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Asthma-related lung function, sleep quality, and sleep duration in urban children☆,☆☆

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ABSTRACT

Objectives: Examine (1) the extent to which changes in objectively measured asthma-related lung function (forced expiratory volume in 1 second) within a sleep period are associated with sleep quality and sleep duration during that sleep period in a group of urban children with persistent asthma, (2) associations between morning and evening asthma-related lung function and sleep quality and duration on the adjacent night, and (3) whether these associations differ by ethnic group.
Design: Cross-sectional, multimethod approach. Children completed a clinic assessment of asthma and allergy status and used home-based objective measurements of asthma-related lung function and sleep.
Setting: Children and their caregivers participated in a clinic assessment at an asthma and allergy clinic and completed additional assessments at home.
Participants: Two hundred and sixteen African American, Latino, and non-Latino white urban children, ages 7-9 years, and their primary caregivers.
Measurements: Participants took part in a clinic assessment of asthma and allergy status, completed interview-based questionnaires including a diary to track asthma symptoms and sleep patterns, and used actigraphy and home-based spirometry daily across a 4-week period to assess sleep and lung function.
Results and conclusions: Results from analyses using structural equation modeling revealed an association between worsening asthma-related lung function and poor sleep quality in the full sample, as well as better asthma-related lung function at night and more optimal sleep efficiency that night. Ethnic group differences emerged in the association with morning or nighttime lung function measurements and sleep quality. Urban minority children with asthma may be at heightened risk for poorer quality sleep. Timing of lung function worsening may be important when considering when and how to improve both asthma health outcomes and sleep quality within specific groups.

Introduction

Good quality sleep (with no interruptions) and a developmentally appropriate amount of sleep are integral to children's optimal daytime functioning and physical health.[1,2] Children with asthma are particularly vulnerable to poor quality sleep, as nocturnal asthma symptoms can make it difficult to initiate and maintain sleep.[3,4] Furthermore, when asthma is poorly controlled, children may awaken often during the night.[5–7] Those with severe, persistent asthma are more at risk, as nocturnal asthma symptoms may occur more frequently and disrupt sleep continuity.[3,8] Cross-sectional studies of

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children with asthma have shown associations between caregiver reports of nighttime symptoms and disturbed or insufficient sleep, as well as links between disturbed sleep and increased daytime sleepiness,[9,10] poorer school performance, and more school absences.[8,11] Results from a few small studies using polysomnography also have shown that adults with asthma have longer sleep onset latencies than healthy controls.

Disrupted and shortened sleep also may affect the occurrence of asthma symptoms, although research to date is sparse and is based on studies with very small samples. In two experimental studies of adults with asthma, acute sleep restriction was associated with increased bronchoconstriction.[12,13] A study of adolescents with asthma showed that sleep restriction resulted in an average 7%-8% decrease in overnight lung function.[14] Thus, asthma can affect sleep, and shorter sleep may impact nocturnal asthma,[15–17] although more research is needed to assess this bidirectional relationship.

Multilevel factors (eg, pathophysiological, environmental, individual, and family related) can contribute to the association between nocturnal asthma and sleep disruption.[4] Briefly, increased exposure to home environmental triggers,[18] pollen counts, poorer adherence to daily controller medications,[19] and sleep posture can facilitate mucus production and inflammation, and increase risk for nocturnal symptoms and night awakenings.[20,21] Furthermore, urban minority children with asthma are exposed to a range of contextual and cultural risk factors that can increase asthma symptoms,[2,3,22] challenge symptom management,[23] and affect optimal sleep.[3,24] These urban risks, detailed elsewhere,[3,22] include increased poverty, which can contribute to higher levels of stress within the home; neighborhood stressors (eg, crime); and acculturative stress and discrimination.[25] Furthermore, urban stressors (eg, noise, crowded housing) can affect children's sleep environment[2] and sleep behaviors (eg, inconsistent sleep/wake times).[26] Urban children with asthma are at greater disadvantage for poor sleep quality and shortened sleep due to combined risks related to asthma status and urban poverty.

The extent to which sleep is disrupted due to asthma, or the frequency of nighttime awakenings, is a critical indicator of asthma control and severity.[27] Given that urban minority children with asthma are at increased risk for poor sleep, decreasing nocturnal asthma symptoms and enhancing sleep quality are important targets for intervention for this high-risk group. Yet, to date, there are no published studies that have objectively assessed the extent to which asthma is associated with sleep quality in urban children over time. In the current study, we used objective methods to assess asthma-related lung function (namely, FEV1 percent predicted, through home spirometry) and sleep quality (sleep efficiency, awakenings, and sleep duration through actigraphy) in real time over a 4-week period in a group of urban school-aged children with persistent asthma from non-Latino white, Latino and African American (AA) backgrounds. Specifically, we examined the extent to which changes in FEV1% predicted measured in the evening to the following morning of the sleep period were associated with sleep quality and sleep duration within the same sleep period. Based on prior work,[3,22] we expected that greater changes in asthma-related lung function (greater reduction in FEV1) would be associated with poorer sleep quality and shorter sleep duration in the entire sample and that the association would be more robust in children from Latino and AA backgrounds, given increased asthma morbidity documented in these groups.[28–31]

To further understand the extent to which the timing of asthma-related lung function worsening (ie, time of day) affects sleep in the children of our sample, we also examined the extent to which morning and evening lung function values were associated with sleep quality and duration on that adjacent night over the sleep period. Results from this analyses may more precisely inform targeted interventions integrating asthma and sleep for this high-risk group. Given published reports showing diurnal lung function variation in children with asthma, with the lowest lung function levels occurring during children's first awakening in the morning,[32–35] we expected the association between FEV1 in the morning and sleep quality and duration for the prior night to be more robust; however, we also recognized that lower FEV1 in the evening would certainly affect that night's sleep quality. This hypothesis was examined on an exploratory basis given that there is no prior literature that has tested this question in our targeted population.

