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Interactive effects of family functioning and sleep experiences on daily lung functioning in pediatric asthma: An ecological momentary assessment approach

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ABSTRACT

Objectives: Children living in urban, underserved settings are at risk for experiencing sleep difficulties as well as poor asthma outcomes. The family is important for both asthma management and ensuring children are getting the necessary amount of sleep, but how family functioning and sleep patterns influence children's asthma remains unclear. **Methods:** Fifty-nine children (7–12 years old; 90% African American) diagnosed with asthma, and their primary caregivers, participated in this study. In a single research session, caregivers rated overall family functioning via the Family Assessment Device. Caregivers also completed daily diaries delivered via smartphone for a two-week period rating their children's daily sleep quantity and quality; a home-based spirometer (AM2) was used to assess children's pulmonary functioning across that same period. Two-level multilevel models tested associations among overall family functioning, children's sleep quality/quantity, and pulmonary functioning. **Results:** Child sleep quality, quantity, and general family functioning did not predict child pulmonary functioning directly. Family functioning and sleep quality interacted to predict children's pulmonary functioning; children with poor family functioning and bad/very bad sleep quality had the poorest levels of lung functioning. **Conclusions:** These findings highlight a subset of children who are at higher risk for poor lung functioning based on sleep quality and family functioning. Results may inform routine monitoring of family functioning and sleep difficulties at pediatric asthma visits and intervention strategies to augment children's lung functioning.

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Introduction

Asthma is the most common childhood chronic illness and disproportionately affects African American children living in urban areas [1]. Children living in underserved, inner-city neighborhoods are at greater risk for experiencing poverty, environmental toxins, poor access to healthcare, and other stressors that can affect asthma control and symptomology [2,3]. Asthma symptoms impact children's daily functioning; nocturnal exacerbations may also disrupt children's sleep, which subsequently affects the child's daily functioning [4,5]. Therefore, research examining factors associated with the severity of asthma, especially among children living in high risk areas, is important for reducing the burden of asthma on children and families.

Sleep plays a crucial role in physical development, emotional well-being, school performance, and quality of life [6]. Moreover, children living in urban settings

are at risk for poor sleep [7]. In longitudinal studies, children's sleep disturbances have been found to predict later anxiety and depressive symptoms, as well as behavior problems [8]. Research to date suggests that an association exists between sleep problems and asthma symptomology, although directionality of the association and which sleep characteristics matter have yet to be established [9,10]. For instance, nighttime wheezing, chest tightness, trouble breathing, and/or coughing have been consistently related to disrupted sleep for children with asthma [9]. However, poor sleep quality has been documented even when asthma symptoms are stable and well controlled [9,11]. The reverse association has also been examined, and findings suggest that reduced sleep quality may be associated with bronchoconstriction, poor asthma control, and impaired quality of life [2,10,12,13]. Past pediatric asthma and sleep studies, however, have been limited by small sample sizes,

cross-sectional designs, and reliance on subjective measures of asthma control [6,10,12,13]. Moreover, whereas lung functioning has been associated with poor sleep quality, the link between lung functioning and sleep duration has not been consistently demonstrated in pediatric asthma [14]. Further research is needed to disentangle how child sleep quantity and quality influence children's lung functioning.

A daily diary approach addresses several limitations associated with cross-sectional or aggregated data by evaluating temporal patterns of sleep and pulmonary functioning [15–17]. Daily diaries are an example of ecological momentary assessment (EMA), a naturalistic method of capturing information about people's daily lives that also minimizes recall biases associated with retrospective reports [18]. By administering repeated surveys over time and closer to the actual event, EMA methods reduce the recall period in which participants report on real-world experiences (e.g., by reporting on sleep upon waking). Mobile-administered EMA surveys are particularly useful as they increase participants' compliance to completing surveys in comparison to paper diaries [17]. Therefore, a mobile EMA approach increases the accuracy and quality of data regarding participants' real-world experiences.

