



Association of exercise-induced wheeze and other asthma symptoms with emergency department visits and hospitalizations in a large cohort of urban adolescents



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ABSTRACT

Objective: Exercise-induced wheeze (EIW) has been found to be associated with asthma-related urgent care in school-aged children. Despite asthma's high prevalence and morbidity among adolescents, this association has not been examined in adolescents. We tested the association of EIW and other asthma symptoms to asthma-related ED visits and hospitalizations in urban adolescents with probable asthma. We hypothesized that EIW would be associated with urgent care.

Methods: In this cross-sectional study 30,467 high school students (mean age = 16.0) from 49 NYC schools completed two brief validated measures, one assessing probable asthma and the other the frequency of six asthma symptoms over the past year. Adolescents also reported if in the past year they had an asthma-related ED visit or hospitalization. Analyses presented here included students with probable asthma (n = 9149). Using logistic regression, we modeled each asthma symptom as a function of ED visits and hospitalizations adjusting for sex, age, race/ethnicity and asthma severity. Multivariable models included all symptoms to account for the potential interaction between symptoms.

Results: Among adolescents with probable asthma, EIW was associated with ED visits and hospitalizations. In multivariable models wheeze without a cold, chest tightness, night waking, but not EIW, were significantly associated with both ED visits and hospitalizations.

Conclusions: Unlike findings with younger children, EIW does not appear to be associated with ED visits and hospitalizations among urban adolescents with probable asthma. Instead, symptoms, such as chest tightness and night waking, appear to be important at identifying adolescents at risk for asthma-related urgent care.

1. Introduction

In the United States, relative to elementary school aged children, adolescents suffer from a higher prevalence of asthma [1–4], more frequent asthma exacerbations [5], and have a higher mortality rate due to asthma [2,5]. Asthma exacerbations can be dangerous and costly, with one exacerbation potentially increasing annual costs threefold [6–8]. As such, exacerbations impose a significant burden on children, their families, and the health care system. A major challenge for asthma management is to develop effective methods for identifying risk factors that predict asthma exacerbations, which will allow us to intervene to prevent these exacerbations.

Epidemiologic research has clearly shown that socio-economic

status, race, access to preventive medical care and geography are good overall predictors of the risk of exacerbation and emergency treatment [9]. Urban areas have a disproportionate burden of the disease [10,11]. In New York City (NYC), children living in lower income neighborhoods are up to 17 times more likely to be admitted into the emergency department (ED) or hospitalized for an asthma-related incident than those living in wealthy neighborhoods [12]. These socioeconomic predictors, however, are not very useful for predicting risk for exacerbation in individual children.

While increased symptom frequency, resulting both from poor asthma control and more severe disease is a clear indicator of risk for ED visits and hospitalizations, there is also evidence that certain asthma phenotypes have an increased likelihood of these morbidities [13].

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Identifying specific asthma symptoms that could indicate increased risk for ED visits and hospitalizations, independent of increased symptom frequency, could be useful in the clinic, as well as for public health interventions. In two cohort studies of NYC elementary school age children, we found that children with asthma reporting exercise-induced wheeze (EIW) were more likely to have urgent medical visits for asthma than children with asthma without a report of EIW [14,15]. Strikingly, these associations were independent of other indicators of asthma severity (e.g., frequency of symptoms, lung function) and other asthma symptoms. We also observed that EIW was more common for children with asthma living in neighborhoods with a higher burden of ED visits than among those children in neighborhoods where ED visits were less common [14].

While these findings suggest that asking about EIW may be a useful tool for identifying elementary school age children who are at increased risk for asthma-related urgent medical visits, the relevance to high school age children with asthma, whose asthma morbidity and asthma care differ from elementary school aged children [1–5,16,17], has not been investigated. Among a cohort of NYC high school students with asthma, we hypothesized that EIW would be associated with asthma-related emergency department visits and overnight hospitalizations, independent of other indicators of asthma control.

2. Methods

2.1. Data collection procedures

In this cross-sectional study 30,468 high school students (mean age = 15.98) from 49 NYC public high schools housed in 19 school buildings were screened for eligibility for a randomized control trial (RCT) to test the efficacy of an asthma intervention for high school students [18]. Schools were selected to participate in the RCT if they served those most at risk for asthma, namely, lower income (i.e., at least 50% of the student body received free or reduced lunch) and primarily African-American and/or Hispanic students.

To identify eligible students for the larger study from which the data for this study is drawn, students in each school completed a case detection survey in class during the fall semester each year for four consecutive years; this study utilizes the case detection data from Study Years 2–4 (2009–2011). The institutional review boards of New York University School of Medicine, Columbia University College of Physicians and Surgeons, and the New York City Department of Education (DOE) approved all study procedures, including a waiver of parental consent for the case detection survey.

Trained study personnel distributed to the students letters describing case detection purpose and procedures. Students were asked to bring the letters home to caregivers who could call the investigators with questions. Several days later, students were asked to complete the case detection survey in class with the assistance of trained study personnel who visited each class a second time to allow absent students to complete the survey. For this study, we analyzed responses from those students who reported signs and symptoms of probable asthma, resulting in a sample size of 9149.