Participant and methods

Data were collected for a larger study—Project Nocturnal Asthma and Performance in School—that assessed the cooccurrence of asthma, sleep quality, and academic functioning in urban children with persistent asthma and healthy controls across one academic year. The current study includes data from asthma participants.

Participants were recruited from the four largest and adjacent urban school districts in an urban Northeast US city, from hospital-based ambulatory pediatric clinics, and from a hospital-based asthma education program. “Consent to Contact” forms were distributed in these locations; these are forms that, when signed by the caregiver, allow study staff to call the family to describe the study and determine the child's eligibility and family's interest in participating. We also received direct referrals from these recruitment sources.

Eligibility criteria required that the child was between 7 and 9 years old; child's legal guardian was willing to participate and self-identified as Latino (Dominican or Puerto Rican), black/AA, or non-Latino white; child attended public school in 1 of the 4 targeted urban school districts and resided in 1 of these 4 targeted urban areas as defined by the family's zip code; and child had physician-diagnosed asthma or breathing problems in the previous 12 months. Additionally, at screening, each child could be classified as having persistent asthma either by caregiver report of a current prescription for an asthma controller medication or by report of recurrent daytime or nighttime symptoms, activity limitation, rescue medication use, or 2 or more oral steroid bursts the prior 12 months.[27] Exclusionary criteria included moderate to severe cognitive impairment as indicated by school placement, use of stimulant medication for attention-deficit/hyperactivity disorder, another pulmonary or chronic health condition, or a diagnosed sleep disorder (eg, restless leg syndrome, chronic insomnia) that would confound the primary hypotheses of the larger study. We elected to not exclude children with sleep-disordered breathing (SDB), as this is a highly comorbid condition in this population and we are ultimately interested in designing “real-world” interventions for this group. We did assess the extent of SDB using a well-validated caregiver report measure.[36]

Data included in the current report were collected during the fall and winter of each study year. Demographic information and information regarding asthma and allergic rhinitis (AR) medication use were collected at the initial study visit. The second session occurred at our hospital-based asthma and allergy clinic at least 2 weeks later, during which study clinicians evaluated children's asthma and AR diagnosis and severity and their allergy status, and confirmed asthma and AR medication use. Immediately following this visit, children and their caregiver participated in a 4-week home-monitoring period, during which the child used a portable device twice daily to assess lung function and wore an actigraph to assess sleep quality. Participants also completed a daily diary containing information relevant for processing and scoring objective sleep and asthma data (eg, times when actigraph was not worn, days child experienced illnesses other than asthma). Standardized training procedures on the use of these devices were implemented during the first visit and the subsequent clinic visit (see below). Midway through the monitoring period, study staff returned to the home to download and review

electronic sleep and lung function data and to collect information on asthma and AR control and sleep hygiene. Staff implemented standard procedures to encourage protocol adherence.[3,37]

Assessments were administered verbally in English or Spanish by research staff fluent in both languages and according to participants' preference. Standardized procedures were used for the translation of instruments.[38] Participants received monetary compensation for all sessions completed. Approval for the larger study was obtained from the Institutional Review Board of the hospital where this study was conducted.

Measures

Demographic and descriptive information

Primary caregivers provided key demographic information (Table 1). Poverty status was a dichotomous variable that was computed by comparing each family's annual income to the US per capita poverty threshold for the year of their study participation.[39] Caregivers reported on children's risk for SDB using a well-validated and reliable questionnaire.[36]

Physician query

Child participants' primary care providers as well as asthma/allergy specialists (when applicable) completed a checklist detailing the date of child's last office visit, asthma and/or AR diagnosis, suspected allergy triggers, significant past medical history, and current asthma and rhinitis treatment. The study clinician used this query as background information to evaluate the child's asthma and allergy status see below.[22,40]

Asthma diagnosis and classification of asthma severity

The clinic study visit consisted of a medical history and physical examination, allergy skin prick testing, and pulmonary function testing. Confirmation of both asthma diagnosis and severity classification were made by a study clinician using standard asthma clinical guidelines.[27] Caregiver reports of children's asthma medication use and adherence were noted. Lung function measurements (FEV1, forced vital capacity, etc) were evaluated using the Koko incentive spirometer (nSpireHealth, Longmont, CO) before and after short-acting β-agonist administration.[41] Children's height and weight were measured at this visit, from which body mass index was computed using normative data.[42]

