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Changes in asthma severity in the first year of school and difficulty learning to read

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ABSTRACT

Objective: Asthma is a risk factor for poor early reading in children, for reasons that are unclear. This analysis examines the relationship between changes in asthma severity during the first year of school and being in the lowest quartile of reading achievement after 1 year of school.

Methods: We used previously unreported data from our cohort study. Parent interviews and teacher questionnaires enquired about asthma and covariates of achievement at school entry (T1) and 12 months later (T2). Asthma severity scores at T1 and T2 showed that in 27 of 51 children with asthma, symptoms improved over the year, whereas in 24, symptoms persisted or worsened. Word and story reading were assessed at T1 and T2. We compared reading achievement at both timepoints between children with asthma and children who had no reported respiratory symptoms between birth and T2 (controls, $N=74$), and between those with persistent versus improved symptoms.

Results: More children with asthma than controls were in the lowest quartiles for reading. Further, significantly more children in the persistent group compared to the improved group were in the lowest quartiles for word reading (58 versus 30%, respectively) and story reading (54 versus 26%, respectively). School absences, increased behavior problems, stressful life events or parental mental health were not associated with the differences in either comparison. Logistic regression modeling identified persistent asthma as the most important variable associated with being in the lowest quartile of reading after 1 year in school.

Conclusions: Active asthma symptoms during early school may influence early reading achievement.

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Cohort study; children; achievement; reading; literacy; interviews; persistent asthma

Abbreviations

ISAAC	International Study of Asthma and Allergies in Childhood;
SES	socioeconomic status;
NZDep	New Zealand Deprivation Decile Score; a national measure of socioeconomic status linked to small residential areas (meshblocks) within New Zealand;
WIAT-II	Wechsler Individual Achievement Test-Second Edition;
NHIS	National Health Interview Survey;
BPI	Behavior Problem Index;
WHO-5	World Health Organization 5-Item Wellbeing Index;
NZ	New Zealand;
T1	Time 1 for study data acquisition (school entry);
T2	Time 2 for study data acquisition (12 months after school entry);

Improved

Group Group whose asthma symptoms reduced by >10% at T2 compared to T1;

Persistent

Group Group whose asthma symptoms increased or persisted at T2 compared to T1

Introduction

Asthma is common in childhood and has been associated with general low achievement, including reading and math (1–5).

In our previous study (4), we looked at the proportion of children in the lowest quartile of word reading and story reading after the first year of school. In that study, we reported that children who entered school with asthma were, at the end of the first year in

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school, more likely to be more than 6 months behind other participants in reading words and books, but not in math. In prospective analyses, the differences were not attributable to variables we measured at the start of school, including low intelligence, low reading readiness, gender, family composition, socioeconomic status, minority status or asthma severity assessed at that timepoint.

It is important to consider that asthma severity is not a constant during this age period (6). Changes in asthma severity, activity or control during the first year of school may partly explain why children with asthma were disproportionately likely to be low achieving after 1 year of school.

Asthma during the school year might plausibly contribute to low achievement because of changes in variables commonly associated with asthma severity, or control, including sleep problems, leading to tiredness and distractibility during reading instruction (2,5,7,8), or increased school absence (9), and parents of children with more severe asthma recognize that their children need additional learning support (10). Some studies of children with asthma have attributed low achievement to lower attendance (3,11,12) but others showed no differences in attendance or no relationship between attendance and achievement (13,14). This might be because some studies compared mean reading scores, rather than the distribution of reading scores, including the lowest quartiles.

Our research question arose by considering why, at school entry, asthma diagnosis but not asthma severity was predictive of low reading achievement. If this is a biologically plausible relationship, then there ought to be a relationship with severity—a dose-response. We wondered if active asthma symptoms occurring during the period of reading instruction may be a more important consideration than reported severity at school entry. Therefore, in the present secondary analysis, we investigated reading outcomes as they related to changes in asthma severity that occurred during the first year in school.

Our hypothesis is that, among children with asthma, those whose symptoms persist or worsen over the first year of school will have lower reading achievement than children whose symptoms improve. If so, this increases the biological plausibility of a causal relationship between asthma and reading achievement.

Other changes during the school year could confound the relationship of changes in asthma severity with reading achievement. The literature identified the following potential factors: increased behavior

problems (10,15–17), school absences (9), life events (18–20) and low parent mental health (21–23).