2.2. Measures

2.2.1. Asthma status and severity

Students reported if they were ever diagnosed with asthma. The case detections survey included a brief validated measure assessing *probable asthma* [19]. Students first indicated how often they experienced (0 = Never, 1 = Sometimes, 2 = A lot) seven signs and symptoms of asthma: (1) noisy or wheezy breathing, (2) difficulty taking a deep breath, (3) difficulty stopping coughing, (4) chest tightness or chest pain after running or exercising, (5) night wakening due to coughing, (6) night wakening due to trouble breathing, and (7) coughing when running, climbing stairs or exercising. Those who

Table 1

Descriptive statistics of study participants by asthma characteristics.

	Full Sample ^a (N = 9149) % (n) ^a	Asthma-related ED Visit (N = 1253) % (n) ^a	Asthma-related Hospitalizations (N = 613) % (n) ^a
Sex			
Male	33.2% (3038)	28.0% (352)	30.5% (187)
Female	59.4% (5440)	64.7% (811)	62.8% (385)
Age, mean (SD)	15.94 (1.31)	15.88 (1.35)	15.97 (1.45)
Grade			
9	31.1% (2847)	33.2% (416)	32.5% (199)
10	30.5% (2789)	28.8% (361)	29.5% (181)
11	26.9% (2459)	26.0% (326)	25.6% (157)
12	8.7% (794)	9.3% (117)	9.6% (59)
Ever diagnosed with Asthma			
Yes	40.3% (3685)	81.0% (1015)	82.1% (503)
No	58.5% (5350)	17.9% (224)	17.0% (104)
Asthma Severity^b			
Mild	31.3% (2869)	14.4% (181)	13.5% (83)
Medium	38.0% (3477)	28.6% (358)	26.8% (164)
High	25.2% (2302)	50.3% (630)	53.0% (325)
Asthma-related ED Visit			
Yes	13.7% (1253)	100% (1253)	74.7% (458)
No	81.6% (7466)		24.0% (147)
Asthma-related Hospitalization			
Yes	6.7% (613)	36.6% (458)	100% (613)
No	88.7% (8117)	62.3% (780)	
Race/Ethnicity			
African/African American/Black/Caribbean	31.0% (2835)	33.1% (415)	36.1% (221)
Black, not Latino			
Asian/Asian American/Pacific Islander	5.5% (499)	2.8% (35)	2.9% (18)
Hispanic/Latino	41.2% (3766)	41.4% (519)	40.3% (247)
White/Caucasian/European American, not Latino	3.8% (348)	2.6% (32)	2.0% (12)
Other	7.8% (717)	7.2% (90)	7.0% (43)
Multi race/ethnicity	9.2% (842)	12.5% (156)	11.7% (72)

^aThe full sample of those with probable asthma, defined as reporting three or more signs and symptoms of asthma.

^a Percentages may not add to 100% because of missing data.

^b Tertiles determined by total asthma probability score, where: 0 = fewer than 3, 1 = 3, 2 = 4 and 5, and 3 = 6+.

Table 2

Asthma symptom frequencies by probable asthma and asthma-related ED visits and hospitalizations.

Symptom in Past Year (yes/no)	Probable Asthma ^a (n = 9149)	Asthma-related ED Visit (n = 1253)	Asthma-related Hospitalization (n = 613)
Persistent Cough	53.9% (4933)	68.5% (859)	69.3% (425)
Wheeze No Cold	36.4% (3331)	62.2% (780)	64.1% (393)
Exercise Wheeze	58.3% (5334)	75.0% (940)	74.0% (454)
Exercise Cough	61.9% (5669)	73.5% (922)	73.0% (448)
Chest, Tight, Heavy	66.9% (6123)	86.4% (1083)	86.7% (532)
Wake up cough	38.6% (3535)	64.4% (808)	68.6% (421)

^a Probable asthma is defined as citing three or more probable asthma symptoms.

reported at least three symptoms were classified as having probable asthma. Endorsement of three or more symptoms was found to have a sensitivity of 80% and specificity of 70% against clinical data [19]. An *asthma severity* score was computed by summing each of the seven

