Featured Article: Multiple Comorbid Conditions, Sleep Quality and Duration, and Academic Performance in Urban Children With Asthma

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Abstract

Objective  Common comorbid medical conditions including allergic rhinitis (AR), obesity, and sleep disordered breathing (SDB) have been linked with asthma exacerbations; however, these conditions also impact sleep and academic functioning. The current study sought to examine unique and combined associations of these common comorbidities on sleep and academic performance among urban minority children with persistent asthma. We expected additional comorbid diagnoses would be associated with poorer sleep and academic functioning. Method  Urban children 7–9 years old (n = 249) with persistent asthma from African American, Latino, and non-Latino White backgrounds participated in this cross-sectional study. Asthma and AR were assessed using guidelines-based approaches. Overweight/obesity was assessed using body mass index and parents reported on SDB risk. Sleep quality (sleep efficiency) and sleep duration were assessed via 4 weeks of actigraphy. A cumulative risk index (CRI) score of asthma-related comorbidities (i.e., number of comorbidities for which each child met criteria) was calculated. Results  Comorbid conditions were prevalent (AR, 85%; overweight/obese, 39%; SDB risk, 44%). Lower SDB risk and better AR control were both associated with fewer school absences. A higher CRI score was associated with shorter sleep duration and more absences. For children with 1 comorbid condition, better lung function was associated with better sleep efficiency. Conclusion  Findings suggest increased risk of shorter sleep and more frequent school absences among urban minority children with asthma and more comorbid conditions. Assessment and treatment of this high-risk group must consider how comorbid conditions exacerbate children’s asthma and may affect sleep and daytime functioning.

Key words: academic functioning; asthma; children; comorbidity; sleep.

Asthma morbidity is highly prevalent in urban minority children (Akinbami et al., 2012). Multilevel factors impact asthma morbidity, including individual and family factors such as stress, asthma medication adherence, immune function and/or genetics, and cultural factors (Koinis-Mitchell, Kopel, Salcedo, McCue, & McQuaid, 2014). Environmental and systems-level factors such as increased allergen exposure within urban environments (Morgan et al., 2004) and healthcare access factors (e.g., use of a consistent provider for asthma care; Zambrana & Carter-Pokras, 2004) further amplify asthma morbidity for urban minorities. Interactions between these multilevel factors create a complex picture of asthma morbidity among urban minority youth (Koinis-Mitchell et al., 2007).
Managing asthma can be challenging for all children and their families, as it involves identifying asthma symptoms, using controller and quick-relief medications as prescribed, and avoiding asthma triggers (Petrov & Wenzel, 2010). Asthma management can be further complicated by common comorbid medical conditions, such as allergic rhinitis (AR; Grossman, 1997), obstructive sleep apnea (Bixler et al., 2009), and obesity (Stingone, Ramirez, Svensson, & Claudio, 2011). Management of asthma in addition to common comorbid conditions places a large burden on urban minority families in the context of potential urban stressors (e.g., environmental triggers and insurance access) that may complicate treatment adherence and illness control (e.g., removing carpet throughout an apartment or replacing windows that do not function properly may be difficult for urban families; de Groot, Nijkamp, Duiverman, & Brand, 2012).

Indeed, AR is common in children with asthma (de Groot et al., 2012) and, when poorly controlled, can increase asthma morbidity (Esteban et al., 2014). The asthma–obesity comorbidity is also highly prevalent in urban minority children (Rodriguez, Winkleby, Ahn, Sundquist, & Kraemer, 2002). Obesity in the presence of asthma can increase risk for poor asthma control in children (Stingone et al., 2011), and specific mechanisms common to both obesity and asthma link these conditions (e.g., inflammatory mediators of obesity may also impact airway smooth muscle; Fantuzzi, 2005). Sleep disordered breathing (SDB), defined as different varieties of airway obstruction during sleep, is common in children with AR (Bixler et al., 2009), and AR symptoms exacerbate obstructive sleep apnea risk in children (McColley, Carroll, Curtis, Loughlin, & Sampson, 1997). Obesity (Gennuso, Epstein, Paluch, & Cerny, 1998), AR (Pénard-Morand et al., 2010), and SDB (Fagnano et al., 2009) are highly prevalent in urban minority children with asthma; however, limited work has examined the co-occurring effects of these comorbidities on the sleep and academic functioning of children with asthma.

A number of studies have linked asthma with specific sleep and academic outcomes in children. Asthma has been associated with poorer school attendance in children (Gruchalla et al., 2005), and nocturnal asthma symptoms have been linked with poorer school performance (Stores, Ellis, Wiggs, Crawford, & Thomson, 1998). For children with asthma, additional comorbid conditions may increase risk for sleep and academic problems: For example, poor AR control in children with asthma has been associated with increased parent-reported sleep problems (Koinis-Mitchell, Kopel, Boergers, Ramos, et al., 2015), and children with comorbid asthma and obesity have more parent-reported nighttime asthma symptoms (Stingone et al., 2011) and shorter objective sleep duration (measured via actigraphy) than children with obesity alone (Fedele, Janicke, Lim, & Abu-Hasan, 2014).