Material and methods

Study recruitment and participants

The New Zealand National Health Research Human Ethics Committee and the University of Canterbury granted ethical approval and the study was conducted according to the WMA Declaration of Helsinki protocols (24). Eight randomly selected schools consecutively recruited 298 5-year-old children, with parental consent, at entry to primary school (20 parents declined, giving a recruitment rate of 93.7%). Measures (4) were obtained (with written informed parental consent) at school entry (T1) and 12 months later (T2) by face-to-face parent interview and individual child assessment conducted by trained post-graduate research assistants. At T2, 278 of the 298 children completed assessments (93% retention).

Questions from *The National Health Interview Survey (NHIS)* (25) were used to collect demographic data: age, gender, family income and ethnicity (modified using NZ census indices of ethnicity). The NZ Deprivation Decile (NZDep) Score for the family's address was determined. This is an SES indicator available to researchers, derived from census indicators and averaged within each small residential area of New Zealand (4,26). During the T1 interview, 286 parents reported family income, which correlated highly ($p = .0001$) with the NZDep score.

Definition of controls and asthma

Asthma was ascertained using items from the International Study of Asthma and Allergies in Childhood (ISAAC) Phase One Core Questionnaire, administered during the parent interview (27,28), and information collected from the child's physician. Supplementary questions in the interview elaborated a history of other respiratory conditions since birth (parents frequently reported croup, pertussis, pneumonia, bronchiolitis or other forms of coughing), limitations on activity, and medications used. Children were considered to have asthma at T1 if parents reported a diagnosis of asthma (physician report was received in 40/55 cases, confirmatory in all) and in addition reported either obstructive symptoms (e.g. wheeze, or waking with shortness of breath) or short-acting bronchodilator (reliever) use in the year before school. At T1, 55 of the 298 (16%) had asthma by these criteria; 55 were prescribed relievers and 45 controller medicines.

Items, Responses and Scoring	
Item 1. Frequency of wheeze attacks in the last 12 months? None 0 1 to 3 1 4 to 12 2 More than 12 3 Weekly 4	Item 4. Speech affected by wheeze Never 0 Prior to last 12 months 1 Affected in the last 12 months 2 Limited to two words 4
Item 2. Frequency of disturbed sleep due to wheeze in the last 12 months? Never 0 Less than 1 night/month 1 Less than 1 night/fortnight 2 1–2 nights/week 3 More than 3 nights/week 4	Item 5. Wheeze during or following exercise Never 0 Prior to last 12 months 2 Affected in last 12 months 4
Item 3. Frequency of morning wheeze and asthma symptoms Never 0 1–2 per month 2 1–2 per week 3 Every day 4	Item 6. Symptoms triggered by exertion Rarely 0 Exercise or sports 1 Hills, stairs, active play 2 Exercise/sports + hills/stairs 3 Exercise/sports + hills/stairs + walking on the flat 4
TOTAL:	
/24	

Figure 1. Asthma Functional Severity Scale used in the current study (adapted from Rosier et al. (29)).

Control children from the same cohort ($n=74$) had no current or past respiratory symptoms reported either in the ISAAC questions or in the additional interview questions (i.e. no report of wheeze, cough, pneumonia, croup, pertussis or bronchiolitis) at either T1 (covering years 0–5) or T2 (covering the year since T1). The remaining children in the cohort were not included.

Asthma severity and change in severity

We assessed asthma severity from ISAAC items using the Rosier scale of functional asthma severity (six items scored 0–4 each, total range 0–24 in order of increasing severity (Figure 1) (29,30). The numerical difference between T2 and T1 Rosier scores represented change in severity score. At T2, children with asthma were categorized as “improved” if they had a >10% reduction in their Rosier score compared to T1, otherwise as “persistent”. We used this dichotomy to assess whether persistence of active asthma symptoms during the first year at school was associated with poorer learning achievement, compared to

asthma symptoms that became minimal or inactive, whom we classified as “improved”.

Measures

Word reading

The *Word Reading* subtest of the *Wechsler Individual Achievement Test Second Australian Edition* (WIAT) was administered by an examiner at T1 and T2 (31). Items require naming letters of the alphabet and reading single words of increasing difficulty.