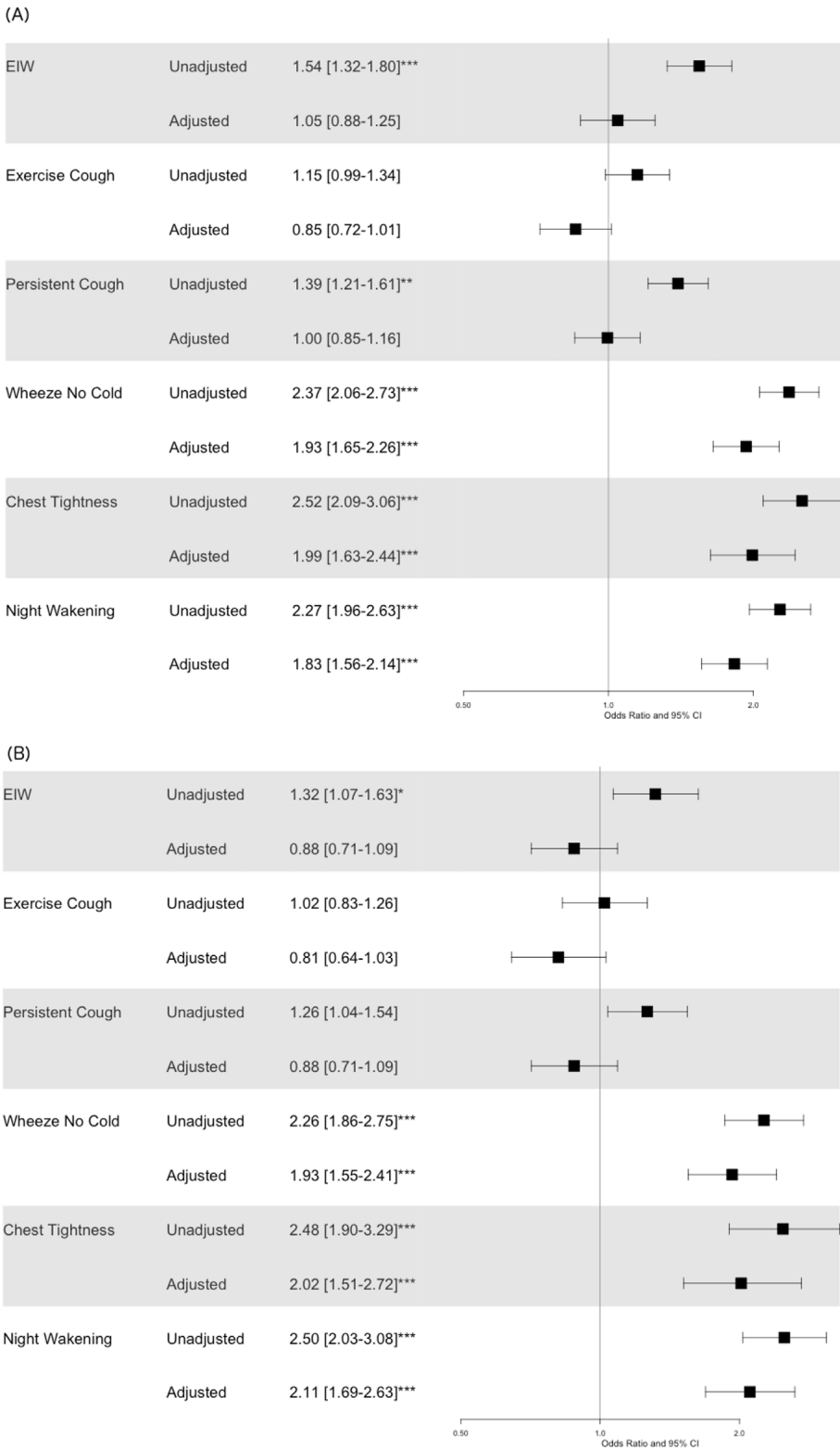


Fig. 1. Unadjusted and adjusted associations of asthma symptoms and asthma related emergency department visits (A) and overnight hospitalizations (B).

(possible range = 0–14), which was then divided into tertiles based on the score's distribution.

2.2.2. Asthma symptoms

Students reported the frequency (Never or rarely [0–4 days/year], 5 or more days a year [5–35 days/year], 3 or more days a month [36–149 days/year], 3–6 days a week [150–300 days/year], every day but not all

the time, every day and all the time) in the past 12 months of the following asthma symptoms: (1) persistent cough; (2) wheeze without a cold; (3) wheeze during exercise; (4) cough during exercise; (5) chest feeling tight or heavy; and (6) night wakening due to wheeze, cough, or trouble breathing [20]. Responses were collapsed into yes/no to account for potential recall bias and under the hypothesis that even rare symptoms can induce exacerbations that may require an urgent medical visit.

Table 3
Prevalence of asthma characteristics by potential effect measure modifiers (%).

		Total (n)	ED Visit	Hospitalization	EIW	Wheeze, No cold	Chest Tight, Heavy	Wake up cough
Sex	Boys	3038	11.59***	6.16	58.20	36.93	62.61***	34.10***
	Girls	5440	14.91***	7.08	58.69	36.19	69.72***	41.07***
Age	Youngest	3034	14.07	6.86	58.67	35.27 [#]	65.46 [#]	38.79
	Middle	2926	12.41	5.81	57.83	35.85	67.22	37.83
	Oldest	2861	14.75	7.10	58.23	38.10 [#]	68.16 [#]	39.25
Neighborhood Asthma Prevalence	1st Quartile	1858	12.33 ⁺	5.65 ⁺⁺	56.24 ⁺	36.92	65.66 ⁺	37.78
	2nd Quartile	1901	15.52	6.89	60.34	35.14	66.39	38.56
	3rd Quartile	1747	14.08	7.04	60.33	36.12	68.46	41.16
	4th Quartile	1460	15.34 ⁺	8.22 ⁺⁺	60.27 ⁺	38.90	69.25 ⁺	38.49

*P < .05, **P < .01, ***P < .001 for comparisons between sexes.

[#]P < .05, [#]#P < .01, [#]#P < .001 for comparisons between youngest and oldest participants.

2.2.3. Urgent asthma-related health care

Students indicated if in the prior year they had asthma-related (1) ED visits and (2) overnight hospitalizations.