The established associations between asthma and both sleep disturbances (i.e., nighttime wakings) and poor academic functioning are further amplified among urban minority children, given the increased asthma morbidity in this group (Daniel, Boergers, Kopel, & Koinis-Mitchell, 2012). Specifically, when objectively assessing sleep quality and duration (via actigraphy) over time, both sleep quality and duration were related to lung function in urban children with asthma (Koinis-Mitchell et al., 2017). Among inner-city children with asthma, increased allergen exposure and sensitivity has also been associated with poorer school attendance (Gruchalla et al., 2005). Although AR, obesity, and SDB each can affect sleep and academic functioning in children with asthma and are frequently comorbid, research to date has not examined their cumulative impact on sleep and academic outcomes in urban minority children with asthma.

In this article, we examine unique and combined associations between common comorbid conditions and sleep and the academic performance of children with asthma. Asthma status as well as each comorbid condition were carefully evaluated. Our previous work has demonstrated the utility of examining cumulative risks related to family’s cultural background, sociocontextual environment, and asthma status on asthma morbidity: an approach found to be a more accurate representation of asthma morbidity within a sample of urban children than single indicators of urban poverty (Koinis-Mitchell et al., 2007, 2010). We apply a similar cumulative approach to understanding the unique and combined associations between each clinically significant asthma-related comorbidity, sleep, and school functioning in a carefully evaluated sample of children with asthma.

The current study has several goals. First, we examine the prevalence of AR, overweight/obesity, and SDB risk in a sample of urban children with persistent asthma from Latino, African American (AA), and non-Latino White (NLW) backgrounds. Second, we evaluate the association between each of these comorbid conditions and objectively measured sleep quality (sleep efficiency and duration) and academic outcomes (absences and teacher report of academic functioning) during a 4-week period in the entire sample and by ethnic group. We expect each comorbid condition to be associated with poorer quality sleep, shorter sleep duration, and poorer academic functioning (more school absences and poorer teacher-rated academic functioning). We also expect these links will be stronger in ethnic minority groups relative to NLW participants. Third, using a cumulative risk index...
(CRI) representing the number and severity of comorbid conditions (see Method), we assess how multiple comorbidities are associated with sleep and academic outcomes across the entire sample and by ethnic group. We expect a higher number of comorbidities (higher CRI score) will be associated with more impaired sleep and poorer academic functioning. Further, we expect associations will be amplified in ethnic minority groups. Finally, we assess the extent to which the number of comorbidities (CRI score) moderates associations between asthma-related lung function (FEV1% predicted) and sleep and academic outcomes. We expect more optimal asthma-related lung function will be associated with more optimal sleep and academic outcomes, in the context of fewer comorbidities (lower CRI scores).

Method

Data were collected as part of a larger study (NAPS [Nocturnal Asthma and Performance in School]) designed to assess the co-occurrence of asthma and AR symptoms, sleep, and academic performance within a group of urban school-aged children with and without persistent asthma. Only participants with persistent asthma were included in the current study. Participants with persistent asthma were included in the current study.

Participants

Participants \((n=249)\) between 7 and 9 years old \((M=8.29, SD=.88; 47\% \text{ male})\) were recruited from four large urban school districts, outpatient pediatric clinics, and a hospital-based asthma education program within a small, urban Northeastern U.S. city. Study inclusion criteria required participants to be 7–9 years old; attend a public school within the four target districts; have caregivers who identified as AA, Latino, or NLW; and have been diagnosed with asthma in the past, or have breathing problems in the previous 12 months by caregiver report. For study entry at screening, evidence was required of persistent asthma, based on clinical guidelines (National Heart Lung and Blood Institute [NHLBI], 2007); persistent status was confirmed at the study clinic visit. Exclusion criteria included (1) use of stimulant medication for attention deficit/hyperactivity disorder, (2) moderate-to-severe cognitive impairment per school placement, (3) another pulmonary or chronic health condition (e.g., cystic fibrosis, diabetes mellitus, or juvenile rheumatoid arthritis), and (4) a diagnosed sleep disorder (e.g., insomnia or restless leg syndrome).

A restricted age range was used to focus on school-aged children, as caregivers begin to transfer asthma management to children around this time (e.g., children administer their own medication during the school day; Buford, 2004). Although sleep disorders for the asthma group were deemed eligible, of whom 55% enrolled. Most common reasons for nonenrollment were lack of interest and/or time.

Procedures

Data in the current study were collected during the fall/winter monitoring period of the NAPS study; only data from this monitoring period were used in the present study, as it allows for the most variability in asthma symptoms. In the initial study visit in families’ homes, children and caregivers completed informed consent/assent, and caregivers answered demographic questions and confirmed asthma medications via interview with study staff. All participants then completed a second visit in an asthma and allergy clinic with a study clinician to confirm asthma diagnosis, evaluate disease severity, and confirm medication use. Next, families completed a 4-week in-home monitoring period to assess sleep efficiency and duration and lung function. The monitoring period enabled a thorough assessment of asthma variability over time, as well as an opportunity to examine associations between asthma variability and sleep and daytime functioning. Each child wore an actigraph and completed twice-daily spirometry (both described later) throughout the monitoring period. The study was approved by the appropriate institutional review board.