Story reading

Children read stories aloud using standard New Zealand beginning-reading storybooks (32). At T1, using the Running Record procedure (33–35), each child was given the opportunity to read aloud from a book suitable for the beginning of year 1 (i.e. grade 1), while the examiner recorded words read correctly, omissions, substitutions, and other errors. A similar procedure, adjusted for age, was conducted at T2. At this time, the first book given to the child (the same book for all children) was of a beginning Year 2 (i.e.

grade 2) level of difficulty. If the child could not read the first book at an independent level (with an accuracy $\geq 90\%$), they were then given books to read of a lower difficulty level; if they read the first book at an independent level, they were then given higher difficulty books. Each child was given the opportunity to read books at three different difficulty levels; the reading series provides books at age levels between 60 and 84 months (36). Story reading age-equivalent scores ("age scores") were determined by the level of the most difficult text read with an accuracy $\geq 90\%$. New Zealand kindergartens and preschools are play-based, and do not commence reading instruction (37). The easiest book in the reading series is at a 60-month (age 5 years 0 months) reading level. All children were given this book at T1. If they could not read this book to an independent level, a reading age could not be determined.

In 10% of the assessments, two observers simultaneously recorded and independently marked children, recording an item as passed or not passed for word reading, or read correctly or not for story reading in order to estimate inter-observer reliability.

Changes in behavior from T1 to T2

Parents reported child behavior problems using the standardized 26 item *Behavior Problem Index (BPI)* (38,39). The Cronbach's alpha was 0.910 in this study. Dichotomous scoring was used (i.e. 0 = "not true" and 1 = "sometimes or often true"). A behavior change score was calculated by subtracting the T1 from the T2 score.

Stressful life events

The *Life Events Checklist* (40,41) has been used with parents of children with asthma (20,21), and was administered during the parent interview at T2. The Checklist includes 46 yes/no questions about potentially traumatic events (e.g. family death, job loss) affecting the child and family in the previous 12 months, classified in seven categories. The number of categories in which traumatic events occurred was summed to create a life events score (range 0–7).

Parent mental health

During the parent interview at T2, parents responded to items on the *World Health Organization-5 Wellbeing Index (WHO-5)* (42,43), about their mood over the previous fortnight (e.g. "I have felt cheerful and in good spirits"). We included five questions, each scored on a six-point scale, and standardized

scores range from 0 to 100. A score below 50 indicates low mental health.

School absence

Schools reported the number of half-days of absence, but the records did not show the cause of absence, whether due to asthma or not.

Data analysis

Our outcome variables were low achievement in word reading and low achievement in story reading, which we report as reading age scores. We dichotomized the outcome scores as the lowest quartile versus the other quartiles. Quartile cutoffs were determined using the scores for controls (children without respiratory conditions), in order to prevent children with asthma from affecting the standard (4). This is a relevant parameter to use in New Zealand, as the lowest quartile of children in schools is used to define referral for remedial assistance. The lowest quartile for word reading corresponded to a delay of ≥ 6 -months after 1 year (approximately 0.5SD below the mean). The lowest quartile for story reading corresponded to a delay of 11 or 12 months (approximately 0.75SD below the mean). Thus, the lowest quartile for each outcome measure is an important measure of, and defines, low achievement.

We used SPSS (SPSS Inc., Chicago, IL) to compare the demographic and outcome variables for the asthma versus control groups and for the persistent asthma versus the improved asthma groups. Independent-sample one-sided *t*-tests, taking significance as $p \leq .05$, were used to compare the mean scores. We used the one-sided test because our hypothesis specifically concerned lower achievement. Contingency table analysis was used to compare proportions.

We performed logistic regression model testing in SPSS to test whether persistent versus improved asthma predicted low (versus not low) achievement in word reading and in story reading at T2, independently of covariates of learning and asthma.

The covariates tested in our model consisted of the following measures (for each dichotomized variable the reference category is listed second).

- Dichotomized predictor variables related to asthma: persistent versus improved asthma, and family member with asthma versus no family member with asthma.

Table 1. Characteristics of children with asthma versus controls at time 1 (T1).

Characteristic		Control, N = 74	Asthma, N = 51	p
Age at T1	Months [mean (SD)]	60 (0.84)	60 (1.0)	.25
Age at T2	Months [mean (SD)]	74 (2.72)	73.5 (1.75)	.23
Gender	Boys (%)	47	51	.72
SES	High (%)	19	18	.13 [†]
	Mid (%)	50	37	
	Low (%)	31	45	
Ethnicity	Māori (%)	12	18	.82 [‡]
	Pacific (%)	7	4	
	Asian (%)	4	2	
	European (%)	74	74	
	Other (%)	3	0	
	Missing data (%)		2	
Living with:	Both biological parents (%)	69	73	.66 [§]
Family history asthma	Yes (%)	52.1	74.5	.009
Word reading age-score at T1	Months [mean (SD)]	58.6 (7.2)	58.4 (6.6)	.91

[†]Comparison of low SES versus all others.

