.

Since the prevalence of EIA amongst children and adolescents in the U.S. is not accurately documented, screening in the schools should be implemented in order to allow referrals for diagnostic confirmation. Prevalence data may be abstracted from school system screening programs to increase awareness of EIA among families, providers, and schools. Once a health care practitioner confirms a diagnosis of EIA, education and treatment may begin. Controlling the symptoms of EIA may lead to more activity among children and thus improve overall quality of life.

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Table 1. Summary of study characteristics.

<table>
<thead>
<tr>
<th>Author</th>
<th>Test Used</th>
<th>Random Sample of Children or Children with Presumed EIA</th>
<th>Mean (Range) Age of Subjects</th>
<th>Sample Size</th>
<th>Criteria for positive diagnosis of EIA</th>
<th>Results: % of children meeting criteria for EIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abu Hasan</td>
<td>6 minute ECT on treadmill</td>
<td>Presumed EIA</td>
<td>14, (6-21)</td>
<td>142</td>
<td>15% ↓ in FEV$_1$</td>
<td>7%</td>
</tr>
<tr>
<td>De Baets</td>
<td>6 minute ECT - FRAST</td>
<td>Random</td>
<td>9.2, (7-11)</td>
<td>15,241</td>
<td>15% ↓ PEFR</td>
<td>7.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10% ↓ PEFR</td>
<td>16.9 %</td>
</tr>
<tr>
<td>Kaslovsky</td>
<td>6 minute ECT on treadmill</td>
<td>Presumed EIA</td>
<td>11.2, (8-16)</td>
<td>19</td>
<td>12% ↓ FEV$_1$</td>
<td>33%</td>
</tr>
<tr>
<td>Ogston</td>
<td>15 minute skiing at race pace</td>
<td>Random</td>
<td>15, (13-18)</td>
<td>100</td>
<td>10% ↓ in FEV$_1$</td>
<td>22%</td>
</tr>
<tr>
<td>Pitsios</td>
<td>6 minute ECT</td>
<td>Random</td>
<td>9.8, (8-12)</td>
<td>268</td>
<td>15% ↓ PEFR</td>
<td>4.1%</td>
</tr>
<tr>
<td>Seear</td>
<td>10 minute ECT on treadmill</td>
<td>Presumed EIA</td>
<td>11.5, (8-14)</td>
<td>52</td>
<td>10% ↓ in FEV$_1$</td>
<td>15%</td>
</tr>
<tr>
<td>Tancredi</td>
<td>6-8 minute ECT on treadmill</td>
<td>Presumed EIA</td>
<td>12.9, (10-15)</td>
<td>154</td>
<td>15% ↓ in FEV$_1$</td>
<td>14.9%</td>
</tr>
<tr>
<td></td>
<td>3 minute step test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.6%</td>
</tr>
</tbody>
</table>

ECT=Exercise challenge test, FRAST=Free running asthma screening test, FEV$_1$=Forced expiratory volume in first second, PEFR=Peak expiratory flow rate
Figure 1. Literature flow diagram.

- 67 articles
- 50 articles
- 39 articles
- 28 articles
- 21 articles
- 18 articles
- 7 primary studies

- 17 articles excluded because they focused on children with diagnosed asthma, but not suspected for EIA
- 11 articles excluded because they focused on elite athletes
- 11 articles excluded because they addressed testing with drugs or chemicals (Mannitol, Methocholine) or invasive tests (laryngoscopy) or tests available in specialized pulmonary labs (impulse oscillometry, eucapnic volume hyperventilation-EVH)
- 7 articles excluded because diagnosis of EIA was based on additional information such as biological markers (Nitric Oxide) or allergens
- 3 articles excluded because they were individual case studies or commentaries not substantive to topic
- 11 articles excluded from study abstract but useful companion papers
Figure 2. Adaptation of Bronfenbrenner’s Ecological Model for EIA screening