2.2.4. Demographic characteristics

Students reported their sex, race/ethnicity, school grade, and date of birth. Date of birth was used to calculate age, which was then divided into tertiles for analysis, enabling comparison between the oldest and youngest students. Adolescents were assigned a neighborhood asthma prevalence based on their zip code, which was linked to data reported by NYC Department of Health and Mental Hygiene [21].

2.3. Statistical analysis

2.3.1. Preliminary analyses

Because students in a given school may not be representative of their home neighborhoods, potential race/ethnicity differences between the sample and borough census data were explored. To account for potential symptom clustering, the correlation and multicollinearity of asthma symptoms and other variables was assessed through a correlation matrix and calculation of variance inflation factors (VIF) for each symptom.

2.3.2. Model testing

Analyses were conducted among those with probable asthma to determine the association between asthma symptoms and urgent medical visits. Odds Ratios with a 95% confidence interval were calculated using each asthma symptom for asthma-related ED visits and overnight hospitalizations through logistic regressions with only the asthma symptom tested and the outcome (e.g., report of ED visit or overnight hospitalization), controlling for sex, age, race/ethnicity, and asthma severity. Next, multivariable logistic regressions that included all asthma symptoms were conducted to account for potential interaction between asthma symptoms, while controlling for the same potential confounders. To assess potential effect measure modification, the same multivariable logistic regressions with all asthma symptoms and confounders were run among specific subsets of potential modifiers: sex (males and females); age (in tertiles); and neighborhood asthma prevalence (in quartiles). All statistical analyses were performed in R [22], and figures were produced with the package “forestplot” [23].

3. Results

3.1. Preliminary analyses

The majority of students from the full sample (71.9%) lived in zip codes different from where they attended school. Proportionally, the students surveyed were more likely report being of African-American race and Latino ethnicity than would be expected based on 2012 census data for the neighborhoods in which they reside if the school

demographics proportionally represented these neighborhoods (Supplemental Table 1).

Table 1 lists the demographic characteristics for those with probable asthma. The majority of those with probable asthma reported EIW in the past year (58.3%; Table 2). Analysis of correlations between symptoms and variance inflation in models suggests little similarity between symptoms and no evidence for multicollinearity (Supplemental Table 2; Supplemental Table 3). Less than five percent of the overall sample reported urgent medical visits, with ED visits about twice as common as overnight hospitalizations; among those with probable asthma, 13.7% reported asthma-related ED visits (n = 1253) and 6.7% reported asthma-related overnight hospital visits (n = 613).

3.2. Model testing

Among those children with probable asthma, EIW was associated with asthma-related ED visits (P < .001) and overnight hospitalizations (P = .011), adjusting for sex, age, and asthma severity in multivariable logistic regressions (Fig. 1a and b). However, in similar models that also included other asthma symptoms, EIW was no longer significantly associated with ED visits or overnight hospitalizations. In these models, wheeze without cold symptoms (P < .001), chest tightness (P < .001), and night waking from cough (P < .001) were independently associated with ED visits (Fig. 1a). The same symptoms were also associated with overnight hospitalizations (Fig. 1b).

Table 3 shows the prevalence of asthma characteristics (e.g., ED and overnight hospitalizations and symptoms) by potential effect measure modifiers, revealing some differences in burdens of disease. Models with all symptoms were therefore tested stratifying by potential effect modifiers. While there were more females than males (59% vs. 41%) with probable asthma, there did not appear to be any effect modification by sex (Fig. 2a and b). Similarly, there was no consistent effect modification by age (Fig. 3a and b) or by the asthma prevalence in the neighborhood where the child lived (Fig. 4a and b).

4. Discussion

In this cross-sectional study of NYC high school students with probable asthma, emergency department visits and hospitalizations for asthma in the past year were common. In support of our hypothesis, we observed that EIW was associated with both asthma-related ED visits and overnight hospitalizations independent of sex, age, and asthma severity. However, when other self-reported asthma symptoms were included in the models, EIW was no longer associated with these urgent medical visits. Three symptoms, however, did remain independently associated with both ED visits and overnight hospitalizations: wheeze without cold symptoms; chest tightness and heaviness; and nighttime symptoms. While wheeze has previously been found to be predictive of urgent care, the significance of the study results regarding chest tightness and nighttime symptoms may be of value in the search for