[‡]Comparison of priority ethnicity (Māori and Pacific Island) versus all other ethnicities.

[§]Comparison of children living with both biological parents versus all other living situations.

- Additional predictor variables, dichotomized based on established risk from the literature review: low versus not low word reading at school entry (T1), boy versus girl, priority ethnicity versus other ethnicity, low SES versus other SES, low parent mental health (using the WHO cut-off (43)) versus not low parent mental health.
- Continuous variables: half days absent, change in behavior problem score, and life events score.

We developed a logistic regression model in SPSS (Backward Stepwise Conditional modeling) according to established procedures (44) for the dichotomized reading scores. Single-variable testing provided *p* values, and the variables were ranked from most to least significant *p* values. Variables with $p \leq .05$ were then entered one-by-one into the model, starting with the most significant. At each step, variables with adjusted $p \geq .1$ were removed before entering the next most significant variable in turn. The final model contained only those variables with $p < .05$ that remained after all these steps.

Results

Reading outcomes for asthma versus control

Fifty-one children with asthma, and 74 children who had no history of any respiratory conditions (controls) were retained at T2. According to parents of the children with asthma, 39 (77%) were continuing to take a reliever and 26 (51%) a controller. Inter-observer reliability was 99% for word reading and 96% for story reading assessments. At T1 (school entry), there were no significant differences in demographic variables nor in word reading between the children with asthma and the controls (Table 1). At T1, fewer than

five children were able to read any words in the easiest story and none reached the 60-month level, thus story reading is not shown.

In contrast, after the first year of school, at T2, there were marked differences in reading: children with asthma were on average about 4 months behind in reading compared to controls (Table 2). This represents 40% of the 10-month school year, and is a level associated with functional impairment. Significantly more children with asthma than controls were in the lowest quartiles for word reading and story reading at T2.

There were no significant differences between controls and children with asthma in the frequency of school absences over the first year of school (Table 3). Neither were there any significant differences in other covariates that are associated with reading difficulties: experiences of adverse life events, changes in behavior problems or parent mental health. Therefore, these explanations for the differences in reading outcomes between asthma and control were not supported. Thus, we went on to investigate differences within the asthma group with reference to low reading achievement.

Reading outcomes within the asthma group

Within the asthma group, there were clear differences between children: for instance, 39.2% children were low achieving on word reading, whereas the other 61.8% were at or above the level of their control peers. In the group of children with asthma, average severity was not significantly different at T1 (mean = 7.9, SD = 4.5) and T2 (mean = 7.1, SD = 5.4, $p = .41$). However, following from our hypotheses, we next calculated a change in severity score. Severity scores at T2 were improved in 27 children (53%; 16 had zero

Table 2. Reading measures at time 2 (T2) in children with asthma versus controls.

Outcome measure at T2			Control, <i>N</i> = 74	Asthma, <i>N</i> = 51	<i>p</i>
Reading age score (months)	Word reading	Mean	76.2 (10.8)	72.3 (7.8)	.02*
		Range	46.1–105.1	57.6–88.5	
	Story reading	Mean	73.0 (12.9)	68.6 (10.9)	.03*
		Range	60.0 [†] –95.8	60.0 [†] –95.8	
Proportion in lowest quartile (%)	Word reading		21.6	39.2	.03*
	Story reading		24.3	43.1	.03*

[†]60 months (5 years) is the lowest possible score on this test.

*Difference is statistically significant, $p < .05$.

Table 3. Covariates of reading achievement between time 1 (T1) and time 2 (T2), or at T2 in children with asthma versus controls.

Covariate	Control, <i>N</i> = 74	Asthma, <i>N</i> = 51	<i>p</i>
Half days absent T1 to T2, mean (SD)	11.11 (7.79)	12.69 (8.11)	.27
Life events score T1 to T2, mean (SD)	1.77 (1.6)	2.14 (1.7)	.22
Change in behavior problems T1 to T2, mean (SD)	0.65 (4.2)	0.78 (4.1)	.86
Low parental mental health T2 (%)	23.0%	15.7%	.34

symptoms, 11 had fewer symptoms). Severity scores of the other 24 children (47%) indicated persisting symptoms (16 worse, 8 the same). The mean severity scores between the children with improved (mean = 3.9; SD = 3.4) and persistent asthma (mean = 10.8; SD = 4.8) were significantly different (mean difference = 6.9; 95% CI = 4.58, 9.22, $p = .001$). Relievers were reportedly being used by 21/24 (88%) of the persistent group and 18/27 (67%) of the improved group ($p = .080$), whereas controllers were reportedly used by 16/24 (67%) of the persistent group, significantly more than among the improved group (10/27, 37%, $p = .035$).