AR diagnosis and classification of severity

Previous diagnosis of AR was not a requirement for study entry; however, AR was evaluated by (1) evidence on physical examination, (2) type and frequency of parent report of AR symptoms in the past-month AR Symptom Summary[43,44]; and (3) allergy skin prick testing

Table 1
Demographic variables, asthma and AR clinical characteristics, and sleep characteristics: full sample and by ethnic group† a, ab, bc, cd

	Sample	Latino	Black/AA	Non-Latino white	Ethnic group differences	Effect sizes[a]
n	216	111	71	34	–	–
Sociocontextual characteristics						
Child age (y), *M* (95% CI)	8.3 (8.2-8.4)	8.3 (8.2-8.5)	8.3 (8.1-8.5)	8.3 (8.0-8.6)	$F < 1.0$	−.01
Male (%)	53%	51%	63%	38%	$\chi^2 = 6.3^*$	.17
Caregiver race/ethnicity (%)						
Black/AA	33	–	–	–	–	–
Latino	51	–	–	–	–	–
Non-Latino white	16	–	–	–	–	–
At/below poverty threshold (%)[b]	70	80	64	45	$\chi^2 = 15.7^{***}$	.28
Asthma and allergy clinical characteristics and comorbidities						
Asthma severity (%)	–	–	–	–	$\chi^2 = 6.1$	.12
Mild persistent	56	58	50	60	–	–
Moderate persistent	31	30	29	36	–	–
Severe	13	12	20	3	–	–
Asthma poorly controlled (%)	40	33	49	39	$\chi^2 = 4.7$	.15
No. of positive allergy skin test results, *M* (95% CI)[c]	3.2 (2.8-3.5)	2.8 (2.3-3.3)	4.1 (3.4-4.8)	2.3 (1.8-3.0)	$F = 7.5^{**}$	.07
FAMSS environmental control rating, *M* (95% CI)[d]	3.9 (3.6-4.3)	4.3 (3.8-4.7)	4.0 (3.3-4.6)	2.7 (2.0-3.5)	$F = 4.5^*$	.03
Rhinitis symptoms poorly controlled (%)	39	40	45	21	$\chi^2 = 4.5$	.16
Asthma medications (%)						
Any controller medication	78	77	84	76	$\chi^2 = 1.5$	.09
Inhaled corticosteroid	73	72	78	64	$\chi^2 = 2.3$	.11
Asthma medication adherence (FAMSS), *M* (95% CI)	3.6 (3.4-3.9)	3.5 (3.2-3.9)	3.7 (3.3-4.0)	3.9 (3.3-4.4)	$F < 1.0$	.01
AR medication use, first-generation antihistamine (%)	18	19	19	9	$\chi^2 = 1.9$	.10
BMI percentile, *M* (95% CI)	73.3 (69.7-76.8)	75.3 (70.5-80.2)	70.8 (64.7-76.9)	72.3 (61.9-82.7)	$F < 1.0$	.00
Asthma-related lung function indicators						
FEV1% predicted, morning measurement, *M* (95% CI)	81 (79-83)	80 (77-83)	85 (82-88)	79 (73-85)	$F = 2.7$	.02
FEV1% predicted, evening measurement, *M* (95% CI)	84 (82-86)	84 (81-86)	87 (84-90)	81 (75-88)	$F = 1.9$	.01
FEV1 change (%), M (95% CI)	−2.3 (−3.2 to −1.4)	−2.6 (−3.8 to −1.3)	−2.39 (−4.2 to −0.5)	−1.4 (−3.2 to 0.3)	$F < 1.0$	.00
Sleep characteristics						
SDB score, *M* (95% CI)	.33 (.31-.36)	.34 (.30-.37)	.35 (.31-.39)	.29 (.23-.35)	$F = 1.6$	.01
Sleep hygiene total score, *M* (95% CI)[b]	4.5 (4.4-4.6)	4.4 (4.3-4.5)	4.5 (4.3-4.6)	4.7 (4.5-4.9)	$F = 3.3^*$	.02
Sleep efficiency (%), *M* (95% CI)	87 (86-87)	87 (86-88)	86 (85-87)	87 (86-88)	$F = 2.6$	.02
Sleep duration (h), *M* (95% CI)[b]	9.3 (9.2-9.3)	9.1 (9.0-9.2)	9.3 (9.1-9.4)	9.6 (9.4-9.8)	$F = 9.6^{***}$	.08
Mean # of awakenings per night, *M* (95% CI)	5.3 (5.0-5.7)	5.2 (4.7-5.7)	5.6 (5.0-6.2)	5.2 (4.4-6.0)	$F < 1.0$	−.01

$^*P < .05$, $^{**}P < .01$, $^{***}P < .001$.
[a] ANOVA effect sizes are ω^2_p; χ^2 effect sizes are ϕ_c.
[b] Significant group differences were between non-Latino white and Latino ethnic groups.
[c] Significant group differences were between AAs and the other 2 ethnic groups.
[d] Significant group differences were between non-Latino whites and the other 2 ethnic groups.