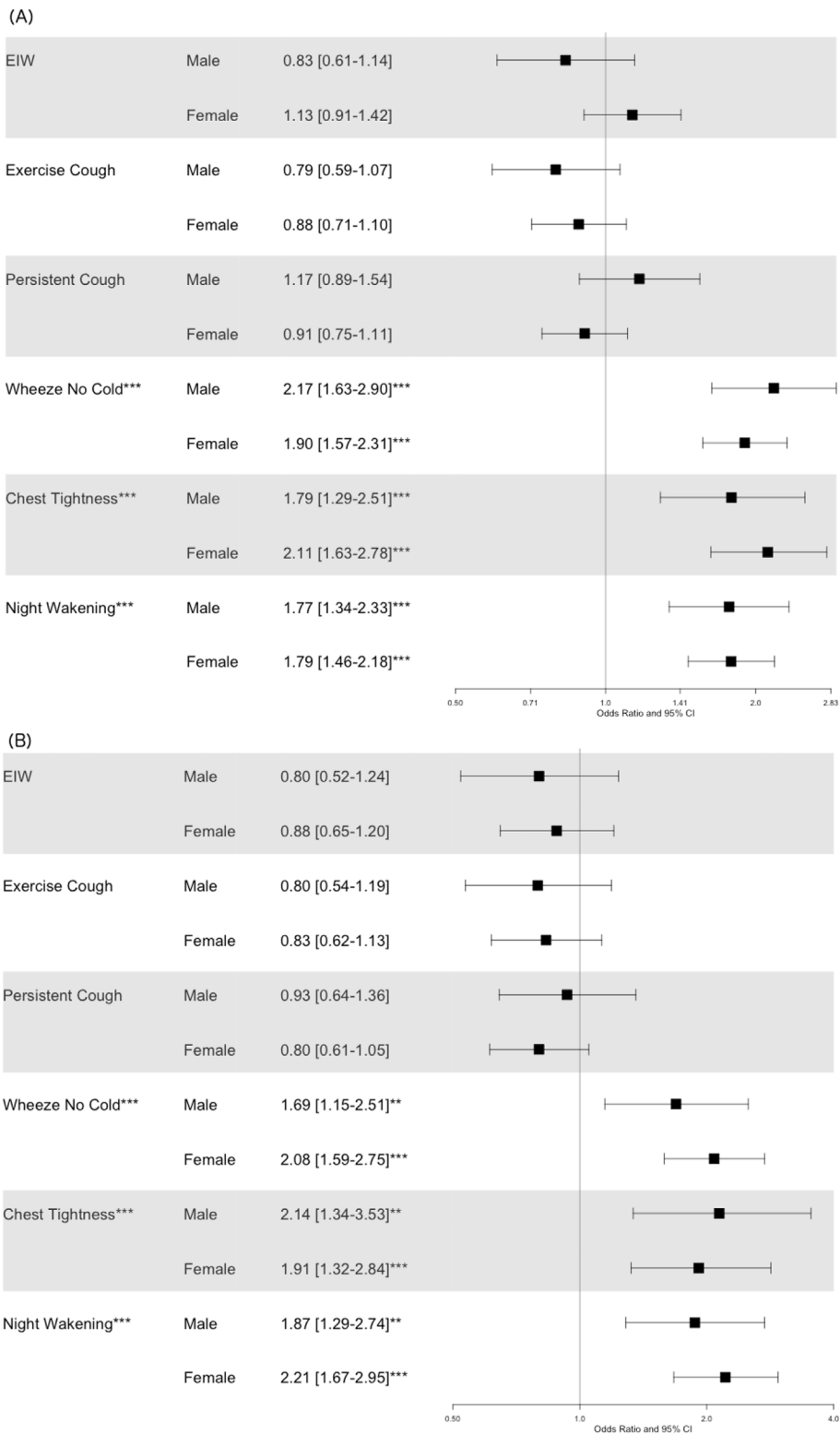


Fig. 2. Adjusted associations of asthma symptoms and asthma related ED visits (A) and overnight hospitalizations (B) by sex.

symptoms that patients can recall easily that are associated with urgent care visits. These findings could be of potential interest to clinicians as they indicate under-treatment of asthma, suggesting the need to use controller medications (e.g., inhaled corticosteroids) and/or beta-agonists prior to exercise.

There are several possible reasons why we observed a different pattern of symptoms associated with asthma-related ED visits and hospitalizations in these adolescents than we have observed in younger

children. One of the most likely explanations is that the management of asthma among high school children differs from that among elementary school children in ways that specifically impact the relevance of EIW as an asthma trigger [16,17]. It is plausible that exercise-induced asthma is better managed than other asthma phenotypes because limiting exercise is qualitatively easier than other asthma-phenotype management requirements. Adolescents regardless of asthma status are, on average, more sedentary than elementary school aged children [24,25], making