Past studies demonstrate the utility of EMA when examining associations between asthma symptoms and sleep patterns. For instance, Koinis-Mitchell and colleagues (2017) identified associations between nighttime pulmonary functioning and sleep efficiency using daily diaries and home spirometers over a four-week period [14]. Similarly, Hanson and Chen (2007) collected three days of children's self-reports of sleep quality and quantity from 36 children with asthma; poorer sleep quality and shorter sleep duration at night predicted more severe asthma symptomology, but the reverse association was not supported [15]. The current study adds to these findings by examining associations between sleep quantity and quality and objective lung functioning in a low-income, urban sample of children and their families. We examined patterns across a two-week period, accounting for day-to-day variance in ratings.

Additionally, our study extends previous research by examining the effect of family functioning on the association between sleep and lung functioning. Research to date highlights the important role of families in child asthma management [19]. As the primary system through which asthma is managed, family factors understandably contribute to worse lung functioning via medication adherence or psychological

well-being [19–21]. Family functioning can influence each family member's ability to care for the child's asthma and subsequently result in poor control and increased hospitalizations [19,22]. Recent findings have even linked changes in family dysfunction to changes in immune functioning that subsequently affect asthma symptoms [23]. The association between family characteristics and sleep patterns in children with asthma, however, is not well established [2,20]. In the general child literature, studies have identified associations between youth sleep and maternal, parenting, and family characteristics [24–26]. In particular, the family emotional climate may influence children's perceptions of safety and security within the home environment and affect overall sleep quality; for instance, levels of marital conflict at home have been associated with poor sleep quality and quantity in youth [27]. Among children with asthma, parent-reported daily hassles, mood, and disrupted routines have been associated with more frequent nighttime waking [28]. Missing from the literature to date is whether overall family functioning influences daily sleep quantity/quality in children with asthma and how family functioning and sleep may interact to influence child asthma symptoms. An ecological approach is well-suited to answer these questions by providing a representation of children's daily sleep and lung functioning within the family context.

In this study, we utilized EMA delivered via smartphone devices to examine associations between daily parent-reported children's sleep quantity and quality and children's objective lung function. Consistent with recent cross-sectional findings, we hypothesized that children would experience poorer pulmonary functioning, as evidenced by lower peak expiratory flow (PEF), following nights where they experienced shorter sleep duration and poorer sleep quality [9,12]. We also hypothesized that family functioning would moderate the association between sleep and lung functioning. Though the paucity of research on these associations precludes definitive hypotheses regarding directionality of the effect, we reasoned that poor family functioning would exacerbate the effects of poor sleep quality and quantity on lung functioning [19,20].

Methods

Participants

These data were part of a larger IRB-approved study examining the daily experiences of urban families of children with asthma [29]. Participants included 59

children, ages seven to 12 years ($M = 9.56$, $SD = 1.53$), and their primary caregivers. Approximately 90% of participating caregivers self-identified as Black or African American, and 79.7% of participating caregivers were biological mothers. Other caregivers included biological fathers, step/adoptive mothers, grandmothers, and an aunt. Seventy-five percent of the sample reported a total household income (prior to taxes) less than \$35 000 for the past year. At enrollment, 41 children (69.5%) were prescribed an asthma controller medication. Table 1 describes other sample demographics.

Children with asthma were identified through a large, urban hospital's electronic health records. Identified families were screened for eligibility by a research assistant. Inclusion criteria included: 1) current or persistent asthma as evidenced by a prescribed controller medication or symptom severity/frequency over the last month matching National Heart, Lung, and Blood Institute guidelines [30]; 2) ability for the caregiver to speak and respond to surveys in English; 3) children and caregivers identifying as African American, Caucasian, and/or Latino; and 4) families residing in an urban area verified by zip code. Families were ineligible if their children had another pulmonary disease(s) or if caregivers or children had severe psychiatric or medical conditions that would make study participation challenging.

Procedure

After initial phone contact, eligible families were invited to attend a baseline research session in the research laboratory or the family's home, depending on the family's preference. Written informed consent and assent were obtained and then trained research assistants administered questionnaires to caregivers and children separately. Caregivers reported demographics, children's sleep patterns, and family functioning.