Measures

Demographics

Caregivers provided demographic information. Poverty status was determined by dividing each family’s annual income by the U.S. federal per capita poverty threshold for a family of that size (U.S. Department of Health and Human Services, 2014).

Asthma Classification, Severity, and Control

Each participant underwent a physical examination, allergy skin testing, and pulmonary function testing to confirm asthma diagnosis and evaluate asthma severity. Caregivers reported on current asthma medication use and adherence. A study clinician confirmed participants met criteria for persistent asthma (mild, moderate, or severe) based on NHLBI Expert Panel Report 3 guidelines (NHLBI, 2007). Participants also completed the Asthma Control Test (ACT; Liu et al., 2007), a well-validated measure of asthma-related impairment. Scores at or below 19 indicated poorly
controlled asthma (Nathan et al., 2004). The ACT was used for descriptive purposes.

AR Classification, Severity, and Control
AR was evaluated by a study clinician using clinical guidelines (Bousquet et al., 2008), including a physical examination, caregiver-reported child rhinitis symptoms, and allergy skin prick testing to perennial and common regional seasonal allergens (i.e., cat, dog, cockroach, mold mix, tree, grass, ragweed, plantain pollen, and mouse). Skin testing was performed after appropriate medication washout. Caregivers also reported on AR control during the monitoring period using the Rhinitis Control Assessment Test (Schatz et al., 2010). Scores (range: 6–30) of 21 or lower were indicative of “poorly controlled rhinitis.” As in our previous work (Koinis-Mitchell, Kopel, Boergers, McQuaid, et al., 2015; Koinis-Mitchell, Kopel, Boergers, Ramos, et al., 2015), AR control rather than diagnostic status served as the predictor in regression models examining the unique impact of AR on sleep and academic outcomes.

Overweight/Obesity
Height and weight were measured during the clinic visit and converted to body mass index (BMI) percentiles using standard Centers for Disease Control and Prevention (CDC) procedures (CDC, 2009). Cutoff values were specified (i.e., 85th–95th percentile, overweight; greater than 95th percentile, obese); overweight and obese were combined for the current study to compare this group with same-age peers of normal weight and to highlight this subgroup who are at highest risk for interventions.

SDB Risk
During the initial study visit, caregivers completed the well-validated Pediatric Sleep Questionnaire, which included a Sleep-Disordered Breathing subscale (22 yes/no items; Chervin, Hedger, Dillon, & Pituch, 2000). Scoring produces a proportion of endorsed items; scores greater than 0.33 suggest high SDB risk. Reliability of this measure in the current study was acceptable (α = .77).

Asthma-Related Lung Function
This was objectively measured twice daily during the monitoring period via a handheld computerized spirometer (Jaeger AM2; ERT, Yorba Lina, CA). The best of three FEV1% predicted values per trial were retained. Participants were instructed to complete three “blows” before any asthma or allergy medications in the morning and at night. We used a 7-day threshold (i.e., at least 7 days with either a morning or evening “blow”) for computing mean FEV1 across the monitoring period. Days were not required to be consecutive. This cutoff was based on simulations with data from a previous study in our lab (Seifer et al., 2009). Within the NAPS sample, 88% of children met this criterion, and the majority provided much more than this minimum. Adherence to the AM2 protocol was generally quite good, with a mean rate of completion of morning and evening blows at 75%.

CRI of Asthma-Related Comorbidities
Using a similar approach involving the assessment of the accumulation of urban, cultural, and asthma-related risk factors among urban children with asthma (e.g., asthma severity, poverty, neighborhood disadvantage, and perceived discrimination) based on our previous work (Koinis-Mitchell et al., 2007, 2010), a CRI was developed to capture the number of comorbidities for which children in the current sample qualified. This CRI involved a diagnostic and/or clinical criterion for each condition. Each comorbidity was coded 0 if the child did not meet the criterion for that condition, and 1 if they did (i.e., positive diagnosis of AR, BMI ≥ 85%, SDB risk scores > 0.33). Codes were summed to produce a total CRI score, ranging from 0 to 3, reflecting the number of comorbidities for which each child qualified.

Sleep Quality and Duration
Sleep outcomes were assessed using actigraphy (Actiwatch 2; Philips Respironics, Pittsburgh, PA, USA) data collected over the monitoring period. Average sleep duration and efficiency data were included in the current analyses. Children wore the actigraph on their nondominant wrist at all times except when bathing or swimming. To facilitate scoring, families recorded additional information, including morning wake times and evening bedtimes, instances of illness other than asthma, and times when the actigraph was not worn. Standard scoring rules were applied to each nighttime sleep period (Acebo et al., 1999). As in our previous work, nights were excluded when (1) concurrent diary information was not available, (2) the actigraph was off for all/part of the sleep period, (3) diary indicated illness other than asthma that could have impacted sleep, or (4) when all/part of the sleep period included external motion (e.g., sleeping in a car; Koinis-Mitchell, Kopel, Boergers, McQuaid, et al., 2015). The current study included only cases for which actigraphy was complete (n = 212). Participants with actigraphy data had, on average, 18.82 scorable nights (SD = 7.64; range = 2–40). Actigraphy data were not available for 37 children due to protocol nonadherence (n = 34) or device failure (n = 3). There were no differences between those with/without sleep data on demographic (e.g., sex, ethnicity, and poverty status) or clinical (e.g., asthma severity) features.