There were no significant differences between the persistent and improved groups in age (at T1 or T2), gender, socioeconomic status, ethnicity, asthma severity at T1, or reading readiness at T1 (Table 4). Fifteen (63%) of the persistent group versus 23 (85%) of the improved group had a family member with asthma ($p = .06$). Pearson correlations between the change in asthma severity and continuous variables showed a significant relationship with life event score ($r = 0.313$, $p = .027$), whereas there was no significant relationship with days absent ($p = .49$), SES ($p = .63$), parent mental health score ($p = .62$) or change in behavior problems ($p = .78$).

Compared to the improved group, the persistent group had significantly more children in the lowest quartile at T2 for word reading (54 versus 26%; $p = .04$) and story reading (58 versus 30%; $p = .04$) (Table 5). We sought to determine if the same covariates we investigated in Table 3 might also be different or explain the reading differences between the persistent and improved groups. In single-variable analyses, there were no differences between the persistent and improved asthma groups in any of these covariates

(Table 5). Therefore, we proceeded to multi-variable logistic regression analysis.

Logistic regression modeling

Each of the variables was individually tested in a logistic regression model (Supplementary Table S1) and then entered into a backwards stepwise logistic regression analysis in order of their significance (Table 6). The outcome variables tested were low (lowest quartile versus others) word reading and low story reading. Because learning to read words precedes learning to read stories, and because of the high correlation in low word reading and low story reading scores (Pearson correlation: 0.766, $p > .0001$), logistic regression modeling for low word reading was performed first.

In the final model (Table 6) for word reading ($\chi^2 = 26.454$, $df = 2$, $p > .000$, Cox and Snell $R^2 = 0.424$, observed power = 0.813) only two variables were retained: word reading at Time 1 (OR = 1.386; 95% CI: 1.140, 1.686, $p = .01$) and persistent versus improved asthma severity (OR = 9.251; 95% CI: 1.378, 62.094), $p = .022$).

In the final model (Table 7) for story reading ($\chi^2 = 15.210$, $df = 2$, $p > .000$, Cox and Snell $R^2 = 0.272$ observed power = 0.75), the same two variables were retained: word reading at T1 (OR = 1.196; 95% CI: 1.1058, 1.353, $p = .004$) and persistent versus improved asthma severity (OR = 4.534; 95% CI: 1.094, 18.791, $p = 0.037$).

Thus, the association between persistent asthma and poorer reading outcomes after 1 year in school compared to improved asthma is not explained by the potential confounding variables we have tested.

Table 4. Characteristics of children with asthma classified into two groups: improved asthma versus persistent asthma.

Characteristic		Improved asthma, N = 27	Persistent asthma, N = 24	p
Age in months	T1, mean (SD)	59.9 (.85)	60.4 (1.1)	.08
	T2, mean (SD)	73.4 (1.93)	73.6 (1.6)	.63
Gender	Boys (%)	48.1	54.2	.67
SES	High (%)	25.9	8.3	.92 [†]
	Mid (%)	29.6	45.8	
	Low (%)	44.4	45.8	
Ethnicity	Māori (%)	25.9	8.3	.14 [‡]
	Pacific (%)	3.7	4.2	
	Asian (%)	0.0	4.2	
	European (%)	66.7	83.3	
	Other (%)	3.7	0.0	
Living with:	Both biological parents (%)	74.0	71.0	.80 [§]
Family history asthma	Yes (%)	85.2	62.5	.06
Word reading at T1	Lowest quartile (%)	22.2	33.3	.38

[†]Comparison of Low SES versus all others.

[‡]Comparison of Priority Ethnicity (Māori and Pacific Island) versus all other ethnicities.

[§]Children living with both biological parents versus all other living situations.

Table 5. Time 2 (T2) reading outcomes and covariates in children with improved or persistent asthma.