(Greer Laboratories, NC) to perennial and seasonal allergens. AR severity was classified according to clinical practice guidelines[43] as intermittent or persistent (*persistent status* defined as AR symptoms greater than 4 days a week for every week of the month) and mild, moderate, or severe.[45]

Asthma control

At the end of the monitoring period, parents and children completed the Asthma Control Test,[46] a well-validated questionnaire of asthma-related impairment. Using standardized scoring procedures,[47] a dichotomous variable was computed using a total cutoff score of 19; those below were considered to have poor asthma control, and those above to have well-controlled asthma. Continuous asthma control scores (higher scores = better control) were maintained for selected analyses, an approach used in our prior work.[48]

Lung function: FEV1% predicted

Children's lung function measurements were assessed twice daily at home, in the morning and evening, during the 4-week monitoring period using a hand-held computerized spirometer (Jaeger AM2+; VIASYS Healthcare, Yorba Linda, CA). At the beginning of each session, research assistants oriented both the parent and child to the proper use of the device as well as how to perform a forced, sustained expiration into the device using standard procedures from our previous research.[48] Participants were instructed to complete 3 "blows" each morning and each evening prior to taking any asthma or allergy medications. Device data were downloaded by research assistants during a brief research visit at the midpoint and end of each monitoring period. The best of 3 blows (ie, the highest FEV1% predicted value) was retained for each morning and evening trial. Details concerning data cleaning and reduction procedures have been published previously,[37,49] including normative values used for FEV1 based on children's age.[50,51] FEV1 change scores were computed to characterize magnitude and direction of lung function changes from the evening to the next morning.

Nighttime FEV1 values were subtracted from the next morning's FEV1. The difference was divided by the morning measurement and multiplied by 100 to yield a percent change value. Negative change values indicate a decrease in lung function from the evening to the following morning; positive scores indicate an increase in lung function during the night.

Asthma and allergy medication use

During the study clinic visit, the study clinician documented children's current asthma and allergy medications. Caregivers provided ratings indicating how often their child missed doses of daily controller medications on a scale from 1 (misses doses all of the time) to 5 (never misses doses.[52] Seventy-eight percent of caregivers reported that their children were using daily asthma controller medications, and 73% reported inhaled corticosteroid use. Eighteen percent of parents reported that their children were using first-generation antihistamines for AR symptoms. The average medication adherence self-rating for the sample was 3.6, suggesting that few participants were taking their medications as prescribed all of the time.

Sleep

Participants wore an actigraph (MiniMitter Company, Bend, OR) sleep monitor on their nondominant wrist at all times during the monitoring period, except when bathing or swimming. One-minute epochs were estimated as sleep or wakefulness with Actiware-Sleep V 2.53 software using activity levels produced in the surrounding 2-minute interval (medium sensitivity). This algorithm was applied to portions of the record identified as sleep through a combination of diary reports and actigraph event markers set by participants at "lights-off" and "lights-on." In comparison to polysomnography, this algorithm shows high overall epoch-by-epoch agreement and is excellent in detecting sleep (sensitivity = 94%); however, it overestimates wake during the sleep period (specificity = 69%).[53] To inform scoring of sleep data, families recorded in the daily diary instances when the child was sick with an illness other than asthma plus morning wake times and evening bedtimes, and times when the actigraph was not worn.[54] Standard scoring rules were then applied to each sleep episode.[55] Episodes were excluded when (1) the actigraph was off for all/part of the sleep period, (2) the concurrent diary report was not available, or (3) there was a diary-reported illness other than asthma that could have affected sleep on a given night. Actigraphy data were not available for 37 children because of protocol nonadherence (n = 34) or device loss/technical failure (n = 3), and these children were not included in the data set. There were no differences between those with and without sleep data on demographic (sex, age, ethnicity, poverty) or clinical (asthma and AR severity) characteristics. Actigraphy data were available for 216 children, with an average of 18 scorable nights (SD = 8, range = 2-40). The wide range in the number of scorable nights reflects the realities of collecting objective, daily-level sleep data in urban families. A small number of participants used the watch for more than the 4-week period because of challenges scheduling the follow-up research visit, and some had a dearth of data due to protocol nonadherence or device damage/failure. Nevertheless, because our analyses were concerned with testing associations between asthma and sleep quality across all data and all participants (ie, "night" was the unit of analysis rather than case), we retained all available data and conducted analyses nested by case to control for subject-level effects.

Three sleep quality variables were computed as the aggregate across each sleep night,[3] specifically: *sleep efficiency*, defined as the % time asleep/total time in bed for the night; *sleep duration*, defined as total time between evening sleep onset and morning waking, and *mean # of awakenings* per night of at least 3 minutes in duration. We chose 3 minutes as the minimum threshold for detecting meaningful sleep disturbance, as recorded episodes of shorter length could be due to normal movement within sleep.[56] Summary variables used for sample descriptives were computed for each sleep measure by aggregating across all monitored days (weekend and weekdays).

Additional covariates

In addition to demographic and clinical characteristics (child age, sex, BMI, asthma severity, allergic status, asthma controller medication use and adherence, AR medication use, SDB, and family poverty status), we evaluated the following variables as potential covariates:

AR control

At the end of the monitoring period, parents completed the Rhinitis Control Assessment Test,[47] a well-validated questionnaire that assesses rhinitis disease control. Higher scores on this measure indicate better AR control.