Two variables derived from actigraphy data were used for this study: sleep duration (total time between...
evening sleep onset and morning waking) and sleep quality as measured by sleep efficiency (time asleep/time in bed; Koinis-Mitchell, Kopel, Boergers, McQuaid, et al., 2015).

**Academic Outcomes**

**School Absences.** Total absences (e.g., sickness and vacation) were collected from children's final grade reports for the whole academic year in which they participated in the study. Absences from the entire academic year were assessed because this objective measurement, unlike parentally reported absences, was not susceptible to parental error/bias.

**Teacher Report of Short-Term Academic Functioning.** Each participant’s primary classroom teacher reported on academic performance over the monitoring period. The scale was originally developed as one of four domain areas that may be sensitive to changes in children's sleep opportunities (Fallone, Acebo, Seifer, & Carskadon, 2005). The academic functioning scale included five items assessing work quality, percent completed, difficulty recalling material, carelessness with work, and speed of learning. Higher scores suggest poorer academic performance (range = 2–18). Acceptable reliability has been demonstrated for this scale in previous research on healthy school-aged children (average $\alpha = .86$; Fallone, Acebo, Seifer, & Carskadon, 2005); the average score on this scale was 6.68 in previous research (SD = 3.05; Fallone et al., 2005). In the current study, reliability on this measure was excellent ($\alpha = .90$).

**Analytic Plan**

Preliminary analyses were conducted to identify demographic (i.e., sex, socioeconomic status, and age) and ethnic group differences on asthma, comorbid medical condition, sleep, and academic outcomes with analysis of variance, chi-square analyses, and/or Pearson's correlation analyses. Consistent with previous approaches (Martin et al., 2017), only covariates related both to the predictor and outcome were controlled in subsequent analyses. As no variables met these criteria, no covariates were entered into any of the models.

Descriptive statistics examined the frequency of each individual comorbid condition (AR, overweight/obesity, and SDB risk) and CRI scores reflecting the number of comorbidities present per child. Analyses were completed for the entire sample and by ethnic minority group. To examine associations between each individual comorbid condition (AR control, obesity/overweight [BMI], and SDB risk scores) and sleep (efficiency and duration) and academic outcomes (absences and teacher report of academic functioning), a series of generalized linear models were completed for each individual comorbid condition (12 individual regressions). Across aims, individual regressions were used, due to our interest in understanding how each individual comorbid condition is associated with sleep and academic functioning, with the goal of developing tailored interventions for specific groups of families. Models were stratified by ethnic minority group. Accounting for the number of analyses, a conservative Bonferroni adjusted alpha level of 0.004 was applied for models assessing individual comorbid conditions. Next, to assess associations between the CRI scores and sleep and academic outcomes, four generalized linear models were completed, with CRI score entered as the predictor in all models. Analyses were stratified by ethnic minority group.

Finally, four moderation models were conducted to examine the association between lung function (FEV1% predicted) and sleep and academic outcomes, and if associations differed by the number of comorbidities. Specifically, models included CRI score, lung function, and the lung function by CRI interaction term. Post hoc probing was used to examine conditional interaction effects. For all regression models, only significant findings were reported. Analyses were conducted using SPSS version 23.0 and SAS 9.3. Effect sizes are presented as $\eta_{partial}^2$.

**Results**

**Sample Characteristics**

Missing data were not directly imputed, given our interest in daily variability of asthma and sleep (see Figure 1 for missing data description). We used a likelihood-based approach to estimation in which all participants are included without directly imputing missing values. We tested sensitivity of the findings to different approaches to handling missing data (Maximum likelihood estimation vs. listwise detection), and results did not differ; however, we present the former here. Of the sample, 35% ($n = 89$) was classified as having poorly controlled asthma and 64.7% ($n = 161$) reported being on an asthma controller medication. Of the total sample ($n = 249$), 51% identified as Latino ($n = 127$), 33.3% as AA ($n = 83$), and 15.7% as NLW ($n = 39$). A majority of the sample (66.5%; $n = 165$) fell at or below the poverty threshold. Parents had 12 years of education on average (fathers: $M = 11.94$, $SD = 2.57$; mothers: $M = 12.3$, $SD = 2.06$), and there was an average of 4.59 ($SD = 1.73$) people living in the home. Within the sample ($n = 212$), the mean sleep time was 9.25 hr ($SD = 0.58$ hr) and mean sleep efficiency was 86.56% ($SD = 3.60$). Participants averaged 11.87 days ($SD = 9.24$) of school absences, and average teacher report of academic functioning scores were 3.03 ($SD = 0.34$; range = 2.22–3.67).
Enrolled = 249

Session 0/Enrollment
- Child age & sex (249)
- Parent ethnicity (249)
- Poverty status (239)

Session 1: Asthma, AR and comorbidity
- Asthma Severity (249)
- Asthma Control (212)
- AR severity (214)
- AR Control (189)
- Asthma & AR medications (216)
- Overweight/obesity status (216)

Fall monitoring period
- Sleep quality indicators/actigraphy (212)
- Lung function/FEV1 (180)
- Daily self-reported asthma symptoms (221)
- Sleep Disordered Breathing (219)
- Teacher report (205)

End of School year
- School absences (161)

Figure 1. Data collection time points and number of cases with complete data, by assessment.