After the completion of questionnaires, families were trained on the proper use of EMA on smartphones. Samsung Galaxy smartphones, provided by the study team, had texting and other features disabled to limit use to survey completion. Caregivers were asked to respond to twice-daily surveys for a 14-day period [31]. Alarms, scheduled collaboratively with the caregiver, reminded caregivers to complete surveys after waking and shortly prior to going to sleep. Each survey took five to ten minutes to complete and asked questions pertaining to asthma management, daily asthma management hassles, and child

Table 1. Participant characteristics ($N = 59$).

Variable	Mean (SD)
Child age (years)	9.56 (1.53)
Caregiver age (years)	38.14 (9.24)
Family functioning (FAD GF score)	1.90 (.36)
Total child sleep duration (hours)	9.81 (1.43)
Mean AM2 rating	179.80 (71.58)
N (%)	
Child sex (% male)	41 (69.5)
Child race	
African American/Black	53 (89.8)
Caucasian/White	4 (6.8)
Other	2 (3.4)
Child prescribed daily controller medication	41 (69.5)

sleep. Data automatically saved and uploaded to a secure electronic server after each survey. For this study, morning reports of children's sleep quality and quantity were used.

Families were also trained during the baseline visit on how to use the AM2+® Lung Function Monitor (ERT, Inc.) spirometers. Caregivers were asked to have children blow air three times into the spirometer each morning and to record each PEF value into the EMA smartphone app. Researchers calculated each child's daily PEF value as the average of three PEF ratings [32,33].

During the 14-day period, researchers contacted caregivers via phone to inquire about smartphone and spirometer use and troubleshoot any technical difficulties. Phones were collected following study completion and reset for the next participating family. Families received \$25 for participating in the baseline visit and \$50 following the two-week EMA period.

Measures

Demographics

At the baseline visit, primary caregivers completed a demographic questionnaire, including caregiver and child age, child sex, caregiver relationship to child, race/ethnicity, family income, family structure, and whether the child was prescribed an asthma controller medication.

Family functioning

Primary caregivers also completed the Family Assessment Device (FAD), a widely used measure of family functioning, at baseline [34]. The FAD assesses family difficulties with problem solving, communication, roles, affective responsiveness, affective involvement, and behavior control. Caregivers rated 60 statements on a 4-point Likert scale of how accurately each statement described their own family's functioning across multiple domains. This study used the 12-item general functioning (GF) mean score, which has

Table 2. Multilevel models predicting lung functioning.

Variable	Estimate (SE)	P
Model 1: Family functioning predicting lung functioning		
Intercept	169.90	<.001
Time	1.23 (.61)	.05
FAD ^a	−33.85 (23.53)	.15
Model 2: Sleep quality predicting lung functioning (reference group: very good sleepers)		
Intercept	168.69 (9.45)	<.001
Time	1.29	.04
Good sleeper	−.32 (4.77)	.95
Bad or very bad sleeper	−6.02 (6.60)	.36
Model 3: Interaction between FAD and sleep quality in predicting lung functioning (reference group: very good sleepers)		
Intercept	170.16 (9.85)	<.001
Time	1.42 (.49)	.01
FAD*good sleeper	−28.98 (11.57)	.013
FAD*bad or very bad sleeper	−32.52 (16.43)	.049

^aHigher scores on FAD indicate worse overall functioning.

demonstrated strong psychometric properties (i.e., excellent construct validity and good reliability [35] and acceptable internal reliability in this sample (Cronbach's alpha = 0.74). Higher scores on this scale indicate poor family functioning and represent how well families get along together, confide in each other, have open communication, accept one another, and express feelings to each other.

Child sleep quality

Caregivers completed daily morning EMA ratings of their children's sleep quality on a four-point scale ranging from 1 (very good) to 4 (very bad). Specifically, caregivers responded to the question, "Overall, how would you rate your child's sleep quality last night?"

Child sleep quantity

Caregivers also reported their children's bedtime and wake time every morning. Sleep quantity was calculated as the time duration from children's bedtime to wake time, as reported by caregivers.