Children's sleep hygiene

The Children's Sleep Hygiene Scale contains 22 parent-reported items.[57] Caretakers were asked about various behaviors that affect children's sleep initiation and maintenance, with higher scores indicating better sleep hygiene. The scale has acceptable internal consistency with school-aged children and within our own sample (Cronbach $\alpha = .70$).

Environmental trigger control

Environmental trigger control was measured with the Family Asthma Management System Scale (FAMSS),[58,59] a semistructured interview covering multiple domains of asthma management. Trained interviewers rate participants on all domains using a scale

from 1 (poor) to 9 (optimal); a total score is the mean across domains. The FAMSS has been used in cross-sectional and treatment outcome studies and has been validated with minority samples[60] and in English and Spanish.[61] Internal consistency has been very good in prior studies (Cronbach $\alpha = .84$)[62] and in the current sample (Cronbach $\alpha = .76$).

Weekend vs weekday sleep assessments

Given that children's sleep schedules may be less structured during the weekends than when they are in school, we coded all sleep nights as weekend or weekday to evaluate whether there were different patterns of association between asthma and sleep by time of week.

Analysis plan

To address study questions, we first examined the extent to which asthma-related lung function (FEV1% predicted) changes from evening to the following morning were associated with sleep quality (as measured by sleep efficiency, sleep duration, and number of awakenings each night) during that night (eg, change in FEV1 from Monday night to Tuesday morning with Monday night's sleep quality; eg, Fig. 1). We then examined whether FEV1 measured at night or in the morning more closely corresponded to that night's sleep (eg, is Sunday night or Monday morning FEV1 best associated with Sunday night's sleep quality?). Finally, we evaluated the pattern of associations described by the Latino, AA, and non-Latino white ethnic groups in our sample.

All of our study questions involved an examination of the correspondence between asthma-related lung function and sleep quality and duration across all monitored days and cases in the sample using Structural Equation Modeling (SEM).[63] The SEM functionality was used for examining these associations nested within child in a 2-level model (day level and child level). FEV1 change (from evening measurement to the following morning's) was entered as the predictor, and sleep quality (efficiency and number of nighttime awakenings) and sleep duration were entered as criterion variables. This approach still allows for the assessment of the unique association between each asthma-related lung function variable (eg, FEV1 change) and each sleep indicator. For all SEM analyses reported herein, initial models included all covariates described above; only those with statistically significant associations to predictors and criterion variables, or overall model improvement, were retained in the final models. All predictor and criterion variables were nested within subject; covariates were subject-level summary variables.

To assess whether asthma-related lung function measured at night or in the morning was more closely related to that night's sleep, a second set of SEM analyses was undertaken in which the FEV1% predicted measured at night before sleep and that in the morning after waking were considered together in models predicting sleep quality (efficiency and nighttime awakenings) and sleep duration. We then evaluated patterns of association separately for Latino, AA, and non-Latino white ethnic groups in our sample. Parameter estimates (both unstandardized and standardized) are reported in the results and tables and can be interpreted in a similar manner to the regression coefficients in multiple regression analyses. We also report the amount of variance each asthma-related lung function indicator (IV) predicts in each sleep quality variable (DV). Preliminary examination of key demographic and clinical characteristics across participants and by ethnic group was undertaken using analyses of variance (ANOVA) for continuous variables and χ^2 analyses for categorical variable. Effect sizes for ANOVAs were expressed as partial omega squared (ω^2_p), interpreted as small (0.01), medium (0.06), or large 0.14.[64] χ^2 effect sizes are expressed as Cramer's Phi (ϕ_c), the interpretation of which is akin to a point-biserial correlation. Preliminary analyses were conducted in SPSS version 22; structural equation models were evaluated in MPlus version 7.

Results

Preliminary results

Sociocontextual and clinical characteristics of the 216 participants with persistent asthma and available sleep data appear in Table 1. Mean age of participants was 8.3 years (SD = 0.90). Forty percent had poorly controlled asthma. A smaller proportion of non-Latino whites (45%) were below the poverty threshold compared with AA (64%) and Latino (80%) participants ($\chi^2 = 15.7$, $P < .001$, $\phi_c = .28$). There were no ethnic group differences on asthma severity, asthma control, asthma and allergy medication use, or parent-reported medication adherence (Table 1).

Asthma-related lung function and sleep quality and duration

When testing whether changes in FEV1 are associated with sleep quality, FEV1 change (from evening measurement to the following morning) was entered as the predictor, and sleep efficiency, sleep duration, and number of nighttime awakenings were entered as criterion variables (Fig. 1). As mentioned, we tested the contribution of each covariate for enhancing model fit. Child age, sex, and asthma