Preliminary Analyses
Age was significantly negatively related to sleep duration ($r = -0.291$, $p < .001$). Female participants had better academic performance ($F_{1, 203} = 4.78, p = .03$) and sleep efficiency ($F_{1, 210} = 6.239, p = .013$) than male participants. Poverty status was associated with more absences ($F_{1, 153} = 5.454, p = .021$) and poorer academic performance ($F_{1, 192} = 4.499, p = .035$) and approached significance with shorter sleep duration ($F_{1, 201} = 3.593, p = .059$). More severe asthma was associated with worse asthma-related lung function (FEV1%; $r = -0.182, p = .015$) and lower sleep efficiency ($r = -0.160, p = .024$). Better sleep efficiency was associated with shorter duration ($r = -0.137, p = .045$). FEV1% was significantly associated with worse AR control ($r = -0.159, p = .048$). Based on this pattern of associations, no variables emerged as significant covariates for planned analyses.

Comorbidity Prevalence
Figure 2a shows the proportion of AR, overweight/obesity, and SDB risk in the sample and by ethnicity.

Figure 2b depicts the distribution of CRI scores in the sample. There were no significant ethnic group differences on comorbidity prevalence rates or on CRI scores.

Associations Between Individual Comorbid Conditions, Sleep, and Academic Functioning
In regression models examining the association between each individual comorbid condition (AR control, BMI percentile, and SDB risk) and sleep efficiency, sleep duration, school absences, and teacher report of academic functioning (Table I), a conservative Bonferroni-adjusted alpha level of 0.004 was applied due to multiple comparisons. AR control was associated with fewer absences in the full sample ($b = -0.53, SE = 0.17, \eta_{partial}^2 = .08, p = .001$), and higher caregiver-reported SDB risk was associated with more absences in the full sample ($b = 20.46, SE = 4.06, \eta_{partial}^2 = .15, p < .001$) and in the Latino group ($b = 19.38, SE = 5.35, \eta_{partial}^2 = .16, p < .001$). Effect sizes for all models were small to medium (Ferguson, 2009), accounting for <20% of the variance in each specific sleep or academic outcome. All regression models (including nonsignificant models) are presented in Table I.

Association Between Cumulative Comorbidities, Sleep, and Academic Functioning
In regression models examining the association of CRI score and sleep efficiency, sleep duration, school absences, and teacher report of academic functioning (Table I), higher CRI scores (more comorbidities) were significantly associated with decreased sleep duration ($b = -6.69, SE = 3.14, \eta_{partial}^2 = .02, p = .03$) and increased absences ($b = 2.76, SE = 1.07, \eta_{partial}^2 = .05, p = .01$) across the sample. However, effect sizes for both these associations were small, accounting for <5% of the variance in both absences and sleep duration. When examined by ethnic group, higher CRI score was significantly associated with more absences only for NLW children ($b = 7.38, SE = 2.75, \eta_{partial}^2 = .27, p = .01$), with CRI score accounting for 27% of the variance in absences (medium effect size; Ferguson, 2009). All CRI regression models (including nonsignificant models) are presented in Table I.

The Moderating Role of Cumulative Comorbidities in the Association Between Asthma-Related Lung Function, Sleep, and Academic Functioning
When CRI score was examined as a moderator of the association between asthma-related lung function (FEV1% predicted) and sleep (efficiency, duration) and academic outcomes (absences, academic functioning), the interaction between CRI score and FEV1%
predicted ($b = -0.08, SE = 0.03, p = .003$) was significantly associated with sleep efficiency (Table II). Post hoc probing revealed that better lung function was significantly associated only with more optimal sleep efficiency for children with one comorbid condition ($b = .098, SE = 0.04, p = .03$). CRI score was not a significant moderator across remaining models (Table II).

**Discussion**

The current study examines the unique and combined associations among common asthma-related comorbid conditions with sleep and academic outcomes, in a carefully evaluated sample of urban children with asthma. We build on previous work by applying a cumulative risk approach, which uniquely quantifies both the presence and severity of multiple comorbidities.