Child pulmonary functioning

As part of their daily morning surveys, caregivers were prompted to measure their child's pulmonary function via the AM2+® Lung Function Monitor (ERT, Inc.). This AM2 device determines flow and volume of children's air, yielding a peak expiratory flow (PEF) measurement on a linear scale from 60 to 810L/min, consistent with American Thoracic Society guidelines [31].

Data analysis

Preliminary and descriptive data analyses were conducted in IBM's SPSS Version 24. Two-level multilevel modeling (MLM; also referred to as hierarchical linear modeling and mixed effects modeling) with restricted

maximum likelihood estimates via SAS 9.4 PROC MIXED tested associations between family functioning at baseline, child daily sleep quantity and quality, and child pulmonary functioning. MLM is well-suited to EMA responses as it handles missing data flexibly and uses all data points via maximum likelihood estimation methods. Therefore, as opposed to excluding an individual's responses when responses are incomplete, potentially resulting in biased results, MLM incorporates all available data into model estimation. In our analyses, a series of multilevel models were run to examine a) the influence of sleep quantity on AM2 ratings, b) the influence of sleep quality on AM2 ratings, and c) the interaction between sleep and family functioning in predicting AM2 ratings. One period autoregressive (AR) models were used. Child sex and controller medication were tested as control variables in all of the multilevel models. Only main and interaction terms included in our hypotheses were estimated in all models. To augment the interpretability of results, continuous predictors at Level 2 (e.g., FAD scores) were grand-mean centered and predictors at Level 1 (e.g., hours slept) were group-mean centered.

Results

Multilevel models included data from 491 observations and 59 participants. Caregivers completed morning diaries ranging from two to fourteen days, with an average of 10 days of diaries completed. An unconditional model for peak expiratory flow (PEF) from AM2 ratings identified the proportion of variance as 22.7% attributed to within-person and 77.3% attributed to between-person factors. In the model testing the effects of family functioning and sleep quality on lung functioning, 475 observations were used; 482 observations were included in the model testing the effects of family functioning and sleep quantity on lung functioning. Across all observations, children

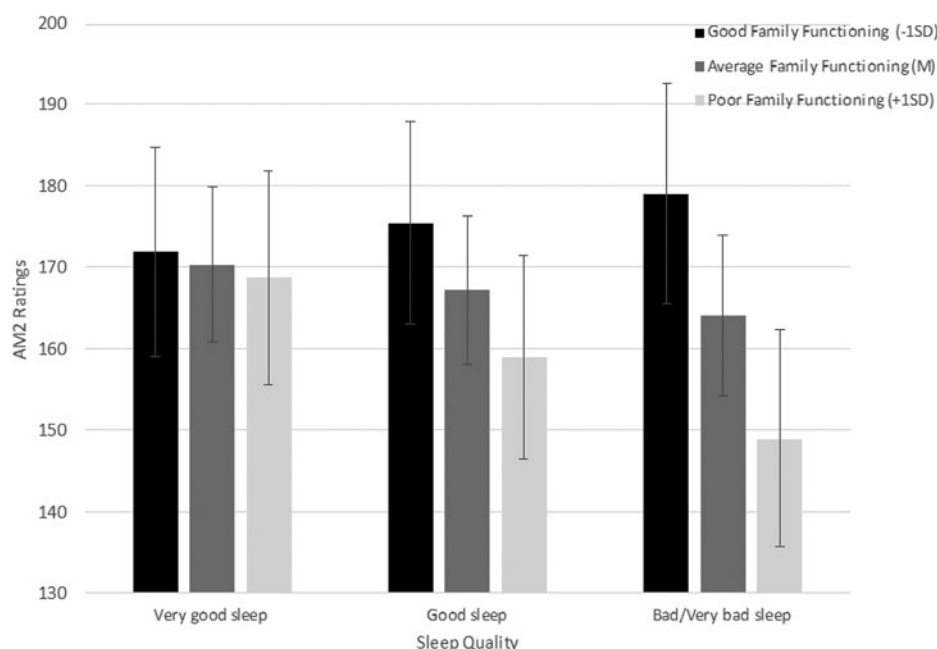


Figure 1. Effects of family functioning and sleep quality on pulmonary functioning.

slept an average of 9.8 h ($SD = 1.43$). Approximately 60% of parents rated their child's sleep as very good, 26% as good, and 15% as bad or very bad. Child sex and controller medication were tested as covariates in all of the multilevel models; none significantly predicted sleep quality, sleep quantity, family functioning, or AM2 ratings and thus were removed from the models. One period autoregressive (AR) models indicated that, on average, there were medium-effect correlations between objective pulmonary functioning ratings one day apart (AR coefficient = 0.36).