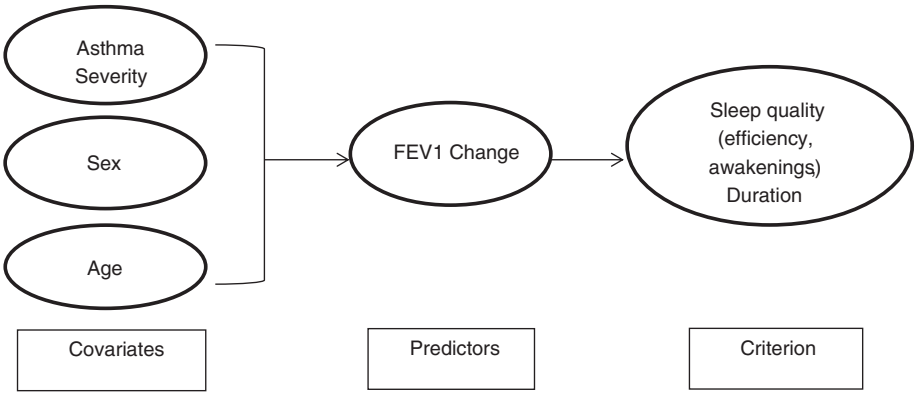

Fig. 1. Example of final model examining association between asthma activity (FEV1 change) and sleep quality and duration across fall monitoring period (nested within case).

severity were significant in initial models and were retained in the final models. Results appear in Table 2 and indicate that the model that best fit the data included sleep efficiency and nighttime awakenings (comparative fit index [CFI] > 0.99; Tucker-Lewis index [TLI] > 0.99, root mean square error of approximation [RMSEA] < 0.01) (a good fitting model includes CFI and TLI values close to 1 and an RMSEA value close to 0, indicating that model fit was not markedly different from the data). Within this model, FEV1 change predicted 13% of the variance in sleep efficiency. The standardized parameter estimate (which can be interpreted similarly to a β weight in regression models) = .36, $P = .09$. Hence, a 1-SD increase in FEV1 change is associated with less than one-half of a SD increase in sleep efficiency, although the association was only marginally significant in this model. FEV1 change did not significantly predict nighttime awakenings. The association between FEV1 change and sleep duration was not significant. Of note, during evaluation of the final model, sleep duration did not contribute to model fit in this or any of the final models we examined subsequently; therefore, duration was not retained in any final models reported herein.

Next, we evaluated whether asthma-related lung function measured at night or in the morning more closely corresponded to the adjacent night's sleep. FEV1% predicted measured at night and that measured the next morning were entered as predictors, and sleep efficiency and nighttime awakenings were entered as the criterion variables. In this model, only child sex and asthma severity were included as covariates in the final model. Results appear in Table 3 and indicated that the model that best fit the data included sleep efficiency and nighttime awakenings (CFI > 0.99, TLI > 0.99, RMSEA < 0.01). Within the model including the entire sample, higher values of FEV1% predicted measured at night were associated with better sleep efficiency that night, explaining 9% of the variance in sleep efficiency (standardized parameter estimate = .30, $P < .05$). Lung function measured in the morning was not associated with efficiency the previous night, and morning FEV1% predicted and nighttime FEV1% predicted were not associated with nighttime awakenings during the adjacent night.

Our final goal was to assess associations between asthma-related lung function and sleep quality and duration by ethnic group, as summarized in Table 4. Child age, sex, and asthma severity were included as covariates in the final models. First, we examined the association between FEV1 change and sleep quality. When we included estimation of the parameters by ethnic group in the model, overall fit remained good (CFI > 0.99, TLI > 0.99, RMSEA < 0.01). We found that patterns of associations were different across the ethnic groups. Within the Latino group, FEV1 change—specifically a decrease in lung function during the night—was significantly associated with lower sleep efficiency (standardized parameter estimate = .36, $P < .01$) and predicted 13% of the variance in efficiency. FEV1 change did not significantly predict nighttime awakenings during that same night in Latinos. Overnight changes in lung function were not significantly associated with sleep quality in the AA and non-Latino white groups.

In the examination of associations between morning and evening lung function assessments and sleep quality, the overall model fit remained good when including parameters by ethnic group (CFI > 0.99, TLI > 0.99, RMSEA < 0.01). After controlling for child sex and asthma severity, for both Latinos and non-Latino whites, we found that lower FEV1% predicted measured in the evening was associated with poorer sleep efficiency during the subsequent night's sleep period (Latinos, standardized parameter estimate = .32, $P < .05$; non-Latino whites, standardized parameter estimate = .35, $P < .05$; Table 5). In Latinos, evening FEV1% predicted accounted for 10% of the variance in sleep efficiency; in non-Latino whites, evening FEV1 accounted for 12% of the variance in sleep efficiency. In non-Latino whites, FEV1 evening measurements accounted for 12% of the variance in nighttime awakenings. Specifically, lower FEV1 evening measurements also were associated with a higher number of nighttime awakenings (standardized parameter estimate = .35, $P < .05$). For AA participants, lower morning FEV1 measurements were associated with lower efficiency (standardized parameter estimate = .36, $P < .05$) and more nighttime awakenings (standardized parameter estimate = −.36; $P < .05$) during the adjacent night's sleep (Table 5). Morning FEV1 accounted for 13% of the variance in both sleep efficiency and awakenings.