There was a high proportion (85%) of children with AR in this sample, consistent with what is expected among children with persistent asthma (de Groot et al., 2012). High proportions of the sample also met criteria for overweight/obesity (39.4%) and elevated SDB risk (43.8%), consistent with previous work examining asthma and these comorbidities (Bixler et al., 2009; Matricardi, Grüber, Wahn, & Lau, 2007). When examining the number of comorbidities within ethnic minority groups, AA children had the highest rates of AR (89.2%) and SDB risk (48.2%), whereas Latinos had the highest rates of overweight/obesity (41.7%). On CRI score, AA children endorsed the most comorbidities (20.5% for 3), followed by Latino children (18.1% for 3; Figure 2b); together, results suggest ethnic minority children in our sample have a high burden of asthma-related comorbidities, consistent with the elevated environmental risks noted for this group (Koinis-Mitchell, Kopel, Boergers, McQuaid, et al., 2015).

**Associations Among Comorbid Conditions, Sleep, and Academic Outcomes**

When examining associations between specific comorbidities and sleep and academic outcomes, we found that SDB risk was more strongly associated with school absences, both in the entire sample and within the Latino group, and that better AR control
was more strongly associated with fewer school absences in the entire sample only. Although effect sizes were small, our findings build on previous work linking asthma morbidity with poorer school attendance (Gruchalla et al., 2005). Minority children, in particular Latino children, miss more school than their AA and NLW counterparts (Daniel, Boergers, Kopel, & Koinis-Mitchell, 2012). As SDB risk in children with asthma has not been examined, our findings suggest that SDB may contribute to declines in academic performance, in the form of greater school absences, among urban children with asthma. In addition, our findings suggest better AR control may decrease risk of school absences among children with persistent asthma. For example, poor AR control may exacerbate asthma, and these combined symptoms may influence decisions about whether to stay home from school. Thus, expanding caregiver education on preventative asthma management to include a review of AR as a trigger for asthma-related lung function.

Table I. Associations Between Comorbid Conditions and Sleep and Academic Outcomes

<table>
<thead>
<tr>
<th>Outcomes by Predictor(s)</th>
<th>Full sample</th>
<th>Latino</th>
<th>AA</th>
<th>NLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR control</td>
<td>0.16 (.06)**</td>
<td>0.12 (0.80)</td>
<td>0.12 (0.11)</td>
<td>0.27 (.14)</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>-0.004 (.01)</td>
<td>0.01 (.01)</td>
<td>-0.01 (.02)</td>
<td>-0.02 (.02)</td>
</tr>
<tr>
<td>SDB risk</td>
<td>-0.93 (1.41)</td>
<td>0.26 (1.97)</td>
<td>-1.15 (2.49)</td>
<td>-3.04 (3.54)</td>
</tr>
<tr>
<td>CRI score</td>
<td>-0.28 (.32)</td>
<td>-0.16 (.44)</td>
<td>-0.32 (.54)</td>
<td>-0.42 (.91)</td>
</tr>
<tr>
<td>Sleep duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR control</td>
<td>0.37 (.59)</td>
<td>-0.59 (.79)</td>
<td>0.86 (1.08)</td>
<td>-0.15 (1.56)</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>-0.22 (.10)*</td>
<td>-0.22 (.14)</td>
<td>-0.29 (.16)</td>
<td>-0.06 (.22)</td>
</tr>
<tr>
<td>SDB risk</td>
<td>-29.53 (13.61)*</td>
<td>-22.83 (17.83)</td>
<td>-30.12 (24.09)</td>
<td>-19.44 (34.34)</td>
</tr>
<tr>
<td>CRI score</td>
<td>-6.69 (3.14)*</td>
<td>-6.94 (4.20)</td>
<td>-4.63 (5.31)</td>
<td>-8.04 (8.49)</td>
</tr>
<tr>
<td>Absences</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR control</td>
<td>-0.53 (.17)**</td>
<td>-0.18 (.24)</td>
<td>-0.94 (.32)**</td>
<td>-0.65 (.31)*</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>0.003 (.03)</td>
<td>-0.02 (.04)</td>
<td>-0.05 (.06)</td>
<td>0.09 (.07)</td>
</tr>
<tr>
<td>SDB risk</td>
<td>20.46 (4.06)***</td>
<td>19.38 (5.35)***</td>
<td>18.89 (7.60)*</td>
<td>27.68 (11.53)*</td>
</tr>
<tr>
<td>CRI score</td>
<td>2.76 (1.07)*</td>
<td>1.82 (1.40)</td>
<td>1.98 (1.96)</td>
<td>7.38 (2.75)*</td>
</tr>
<tr>
<td>Teacher-reported academic functioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR control</td>
<td>0.007 (.006)</td>
<td>0.001 (.008)</td>
<td>0.001 (.01)</td>
<td>0.01 (.01)</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>-0.001 (.01)</td>
<td>0.0003 (.0011)</td>
<td>-0.003 (.001) *</td>
<td>-0.0001 (.001)</td>
</tr>
<tr>
<td>SDB risk</td>
<td>-0.18 (.13)</td>
<td>0.19 (.19)</td>
<td>-0.43 (.22)</td>
<td>-0.72 (.27)*</td>
</tr>
<tr>
<td>CRI score</td>
<td>-0.04 (.03)</td>
<td>0.02 (.05)</td>
<td>-0.09 (.05)</td>
<td>-0.12 (.06)</td>
</tr>
</tbody>
</table>

Note. A conservative Bonferroni correction applied to individual AR control, BMI percentile, and SDB risk (i.e., non-CRI) models due to multiple comparisons; p ≤ .05, **p ≤ .01, ***p ≤ .001; AA = African American; NLW = non-Latino White; BMI = body mass index; SDB = sleep disordered breathing; AR = allergic rhinitis; CRI = cumulative risk index.