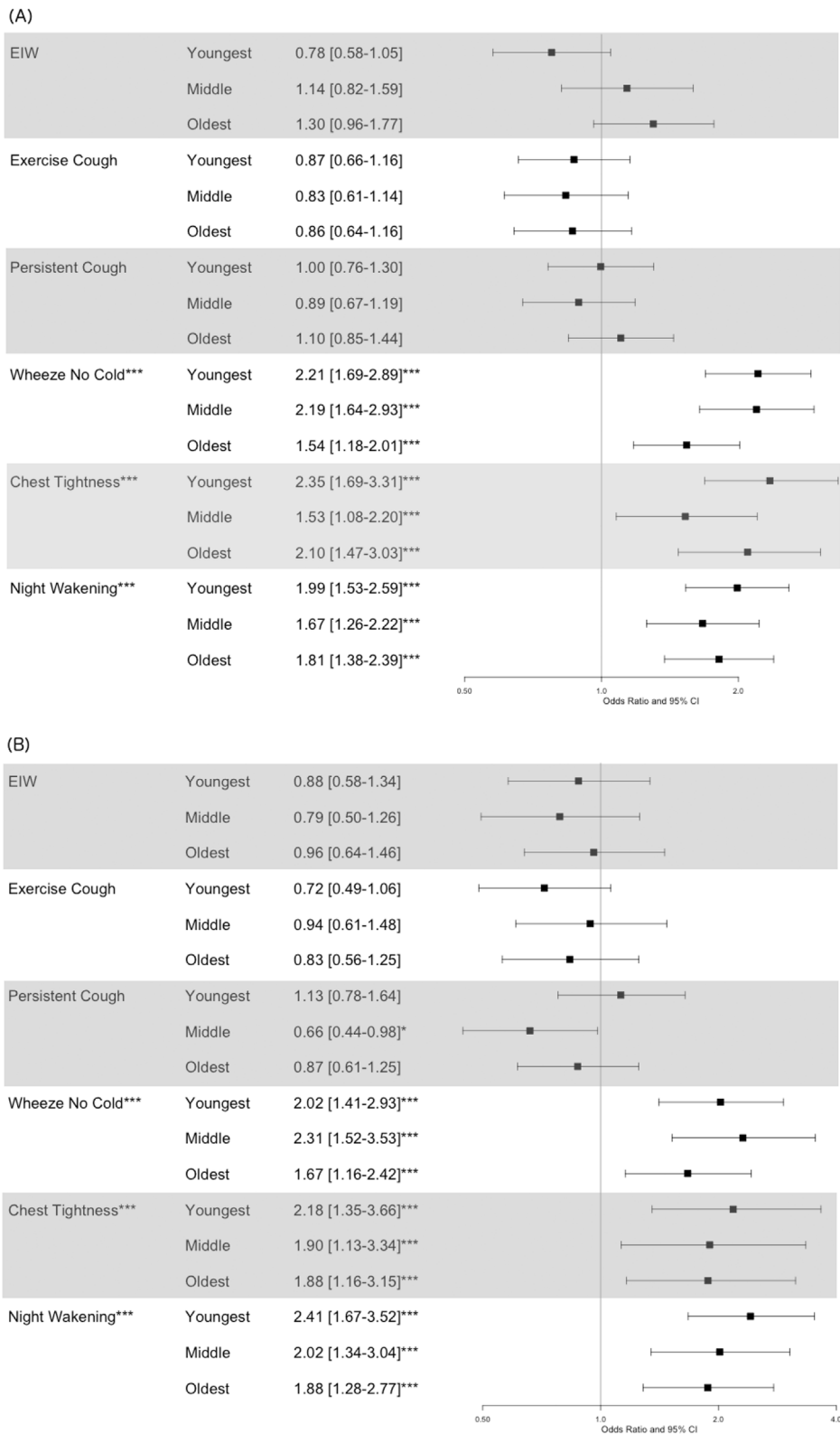


Fig. 3. Adjusted associations of asthma symptoms and ED visits (A) and overnight hospitalizations (B) by age.

it more easier for the adolescent with asthma to avoid exercise. However, it is well known that youth with asthma are less physically active than peers without asthma [26–28], and that this inactivity may develop during adolescence [29]. Physical inactivity may be the consequence of the child feeling that exercise is unpleasant [30,31], and/or feeling anxious about the risk of an exacerbation when exercising [30]. It is also possible that if the adolescents have had asthma for an

extended time, they may have been more likely to receive medications that could ameliorate symptoms or prevent exacerbations in the first place. For many people with asthma who experience exercise-induced symptoms, taking a bronchodilator before exercise can dramatically lower the risk of exacerbation [32]. Another possible explanation for differences in what we observed for the adolescents as compared with the younger children is that the