Child sleep quantity (parent-reported number of hours slept) was not significantly associated with pulmonary functioning (average morning AM2 ratings; $\beta = -0.79$, $p = 0.56$). Overall family functioning was also not significantly associated with daily AM2 ratings ($\beta = -33.85$, $p = 0.15$). Finally, family functioning did not moderate the association between children's sleep quantity and overall pulmonary functioning ($\beta = -3.23$; $p = 0.41$).

MLM analyses did not identify statistically significant group differences in AM2 ratings for parent-reported children's sleep quality (see Table 2). Although children whose sleep was rated as bad or very bad had poorer pulmonary functioning compared to children with very good sleep, with a 6-point lower average AM2 rating, the between-group differences were not significant ($F(2,415) = 0.65$, $p = 0.52$). There was a significant interaction between family functioning and sleep quality in predicting children's pulmonary functioning ($F(2,409) = 3.39$, $p = 0.03$). Overall, children who had poor family functioning

(i.e., high FAD GF score) and bad/very bad sleep quality had the poorest lung functioning (Figure 1). Further, compared to children with very good sleep quality, children with bad/very bad and with good sleep quality evidenced a stronger negative association between poor family functioning and AM2 ratings ($\beta = -32.51$, $p = 0.049$ and $\beta = -28.98$, $p = 0.01$ respectively).

Discussion

In this study, child sleep quality and quantity did not significantly predict child pulmonary functioning on days following the assessment. Results concur with the mixed findings in previous studies regarding associations between children's sleep characteristics and asthma outcomes, and do not support past findings supporting a direct association between daily sleep characteristics and lung functioning [12,15]. Whereas some studies have identified positive associations between sleep duration and pulmonary functioning, other studies have found a negative association [12,15]. Similarly, some studies found no or marginally significant associations between sleep quality and objective lung functioning; others found moderate associations between sleep and asthma outcomes such as nocturnal asthma symptoms [9,10,15]. One potential explanation for the lack of main effects in our findings is that children in this sample were, on average, reportedly getting adequate sleep ($M = 9.8$ h). Also, it is important to note that these findings reflect caregivers' reports of the time their children got into bed and not sleep onset or whether children had

difficulty falling asleep or staying asleep throughout the night. Although studies have identified shorter sleep durations, poor sleep efficiency, and inconsistent sleep schedules in children living in low-income, urban environments [7], approximately 60% of this study's sample was rated by their parents as having very good sleep quality. This might speak to the importance of identifying individual, family, and environmental protective factors - such as family management, social support, or adherence to asthma medication regimen - that may serve to enhance lung functioning among those children experiencing good sleep quality. [2].

Similarly, general family functioning was not directly related to daily objective pulmonary functioning. Although family functioning has been associated with children's health-related QOL and adherence to medication, our findings are consistent with studies that have failed to identify a significant direct association between family functioning and objective lung functioning [20,21,36]. As proposed by bio-behavioral family theories (e.g., the Bio-behavioral Family Model), although family functioning may not relate directly to lung function, it contributes indirectly by affecting children's psychosocial well-being or asthma management behaviors [20,37]. Future studies should incorporate daily measures of potential intervening variables, such as subjective well-being (e.g., daily stress, depression, or anxiety symptoms), to evaluate indirect pathways of effect.