Discussion

This study examined daily correspondence of asthma-related lung function (FEV1) and sleep quality and sleep duration in a sample of urban, ethnically diverse school-aged children with persistent asthma using rigorous methods in a naturalistic setting: their home environments. Sleep is critical for optimal health, development, and functioning in childhood, and uncontrolled asthma can negatively affect sleep.[3,22] To our knowledge, this is the first study to assess the daily correspondence of asthma-related lung function and sleep objectively in this high-risk group. The in-depth examination of asthma-related lung function using morning and evening FEV1, as well as changes in FEV1, can more directly inform integrated asthma and sleep interventions for this group.

In this carefully evaluated sample, we found associations between daily-level measurements of FEV1 and sleep quality. Specifically, in the entire sample, even when controlling for confounding factors, changes in asthma-related lung function from the nighttime to the morning were marginally associated with poorer sleep efficiency. In our sample, worsening lung function may have increased the presence of nocturnal symptoms, which may have interfered with consistent sleep during the sleep period. These results suggest that worsening lung function may be an indicator that children's sleep may be at risk and highlight the importance of intervening on nocturnal asthma to improve sleep health and subsequent daytime functioning in this group.

Furthermore, the association between changes in FEV1 from the nighttime to the morning and poorer sleep efficiency was significant and more robust in the Latino children of our sample. Although this group did not have the highest proportion of children in the sample with poorly controlled asthma and the majority of Latino caregivers reported that their child was using a controller medication, our lung

Table 2
Associations between FEV1 change and sleep quality indicators in full sample

	Unstandardized parameter estimates	SE	Est./SE	Standardized parameter estimates	% Variance
Sleep quality (DVs)					
Sleep efficiency	0.383†	0.222	−1.721	0.356	13%
Awakenings	−0.201	0.286	−0.703	−0.326	11%
Covariates					
Sex	0.292	1.157	0.252	–	–
Asthma severity	−0.841	0.718	−1.172	–	–
Age	−0.025	0.666	−0.037	–	–

† $P < .10$, *$P < .05$, **$P < .01$, ***$P < .001$.

Table 3
Associations between AM and PM FEV1% predicted and sleep quality in full sample

Sleep quality (DVs)	Unstandardized parameter estimates	SE	Est./SE	Standardized parameter estimates	% Variance
Evening FEV1% predicted					
Sleep efficiency	0.322*	0.129	2.498	0.304	9%
Awakenings	0.285	0.194	1.466	0.314	10%
Covariates					
Sex	−0.937	1.745	−0.537	–	–
Asthma severity	−4.077***	1.052	−3.875	–	–
Morning FEV1% predicted					
Sleep efficiency	−0.028	0.126	−0.224	−0.324	11%
Awakenings	−0.044	0.177	−0.249	−0.329	11%
Covariates					
Sex	−1.078	1.921	−0.561	–	–
Asthma severity	−4.567***	1.134	−4.027	–	–

*$P < .05$, **$P < .01$, ***$P < .001$.

function data revealed that, on average, this group had a greater degree of worsening lung function during nights monitored compared with their AA and non-Latino white counterparts. Adherence to daily controllers may have affected these results. Future research efforts should also focus on factors that may affect the timing of asthma-related lung function to better inform interventions targeted for specific groups (eg, timing of rescue inhaler use). Other data from our study indicate that this group had the poorest environmental control scores and the highest proportion of families in poverty, which suggest that greater exposure to irritants and allergens and suboptimal sleep environments and housing may be important targets for future intervention for optimizing asthma and sleep in this group. Finally, several sleep indicators (eg, sleep hygiene and sleep duration) were poorer in Latinos compared with the other ethnic groups in the sample, which also could have affected the level of sleep efficiency in this group. Of note, each of these factors was evaluated in the development of our final models, and only those that contributed to model fit were retained.

Table 4
Associations between FEV1 change and sleep quality indicators by ethnic group

	Unstandardized parameter estimates	SE	Est./SE	Standardized parameter estimates	% Variance
Latino					
Sleep efficiency	0.717**	0.274	−2.614	0.361	13%
Awakenings	−0.458	0.376	−1.216	−0.342	12%
Covariates					
Sex	1.328	1.505	0.883	–	–
Asthma Severity	−0.896	0.925	−0.968	–	–
Age	−0.343	0.945	−0.363	–	–
AA					
Sleep efficiency	0.154	0.235	0.657	0.352	12%
Awakenings	0.252	0.336	0.752	0.312	10%
Covariates					
Sex	−1.831	2.275	−0.805	–	–
Asthma severity	−1.850	1.270	−1.457	–	–
Age	1.993	1.163	1.714	–	–
Non-Latino white					
Sleep efficiency	0.498	0.460	−1.081	0.348	12%
Awakenings	−0.150	0.560	−0.269	−0.306	10%
Covariates					
Sex	−3.188	2.875	−1.109	–	–
Asthma severity	1.039	1.986	0.523	–	–
Age	−1.993	1.431	−1.393	–	–

*$P < .05$; **$P < .01$; ***$P < .001$.

Moreover, in the entire sample, we found that FEV1 measurements in the evening were associated with sleep efficiency during that same night. Results by ethnic group revealed different patterns of associations between lung function measurements taken in the am or pm and sleep efficiency and nighttime awakenings. For example, in the Latino and non-Latino white children, lower FEV1 *at night* was associated with poorer sleep quality, and in non-Latino whites, more nighttime awakenings that same night, whereas in the AA children, lower FEV1 in the *morning*, were associated with poorer sleep quality and more nighttime awakenings that previous night.