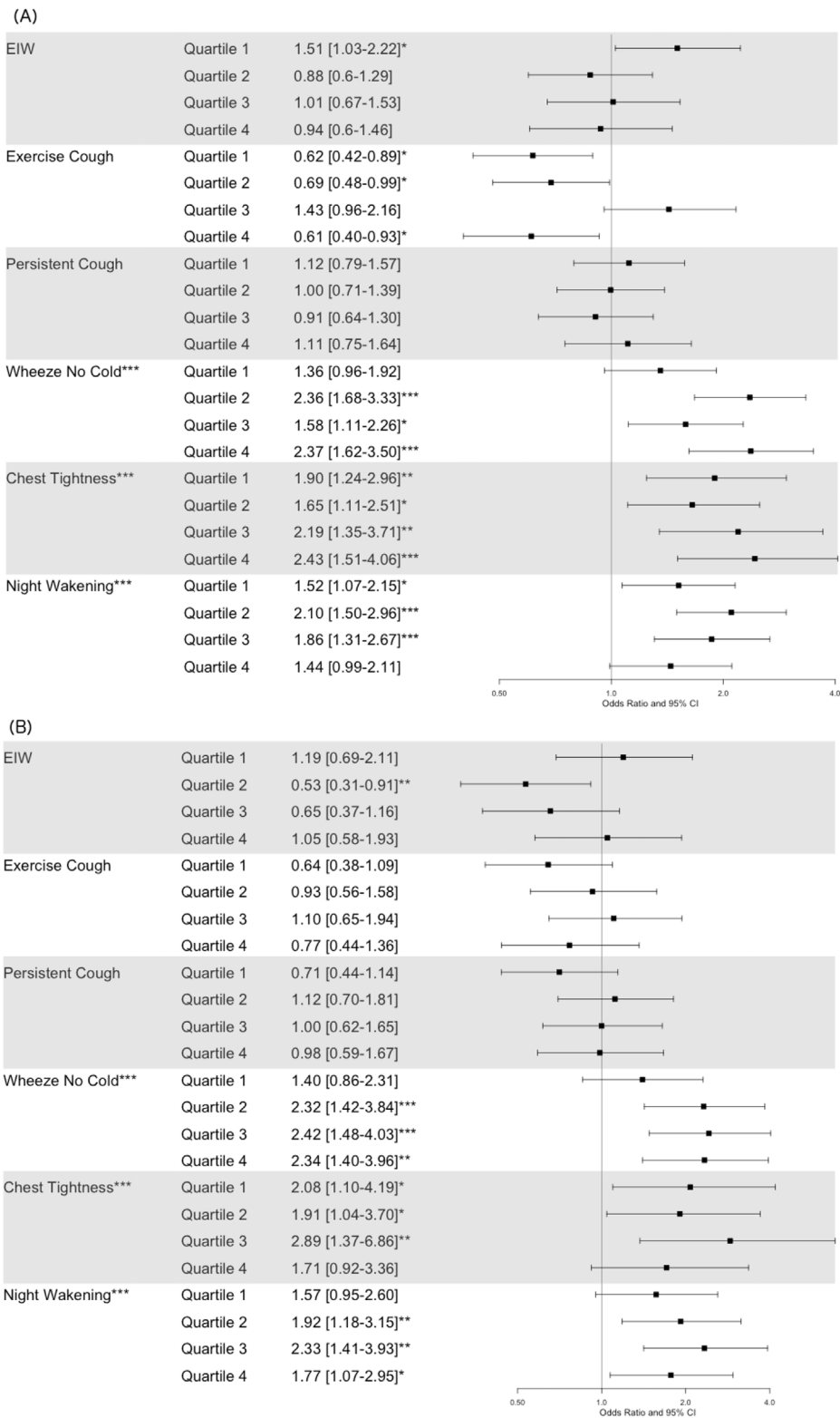


Fig. 4. Adjusted associations of asthma symptoms and ED visits (A) and overnight hospitalizations (B) by neighborhood asthma prevalence.

predominance of asthma phenotypes changes as children get older. Most notably, post puberty, there is a shift in asthma burden from predominately males to females [33], and the onset of the obese asthma phenotype [34], which might have different dominant risk factor patterns. Obesity associated asthma has been shown to be associated with wheeze and shortness of breath [35,36]; it is also less closely linked with exercise-induced bronchial hyper-reactivity, which underlies EIW, than allergic asthma, which is the dominant asthma phenotype in

younger children [37]. Also important is the fact that obesity-related asthma is associated with more sleep disturbance [35,36], which may account for our findings regarding nocturnal symptoms.

The prevalence of probable asthma in the sample was relatively high (30%), which we believe is due to the sample not being generalizable to the total population of NYC adolescents. Rather, because the parent study was testing the efficacy of a school-based asthma intervention, we intentionally focused on schools serving adolescents at the

greatest risk for asthma and asthma-related morbidity, namely African American and Latino students from low-income families. In fact, our preliminary analyses showed that this coupled with the fact that NYC students travel out of their neighborhoods to attend high school, resulted in a sample that was proportionally more Hispanic and African-American than their home neighborhoods.

There are several limitations of this study. The study's cross-section design precludes conclusions about directionality of the associations or causal inferences between specific asthma symptoms and urgent medical visits. Questionnaire responses, additionally, are subject to reporting biases, potentially influencing the results of this study. Importantly, although exercise-wheeze was reported, participants did not report a measure of exercise, limiting the study's ability to understand potential self-regulation of symptoms, which would attenuate the association between exercise-wheeze and urgent medical visits. Although EIW is associated with BMI and obesity, as well as vocal cord dysfunction, such data were not collected. Additionally, since type of medication taken by students was not collected, study findings cannot be related to current asthma medication. An important difference between this study and our previous studies in younger children was that the high school students reported symptoms about themselves, while the parents reported symptoms for the elementary school children. While these approaches are well validated and the most appropriate at these ages, it still may influence the findings. While we do not anticipate the associations between asthma symptoms and urgent medical visits found in this study would change over time, the data used in this study were part of a larger longitudinal trial that began several years ago. Therefore, it is possible that factors not measured in this study that are unique to the time period of data collection account for some of the associations found here. Our definition of having EIW excluded adolescents who may have experienced EIW very infrequently (i.e., 1–4 days per year); it is plausible that if the definition of EIW included rarely-occurring EIW, results may have been different.

In conclusion, contrary to what we have observed among school age children with asthma in NYC, EIW did not appear to be a primary predictor of ED visits and hospitalizations for asthma among adolescents, at least not independent from other symptoms. While our study design did not permit determining the cause for the difference observed between the younger and older children (e.g., possibly related to asthma management exercise avoidance, or changing phenotypes), our findings do suggest important shifts in ED- and hospitalization-related asthma morbidity and asthma triggers as children age. While future prospective studies are needed to demonstrate the predictive relevance of wheeze without cold symptoms, chest tightness and heaviness, and nighttime symptoms to ED visits and hospitalizations, these symptoms, in conjunction with measures of poor asthma control, may be considered important in identifying at-risk urban adolescents and potentially other similar populations with a high burden of these morbidities.