Consistent with our hypothesis, the interaction of family functioning and sleep quality predicted objective lung functioning. For children with very good sleep quality, family functioning did not predict significant differences in pulmonary functioning. However, for children with bad or very bad parent-reported sleep quality, there were significant differences in the extent to which family functioning predicted objective lung functioning. In fact, there was a 30 point difference in AM2 ratings between children that had poor parent-rated sleep quality and good family functioning (-1 SD from mean family functioning) and children that had poor sleep quality and poor family functioning (+1 SD from mean family functioning). The nature of the interaction suggests that the lung function of children who have poor sleep quality is particularly vulnerable to differences in family conflict, whereas those with good sleep habits have lung functioning that remains relatively stable with variations in family conflict. Family functioning and poor youth sleep quality may influence the sense of security a child feels and may also impact the

ability of caregivers to consistently care for the child's asthma, especially if caregiver sleep or quality of life is affected as well [27,38]. These findings also highlight a subset of children at higher risk for poor lung functioning based on sleep quality and family functioning. Further studies are needed to assess whether fluctuations in daily family arguments exacerbate effects of poor sleep quality on lung functioning or whether the overall family environment is what matters most. Family functioning and sleep characteristics could be monitored regularly in routine asthma visits and, if appropriate, empirically supported treatments could be used to target family functioning and children's sleep patterns [39,40].

There are study limitations that warrant consideration. First, this study relies on parent-reported sleep quality and quantity. Future studies may wish to supplement parental reports with sonography or actigraphy. Actigraphy is well-suited for capturing objective sleep characteristics (e.g., delayed sleep onset, number of awakenings, sleep duration) that are important in accurately describing sleep efficiency [41]. Similarly, this study assessed children's sleep quality with one item; future studies should incorporate more questions about different factors that reflect children's sleep quality (e.g., daytime sleepiness; [42]. Further, this study assessed overall parent-reported family functioning at baseline prior to the daily data collection period. Although some researchers view family functioning as a relatively stable construct, daily assessment of family functioning via EMA could identify how daily family experiences influence children's asthma symptoms [43]. Similarly, assessing children's own perceptions of family functioning may be helpful, as family functioning has been linked with health-related quality of life [36]. Finally, some participants likely had access to their own smartphones during this study. Although the use of two phones simultaneously could lead to gaps in data collection, participants received alerts to complete surveys from the study phone to minimize this possibility.

Future research could build upon this study's findings in several ways. First, given that the HPA axis has been proposed as a mechanism through which interactive effects of family and sleep influence children's health [44], pediatric asthma studies may assess changes in cortisol. Future research may also benefit from exploring associations among sleep, family functioning, and lung functioning in adolescence, as it is a developmental period in which youth often have shorter sleep duration, later bedtimes, and excessive daytime somnolence [45]. Similarly, responsibilities in

asthma management often shift during adolescence, and longitudinal studies are necessary to identify how these changes influence children's daily asthma outcomes; this is especially important as adolescents with asthma are at increased risk for asthma morbidity [46]. Future EMA studies may also benefit from examining particular aspects of daily family functioning (e.g., family conflict, routines) that may contribute to daily fluctuations in sleep difficulties and lung functioning [38]. Further research is also needed to understand the mechanisms through which family functioning and sleep, together, influence asthma outcomes; in particular, it would be valuable to examine whether medication adherence, caregiver quality of life, and children's perceptions of the home environment mediate these associations [27,38]. Finally, given the promise of using mobile technology to reach families in "real-world" situations, researchers may extend these tools by developing multi-systemic family and sleep behavioral ecological momentary interventions (EMI) for children with poorly managed asthma. These interventions may overcome barriers often present in in-person interventions, such as difficulty with transportation or child care, and may be tailored based on individual responses to EMA surveys [17].

Conclusions/key findings

Despite limitations, this study provides insight into how sleep and family functioning may interact to influence asthma outcomes for children living in urban, low-income communities. Results reveal that, although sleep and family functioning may not be directly related to objective lung functioning, the interaction of poor family functioning and poor sleep quality predicts poor lung functioning. Results also suggest that although children may experience difficulties with sleep quality, positive family functioning may serve as a protective factor; children with poor sleep quality and good family functioning did not differ in pulmonary functioning compared to children with good sleep quality. Health professionals working with children with asthma should be aware of these sleep and family contributions to lung function. They may wish to assess sleep and family functioning and provide families with psycho-education regarding regular sleep and family routines. These efforts may in turn enhance asthma outcomes.

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