In summary, study results suggest avenues for future research and clinical intervention focusing on asthma and sleep, including the need to evaluate patterns of asthma medication use, timing, extent and duration of exposure to environmental irritants, and/or sleep hygiene behaviors and the sleep environment (eg, consistency of bedtime/wake times, level of sleep disruptions, and number of family members in the bedroom). Several limitations also are noteworthy and suggest future areas of inquiry. Although the study allowed for the examination of the correspondence of asthma and sleep in real time through objective approaches, the design did not capture potential bidirectional or reciprocal associations. Future research using experimental approaches would allow for the assessment of the effects of sleep loss on asthma-related lung function. Furthermore, although use of actigraphy is the standard in the field in terms of providing a rigorous, objective assessment of sleep quality of children in the home environment, some challenges with its use remain. For example, there may be poor specificity of sleep detection when scoring actigraph data.

Moreover, study results showing ethnic group differences in the association between morning and evening lung function measurements and sleep quality suggest the importance of identifying factors that contribute to asthma and sleep patterns in specific ethnic groups. Sleep behaviors (eg, bed/wake time, sleep location) and other urban stressors that affect both asthma and sleep (eg, child/family psychiatric symptoms, family stress), and specific disease-management behaviors (eg, level of exposure to triggers in the child's bedroom, availability and use of rescue inhaler when needed prior to bed) should be investigated. Future research testing ethnic group differences in asthma and sleep patterns should also include larger and comparable numbers of children in each ethnic group.

Our approach did not allow for serial lung function monitoring throughout the day which would have provided an opportunity to evaluate when declines in lung function are first observed. In addition, our study findings cannot be generalized to other times of the year such as spring or summer when, for some children, asthma symptoms may be triggered by specific seasonal allergens. Finally, although study results showed that sleep quality, not duration, was linked to day-to-day changes in lung function or morning or

Table 5
Associations between AM and PM FEV1% predicted and sleep quality indicators by ethnic group

	Unstandardized parameter estimates	SE	Est./SE	Standardized parameter estimates	% Variance
Evening FEV1% predicted					
Latino					
Sleep efficiency	0.479**	0.173	2.768	0.322	10%
Awakenings	0.421	0.241	1.748	0.310	10%
Covariates					
Sex	−0.976	2.358	−0.414	–	–
Asthma severity	−3.323*	1.457	−2.282	–	–
AA					
Sleep efficiency	0.035	0.166	0.208	0.261	7%
Awakenings	−0.040	0.319	−0.124	−0.306	9%
Covariates					
Sex	−1.274	2.758	−0.462	–	–
Asthma severity	−4.392*	1.697	−2.588	–	–
Non-Latino white					
Sleep efficiency	0.765*	0.262	2.916	0.352	12%
Awakenings	−0.977*	0.491	1.988	−0.352	12%
Covariates					
Sex	1.073	6.286	0.171	–	–
Asthma severity	−9.941*	4.362	−2.279	–	–
Morning FEV1% predicted					
Latino					
Sleep efficiency	0.092	0.141	0.656	0.275	8%
Awakenings	0.174	0.210	0.828	0.274	8%
Covariates					
Sex	0.527	2.600	0.203	–	–
Asthma severity	−3.633*	1.572	−2.311	–	–
AA					
Sleep efficiency	0.392*	0.189	−2.071	0.361	13%
Awakenings	−0.601*	0.294	−2.046	−0.363	13%
Covariates					
Sex	−4.104	3.334	−1.231	–	–
Asthma severity	−6.013**	1.968	−3.055	–	–
Non-Latino white					
Sleep efficiency	0.505	0.462	1.094	0.360	13%
Awakenings	0.666	0.656	1.015	0.387	15%
Covariates					
Sex	−1.378	6.151	−0.224	–	–
Asthma severity	−10.008*	4.210	−2.377	–	–

*$P < .05$; **$P < .01$; ***$P < .001$.

nighttime lung function measurements, future work should examine the role of variability in sleep duration and lung function as well as additional indicators of asthma control (symptom reports, control). It may be that variability in sleep duration patterns may be more salient to changes in asthma status than the average amount of sleep duration during a specific sleep period. In experimental studies, restricted sleep has been shown to be important for daytime functioning in healthy children and may affect health outcomes in children of other disease groups (eg, weight status).[1,65,66]

Conclusions

This study documents an association between poor asthma-related lung function and poor sleep quality in urban children. Results suggest that reduced lung function can be a marker of impending poor sleep quality. This may have important implications for the daytime functioning of this high-risk group, who also faces other potential sociocontextual barriers related to urban living that can affect sleep quality. Results also suggest important areas for future research inquiry, including examination of asthma management behaviors and exposure to environmental triggers in relation to sleep timing that might affect both the onset of lung function decline and poorer sleep quality. Integrated interventions that consider the effects of reduced lung function on sleep and daytime functioning and how urban context can affect both asthma management and sleep quality are important for decreasing morbidity and optimizing the health and well-being of this high-risk group.

Disclosure

None.

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