Conflicts of interest

The authors have no conflicts of interest associated with this manuscript.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.rmed.2018.01.005>.

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Supplemental Information

Title: Association of Asthma Symptoms with Emergency Department Visits and Hospitalizations in a Large Cohort of Urban Adolescents

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Methods

Race and ethnicity analysis. To further investigate the results of the recruitment process, students' race/ethnicity was compared to their home borough race/ethnicity proportions using Pearson's Chi-squared test. Specifically, we compared the proportion of African-American (not Hispanic/Latino) students and probable asthmatics in each borough to the proportion of adolescents aged 15-17 in the 2010 census in the same borough. This same analysis was repeated for Hispanic/Latino students.

Correlation of symptoms and multicollinearity. A correlation matrix of asthma symptoms was constructed to investigate the relationship between report of specific symptoms. Multicollinearity in models was additionally investigated by determining variance inflation for each symptom in full models. To do so, all symptoms and confounders were used to predict report of a specific symptom. From these logistic regressions a pseudo- R^2 (Nagelkerke, 1991) was calculated, representing the explanatory power of all other symptoms and confounders on report of a specific symptom. Variance inflation was determined from the pseudo- R^2 . Values above 5 would be of concern and merit further investigation of multicollinearity.

All statistical analyses were performed in R (Version 3.3.2; Vienna, Austria).

Results

Students from Brooklyn, Staten Island, and Queens in this sample were more African-American (non-Hispanic/Latino) and Hispanic/Latino than their home boroughs (Supplemental Table 1). Students in this from Manhattan were notably more Hispanic/Latino than the borough but less African-American. Students from the Bronx were less African-American and

Hispanic/Latino than their borough. Probable asthmatics largely did not differ in terms of race/ethnicity proportion from the students in the sample.

Supplemental Table 1. Race and ethnicity borough-level comparison of probable asthmatics, study participants, and census proportions

Borough	Data source	African-American, not Hispanic/Latino				Hispanic/Latino			
		Yes	% of sample	Probable Asthmatics-Study ^a	Study-Census ^a	Yes	% of sample	Probable Asthmatics-Study	Study-Census
Bronx	Probable Asthmatics	703	23.8%	p=0.483	p<0.001	1731	58.5%	p=0.344	p<0.001
	Study	2337	24.4%			5504	57.5%		
	Census ^b	20154	30.0%			40350	60.0%		
Brooklyn	Probable Asthmatics	1132	46.9%	p=0.693	p<0.001	633	26.2%	p=0.042	p=0.195
	Study	3346	47.4%			1704	24.1%		
	Census ^b	37627	37.2%			23726	23.4%		
Manhattan	Probable Asthmatics	187	18.6%	p=0.002	p<0.001	673	66.8%	p<0.001	p<0.001
	Study	535	14.6%			2670	72.6%		
	Census ^b	7865	20.5%			17297	45.2%		
Staten Island	Probable Asthmatics	126	21.2%	p<0.001	p<0.001	196	32.9%	p=0.149	p<0.001
	Study	765	35.0%			680	36.3%		
	Census ^b	2516	12.5%			4403	22.0%		
Queens	Probable Asthmatics	105	28.8%	p=0.082	p=0.070	145	35.2%	p=0.238	p<0.001
	Study	455	24.3%			680	36.3%		
	Census ^b	18506	22.5%			26352	32.0%		

^a Pearsons's Chi-squared test with Yates's continuity correction.

^b 2010 Census data of adolescents aged 15-17.

Asthma symptoms displayed low correlation (Supplemental Table 2) and there is no evidence of multicollinearity in variance inflation for each symptom (Supplemental Table 3).

Supplemental Table 2. Correlation Coefficients^a between Asthma Symptoms^b

	Persistent Cough	Wheeze No Cold	Exercise Wheeze	Exercise Cough	Chest Tight, Heavy	Wake up cough
Persistent Cough	1.00	0.28	0.23	0.26	0.25	0.33
Wheeze No Cold	-	1.00	0.39	0.23	0.29	0.33
Exercise Wheeze	-	-	1.00	0.39	0.31	0.21
Exercise Cough	-	-	-	1.00	0.28	0.21
Chest, Tight, Heavy	-	-	-	-	1.00	0.28
Wake up cough	-	-	-	-	-	1.00

^a Corresponds with Pearson's product-moment correlation.

^b Symptoms are binary (1=reports symptom in the past year; 0=does not report symptom in the past year).

All correlations are significant at $p < 0.001$.

Supplemental Table 3. Variance Inflation in models^a

Symptoms^b	VIF
EIW	1.55
Exercise Cough	1.38
Persistent Cough	1.30
Wheeze No Cold	1.51
Chest Tightness	1.38
Night Wakening	1.47

^a Models for VIF include all symptoms and covariates as regressions in data analysis.¹

^b Symptoms are binary (1=reports symptom in the past year; 0=does not report symptom in the past year).

¹ Persistent Cough, Wheeze No Cold, Exercise Wheeze, Exercise Cough, Chest Tightness, Wake up cough, Asthma Severity, Race/ethnicity, gender, age tertile.