Measures	Improved group, N = 27	Persistent group, N = 24	p
Word reading, mean age score (SD)	73.6 (7.93)	70.8 (7.55)	.054
Story reading, mean age score (SD)	68.19 (9.9)	68.17 (12.2)	.142
Low achievement in word reading	25.9%	54.2%	.04*
Low achievement in story reading	29.6%	58.3%	.04*
Half-days absent T1 to T2 [mean (SD)]	12.3 (9.1)	13.2 (7.02)	.69
Parents with low mental health T2 (%)	19.0%	12.5%	.52
Life events between T1 and T2 [mean (SD)]	1.9 (1.43)	2.5 (1.96)	.25
Change in behavior problems between T1 and T2 [mean (SD)]	0.54 (4.6)	1.04 (3.6)	.67

*Difference is statistically significant ($p < .05$).

Discussion

The detailed analysis presented in this study within the group of children with asthma identified that children who had persistent asthma during the first year of school were overrepresented in the lowest quartiles for reading achievement after 1 year in school, compared to those with improved asthma. As a whole, children with asthma at school entry were more likely to be in the lowest quartiles for reading achievement, than children with no previous respiratory symptoms reported at school entry.

Our final models for reading achievement at the end of the first of year of school retained only two significant factors: word reading at T1 and persistent (versus improved) asthma. The reading achievement of children after the first year of reading instruction is logically related to the reading skills they bring to school (14). It is therefore not surprising that word reading score at T1, which represented reading skills at school entry in the present study, was a major factor in understanding the reading of children with asthma. However, this is not specific to asthma as children with asthma were not significantly worse than controls on this factor.

It is notable then that in the models, persistent (versus improved) asthma had higher odds ratios than

word reading at T1 (reading readiness) for explaining reading achievement outcomes at T2. In real-world terms, 58% of the children with persistent asthma at age 74 months (T2) were reading stories at a 61-month level, or 13 months below their expected reading age level. This places them about 1 year behind the average child, and two and a half years behind the higher achieving children in their class, after only 1 year in school. By comparison, only 30% of children with improved asthma, and 24% of controls were in the same poor learning category. Persistent asthma, in the way we have defined it, corresponds to children with active symptoms during the first year of school, as opposed to those with few or no symptoms, despite being diagnosed with asthma at school entry. Whether or not this is causal has not been determined, however the association with severity change is essentially a dose-response and increases the biological plausibility of a causal link.

There are few other recent studies that relate asthma severity to learning outcomes. Kohen (13) studied over 4000 Canadian pupils aged 7–15 years in grades 2 and higher. She reported that moderate asthma severity, measured at the same time as reading achievement, was a significant factor (OR = 1.59) in understanding reading achievement after adjusting for SES, school absences, and children's other conditions

Table 6. Model testing for outcome variable: lowest achievement quartile for word reading age scores at T2.

Model step number	Variable	Significance <i>p</i>	Odds ratio	95% confidence interval
1	Word reading T1	.001	1.284	1.115, 1.480
2	Word reading T1	.001	1.386	1.140, 1.686
	Persistent versus improved asthma	.022	9.251	1.378, 62.094
3	Word reading T1	.001	1.379	1.132, 1.680
	Persistent versus improved asthma	.022	9.304	1.380, 62.737
	Low SES	.642	0.686	0.141, 3.349
4	Word reading T1	.001	1.395	1.139, 1.708
	Persistent versus improved asthma	.022	9.593	1.396, 65.942
	Priority ethnicity	.797	0.760	0.094, 6.153
5	Word reading T1	.001	1.374	1.130, 1.671
	Persistent versus improved asthma	.034	8.212	1.169, 57.679
	Life events score	.569	0.885	0.580, 1.349
6	Word reading T1	.001	1.383	1.135, 1.685
	Persistent versus improved asthma	.023	9.181	1.350, 62.434
	Change in behavior problems T1–T2	.450	1.087	0.876, 1.348
7	Word reading T1	.001	1.406	1.153, 1.716
	Persistent versus improved asthma	.029	8.408	1.251, 56.525
	Days absent	.252	0.938	0.842, 1.046
8	Word Reading T1	.002	1.370	1.125, 1.668
	Persistent versus improved asthma	.016	11.261	1.562, 81.200
	No family member with asthma	.214	3.370	0.496, 22.880
9	Word Reading T1	.001	1.389	1.138, 1.697
	Persistent versus improved asthma	.023	9.489	1.369, 65.793
	Gender: M versus F	.437	0.531	0.108, 2.616
10	Word reading T1	.001	1.398	1.145, 1.703
	Persistent versus improved asthma	.021	0.100	0.014, 0.708
	Parent low mental health	.689	0.647	0.077, 5.441
FINAL	Word reading T1	.001	1.386	1.140, 1.686
	Persistent versus improved asthma	.022	9.251	1.378, 62.094

and use of educational services. In addition, children with severe asthma were more likely to use educational services including remedial reading programs. A strength of Kohen's study is the large sample. However, compared to the present study, Kohen's study was cross-sectional, participants were older, and changes in asthma severity and reading readiness at the start of school (or after the first year of school) were not measured. The present study progresses these findings in a longitudinal study, by identifying the importance of persistent asthma for early reading outcomes.