Table II. Moderation of Cumulative Co-morbidities on Sleep and Academic Functioning

<table>
<thead>
<tr>
<th>Outcomes by Model Step</th>
<th>b</th>
<th>SE</th>
<th>t</th>
<th>p</th>
<th>ηpartial^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRI score</td>
<td>6.86</td>
<td>2.36</td>
<td>2.90</td>
<td>0.004***</td>
<td>0.004</td>
</tr>
<tr>
<td>FEV1% predicted</td>
<td>0.16</td>
<td>0.06</td>
<td>2.73</td>
<td>0.007***</td>
<td>0.00004</td>
</tr>
<tr>
<td>CRI score × FEV1% predicted</td>
<td>-0.08</td>
<td>0.03</td>
<td>-3.04</td>
<td>0.003***</td>
<td>0.006</td>
</tr>
<tr>
<td>Sleep duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRI score</td>
<td>-16.89</td>
<td>24.10</td>
<td>-0.70</td>
<td>0.48</td>
<td>0.02</td>
</tr>
<tr>
<td>FEV1% predicted</td>
<td>0.22</td>
<td>0.38</td>
<td>0.38</td>
<td>0.71</td>
<td>0.03</td>
</tr>
<tr>
<td>CRI score × FEV1% predicted</td>
<td>0.13</td>
<td>0.28</td>
<td>0.44</td>
<td>0.66</td>
<td>0.001</td>
</tr>
<tr>
<td>Absences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRI score</td>
<td>0.29</td>
<td>8.54</td>
<td>0.03</td>
<td>0.98</td>
<td>0.05</td>
</tr>
<tr>
<td>FEV1% predicted</td>
<td>-0.03</td>
<td>0.19</td>
<td>-0.15</td>
<td>0.88</td>
<td>0.001</td>
</tr>
<tr>
<td>CRI score × FEV1% predicted</td>
<td>0.03</td>
<td>0.09</td>
<td>0.31</td>
<td>0.75</td>
<td>0.001</td>
</tr>
<tr>
<td>Teacher-reported academic functioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRI score</td>
<td>0.26</td>
<td>0.25</td>
<td>1.05</td>
<td>0.29</td>
<td>0.002</td>
</tr>
<tr>
<td>FEV1% predicted</td>
<td>0.01</td>
<td>0.01</td>
<td>1.71</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>CRI score × FEV1% predicted</td>
<td>-0.003</td>
<td>0.002</td>
<td>-1.14</td>
<td>0.26</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note. *p < .05; **p < .01; ***p < .001; CRI = cumulative risk index; FEV1% predicted = asthma-related lung function.
Associations Among Multiple Comorbid Conditions, Sleep, and Academic Outcomes

When examining associations among the number of asthma-related comorbidities, sleep, and academic outcomes, results indicate children with more comorbid conditions were at greater risk for shorter sleep duration and more absences. Building on previous work examining the association between individual comorbidities (i.e., AR, obesity, or SDB) and sleep and academic functioning (Koinis-Mitchell, Kopel, Boerger, Ramos, et al., 2015), findings from the current study suggest the cumulative presentation of comorbidities (e.g., AR, obesity, and SDB risk) may increase risk for poor sleep and more missed days of school. Even small effects within our observational study suggest that the presence of multiple comorbidities may be associated with poor academic functioning in the form of school absences for urban minority youth. This highlights the importance of assessing and treating each comorbid condition in this high-risk group, as children’s sleep and daytime functioning may be affected. Ethnic group analyses indicated that the association between more comorbidities and school absences was most robust within the NLW group, accounting for 22.8% of the variance in absences within this group. Although the mean number of school absences was highest in the Latino group (M = 13.07, SD = 8.49) relative to the other ethnic groups (AA: M = 10.48, SD = 9.36; NLW: M = 10.96, SD = 10.73), there was more variability in number of school absences in the NLW group, which may have affected study results. Considering the multiple comparisons made in the current study, additional research in larger samples of urban children is needed to replicate our findings. Further, as associations may vary by ethnic group, additional exploration of the unique associations between comorbid conditions, sleep, and academic outcomes should be completed within each specific ethnic minority group.

In models examining the moderating role of CRI score, results suggested a conditional effect of the number of comorbidities on the association between asthma-related lung function and sleep quality (sleep efficiency), although this only accounted for a small portion of the variance in sleep efficiency. Specifically, for children with one comorbid condition, better asthma-related lung function was associated with more optimal sleep efficiency. In our sample, the CRI score did not moderate the association between asthma-related lung function and sleep efficiency for children with two or three comorbid conditions. Considering the potentially increased impairment and greater risk for asthma morbidity experienced by children with more comorbidities, findings suggest children with more comorbid conditions (i.e., two to three) may be better captured from a clinical and academic standpoint because they are in need of more health-related services (e.g., urgent care or Emergency Department visits or visits to the nurse; Koinis-Mitchell et al., 2007). Healthcare utilization and available school supports will be important factors to consider in future research assessing children with asthma who may present with comorbid conditions that can affect their sleep and academic functioning.