Crump et al. (3) reported that chronic asthma was not a significant predictor of low achievement in English language arts (includes reading), after controlling for SES, ethnicity, gender, school absences, grade level, parental education level and receiving special educational services. Children were older, grades 2–11, more likely to come from low SES, and there was a lower prevalence of asthma (6.1%) in this sample compared to ours. By measuring from the start of year 2, and not including reading readiness, both the Kohen and Crump et al. (3,13) studies may have missed crucial early influences on the school achievement of children with asthma, which our study identified.

Limitations

Our study is relatively small for subgroup analyses; however, the relationships between persistent asthma

and worse learning outcomes persist in different analyses even after adjusting for potential confounders.

We could not analyze the relative impacts of asthma medication because all children were on similar prescriptions initially. Reliever and controller use are closely linked to asthma severity and asthma control. Frequent reliever use in acute asthma is often observed clinically to cause restlessness and overactivity. Frequent use in children with poor asthma control could conceivably influence achievement by milder effects on concentration. On the other hand, controller use may bring about better control and improved achievement (45). In our study, children in the persistent group were using more controllers at T2 than children in the improved group; however, we could not dissect out the medication effects on learning because of the likelihood of confounding by indication. Future studies would ideally include an accurate measure of medication, dosage and frequency of use.

Some learning disabilities, including dyslexia, may be first identified when children are older, by which time there can be a substantial discrepancy of between their chronological age and their reading despite targeted assistance (46). Therefore, our study may include children with undiagnosed learning disabilities in the asthma and control groups. However, our sample is unlikely to be biased in regards to the relationship of low reading achievement and asthma, due to the original cohort recruitment process.

Table 7. Model testing for outcome variable: lowest achievement quartile for story reading age scores at T2.

Model Step number	Variable	Significance, <i>p</i>	Odds ratio	95% confidence interval
1	Word reading T1	.004	1.169	1.051, 1.300
2	Word reading T1	.004	1.196	1.058, 1.353
	Persistent versus improved asthma	.037	4.534	1.094, 18.791
3	Word reading T1	.010	1.180	1.040, 1.339
	Persistent versus improved asthma	.034	4.820	1.123, 20.686
	Low SES	.165	0.372	0.092, 1.501
4	Word reading T1	.005	1.204	1.057, 1.373
	Persistent versus improved asthma	.035	4.715	1.114, 19.962
	Priority ethnicity	.746	0.744	0.125, 4.437
5	Word reading T1	.005	1.194	1.054, 1.353
	Persistent versus improved asthma	.047	4.401	1.018, 19.024
	Life events score	.872	0.971	0.677, 1.393
6	Word reading T1	.006	1.190	1.050, 1.348
	Persistent versus improved asthma	.039	4.603	1.078, 19.658
	Change in behavior problems T1–T2	.176	1.144	0.941, 1.391
7	Word reading T1	.003	1.223	1.071, 1.398
	Persistent versus improved asthma	.047	4.325	1.020, 18.339
	Days absent	.132	0.929	0.845, 1.022
8	Word reading T1	.006	1.187	1.050, 1.342
	Persistent versus improved asthma	.026	5.409	1.223, 23.914
	No family member with asthma	.269	2.462	0.498, 12.169
9	Word reading T1	.006	1.194	1.053, 1.354
	Persistent versus improved asthma	.039	4.655	1.078, 20.106
	Gender: M versus F	.143	0.356	0.089, 1.419
10	Word reading T1	.008	1.190	1.046, 1.353
	Persistent versus improved asthma	.026	0.180	0.040, 0.816
	Parent low mental health	.196	0.262	0.034, 0.919
Final	Word reading T1	.004	1.196	1.058, 1.353
	Persistent versus improved asthma	.037	4.534	1.094, 18.791

We did not measure stress directly. Both difficulty learning to read and asthma may increase child or parent stress (19,23), which in turn may negatively affect learning. Therefore, future studies could investigate stress to expand understanding of pathways between changes in asthma severity, stress and reading achievement.