Limitations

To our knowledge, this is the first study to examine a CRI of comorbid medical conditions and its association with sleep and academic outcomes within a sample of carefully evaluated children with asthma and AR. Although this study provides a unique approach, there are several limitations. First, we were unable to measure objective SDB using the gold standard approach of polysomnography (PSG). Dependence on parental awareness of SDB symptoms likely underestimates the true prevalence. However, our findings linking SDB risk with increased absences, especially among Latinos, suggest that further research should invest in PSG-based measurement to replicate and further clarify our findings.

Second, there are limitations that should be noted with regard to our measures of academic functioning. As absences were assessed for the entire academic year in which families participated in the current study, we were unable to determine which school absences were due to asthma status or other factors such as family illness, vacation, etc. In addition, the teacher-reported measure of academic functioning has not been formally validated among urban children who have asthma; thus, future research is needed to replicate our findings with other samples of urban children with asthma.

Third, although the goal of the current article was to examine the cumulative impact of AR, overweight/obesity, and SDB risk on sleep and academic functioning, the potential collinearity across symptoms of asthma, AR, overweight/obesity, and SDB risk may have impacted findings of the current study. Thus, future research is needed to tease apart the specific symptoms within each comorbid condition (e.g., upper respiratory inflammation and decreased esophageal space) for a more nuanced understanding of how these comorbid conditions impact sleep and academic functioning in children with persistent asthma.

Fourth, although not considered in this study, sociocultural factors (e.g., urban stressors such as level of home/neighborhood noise) have been associated with poorer sleep quality (Martin et al., 2017) and may also be related to poorer academic functioning. Fifth, due to our focus on urban children, we oversampled ethnic minorities relative to NLW children in an effort to obtain a representative sample. Sixth, there was a large amount of missing data for
assessments collected after the enrollment session. Though missing data are not uncommon in longitudinal studies or in studies involving urban families, it may have contributed to lack of power in ethnic minority subsample analyses. Further, our results may represent a subsample of urban minority youth, as many eligible participants (45%) chose not to participate. Seventh, a conservative Bonferroni correction was used to correct for multiple comparisons, which may have resulted in missing important findings due to the highly conservative nature of this approach. Eighth, our focus on children between 7 and 9 years old limits the implications of our findings to the early elementary period. Finally, although similar methods have been used to quantify the level of risk within a population, the reliability and validity of our CRI score have not been empirically established.

**Future Directions**

The current study highlights the importance of assessing for comorbid medical conditions among children with asthma. Our findings demonstrated increased risk of poorer sleep and increased frequency of school absences among urban minority children with asthma who also had more comorbid conditions. Results suggest that assessment and treatment approaches for this high-risk group need to consider how these comorbid conditions may relate to asthma morbidity (Koinis-Mitchell, Kopel, Boergers, Ramos, et al., 2015) and to children’s sleep and daytime functioning. Given that managing asthma in the context of urban stressors may be challenging, integrated clinical approaches to medical care for children with asthma, that consider the unique and combined impacts of asthma-related comorbidities, may be more suitable to families burdened with treating several illnesses simultaneously. Enhancing caregiver’s awareness and knowledge of how each condition may relate to asthma and children’s functioning, and developing a step-by-step plan outlining the treatment approach for each condition in the context of the family’s daily life and stressors, may be more acceptable for the family and beneficial to the child’s asthma control. Moving forward, future research in this area should include specific family-level measures of stress (e.g., life stressors, caregiver psychopathology, and level of conflict), as these stressors may alter each family’s ability to access appropriate treatment and manage the child’s asthma, as well as other comorbid conditions.

Proper assessment of potential comorbidities, consideration of how these conditions interact with one another and exacerbate asthma, and treatment approaches that prioritize which condition to treat first based on level of risk are important factors for providers to consider when treating urban children with persistent asthma. Clinically, the burden of care associated with multiple appointments across different clinics, especially for urban minority children with asthma, may be further improved if children receive their asthma care at a multidisciplinary clinic. Thus, asthma and allergy clinics focusing on children with asthma should include additional providers who can assess and treat each comorbid condition simultaneously (e.g., psychologists to implement medication adherence plans and behavioral weight loss/physical activity interventions specific to the needs of children with asthma), reducing patient burden of attending multiple appointments.

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**Conflicts of interest:** None declared.

**References**


**References**


asthma control in children with asthma. Thorax, 67, 582–587.


Matricardi, P. M., Gruiber, C., Wahn, U., & Lau, S. (2007). The asthma-obesity link in childhood: Open questions, complex evidence, a few answers only. Clinical and Experimental Allergy, 37, 476–484.