Other comments

Our study does not explain why asthma symptoms persisted or improved. According to parents in our study, children with persistent asthma symptoms used more controllers than those with improved asthma symptoms. The reasons for temporal changes in asthma severity are not clearly understood (47). The natural history of asthma differs by phenotype: at early school age some phenotypes of preschool asthma or wheeze are starting to improve, others (such as non-atopic asthma) are stable, whereas there is increasing prevalence of atopic asthma (6). Multiple factors, not all understood, influence these changes including genetic, maturational (size, physiology and immune function), medical treatment and adherence, and environmental changes, such as increased air pollution (48). Factors associated with persistence and severity include early troublesome wheeze, multiple allergic sensitizations, and lower lung function (6).

Future research should help explain the pathways between persistent asthma and low reading achievement in the early school years. The children in the persistent group showed deterioration or continued activity in most symptoms included in the severity measure, including more night waking, impairment of speech, reduced activity participation, and, more days absent from school. We explored some documented secondary effects of these symptoms that have the potential to impact on reading achievement—worsened child behavior, school absences, traumatic life events, and lower parent mental health (19,21). None of these factors were confirmed in the model testing, and thus they do not explain the relationship we identified between persistent asthma and low reading achievement.

One intriguing possibility is that difficulties in breathing associated with persistent asthma symptoms may influence the process of learning to read. We have previously studied the impact of asthma on breathing during oral reading, which may impact reading fluency, confidence and learning (49). There were significant differences in breathing patterns of a small group of children with asthma while reading aloud from stories slightly difficult for their age, compared to controls without asthma. Additional research is required to confirm whether this is a factor in the association of persistent asthma with poorer reading achievement in the first year of school as shown in the present study.

In conclusion, the persistence of asthma symptoms (versus improvement in symptoms) in early school life is a risk factor for low reading achievement. These findings suggest that learning to read is specifically associated with persistent asthma, rather than simply with the diagnosis of asthma as we previously showed (4). Thus, we propose that persistent asthma symptoms may negatively influence the process of learning to read, although it will take further study to understand the mechanism. Future research could determine if improved asthma control improves reading achievement in beginning readers.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Asthma Severity & reading

Supplementary Table S1. Binary logistic regression analysis of low achievement in Word Reading in children with asthma, organized from most significant to least significant variable.

Rank	Covariate	Type	Beta	Sig	Exp. (B)	95% lower	95% upper
1	Word Reading at T1	Continuous	0.265	0.000	1.340	1.127	1.508
2	Persistent vs. Improved	Dichotomous	1.217	0.043	3.377	1.041	10.957
3	Low SES vs. all else	Dichotomous	1.003	0.090	2.727	0.856	8.686
4	Priority (minority) ethnicity vs. ell else	Dichotomous	1.303	0.122	3.682	0.704	19.247
5	Life Events Score	Continuous	-0.259	0.148	0.772	0.544	1.096
6	Behavior change score	Continuous	0.110	0.155	1.116	0.959	1.299
7	Parent low mental health	Dichotomous	1.099	0.169	0.300	0.628	14.339
8	No family member with asthma	Dichotomous	0.993	0.177	2.696	0.639	11.389
9	Boy vs. girl	Dichotomous	0.600	0.303	1.821	0.582	5.698
10	Days absent	Continuous	-0.029	0.417	0.972	0.906	1.042

Asthma Severity & reading

Supplementary Table 2. Binary logistic regression analysis of low achievement in story reading in children with asthma, organized from most significant to least significant.

Rank	Covariate	Type	Beta	Sig	Exp. (B)	95% lower	95% upper
Rank	Factor	Type	Beta	Sig	Exp (B)	95% lower	95% higher
1	Word Reading T 1	Continuous	0.156	0.004	1.169	1.051	1.300
2	Low SES vs. all else	Dichotomous	1.358	0.023	3.889	1.205	12.554
3	Persistent vs. Improved	Dichotomous	1.201	0.042	3.325	1.044	10.585
4	Behavior change score	Continuous	0.145	0.069	1.156	0.989	1.351
5	Parent low mental health	Dichotomous	1.584	0.071	4.875	0.875	27.149
6	Boy vs. girl	Dichotomous	0.908	0.119	2.479	0.793	7.755
7	Days absent	Continuous	-0.049	0.184	0.952	0.886	1.023
8	Priority (minority) ethnicity vs. all else	Dichotomous	-0.881	0.239	0.414	0.096	1.793
9	No family member with asthma	Dichotomous	-0.706	0.302	0.494	0.129	1.884
10	Life Events Score	Continuous	-0.155	0.367	0.857	0.612	1.199