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ORIGINAL RESEARCH

The Joint Association of Sleep Quality and Outdoor Activity with Asthma and Allergic Rhinitis in Children: A Cross-Sectional Study in Shanghai

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Purpose: Aiming to investigate the combined association of sleep quality and outdoor activity with the risk of asthma and allergic rhinitis in children.

Patients and Methods: 16,936 children from kindergartens and primary schools in 13 administrative districts of Shanghai, China were involved in the analyses. The Children's Sleep Habits Questionnaire (CSHQ) and the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire were respectively used to evaluate the sleep quality, allergic rhinitis and asthma. Multivariable logistic regression models were used to analyze the correlation of sleep quality, outdoor activities and their combination with children's asthma and allergic rhinitis.

Results: The overall prevalence of asthma and allergic rhinitis in our sampled children were 10.2% and 17.6%, respectively. Poor sleep quality (asthma: aOR, 1.45; 95% CI: 1.23 to 1.73; allergic rhinitis: aOR, 1.16; 95% CI: 1.03 to 1.31) and low outdoor activity (asthma: aOR, 1.30; 95% CI: 1.14 to 1.49, allergic rhinitis: aOR, 1.18; 95% CI: 1.07 to 1.32) were separately associated with higher risk of asthma and allergic rhinitis, and when the two were superimposed, an additive effect (asthma: aOR, 1.76; 95% CI: 1.30 to 2.39; allergic rhinitis: aOR, 1.46; 95% CI: 1.17 to 1.82) was revealed. These associations were independent of sleep duration, but being stronger in sleep sufficiency group. And after stratification by gender, premature birth and family history of allergy, similar associations were validated in general.

Conclusion: Poor sleep quality and low levels of outdoor activity, when combined, have a stronger association with asthma and allergic rhinitis than each factor independently, and this relationship is not influenced by sleep duration. Our findings highlight the need for public health interventions that simultaneously address multiple lifestyle factors to reduce the risk of allergic diseases.

Keywords: asthma, allergic rhinitis, sleep quality, physical activity

Introduction

Allergic rhinitis (AR) and asthma are common allergic diseases in children which share respiratory tract mucosal alterations and immunological pathways.[1] Recent epidemiological studies have shown that Asia is a high prevalent region of AR, with prevalence rates ranging around 27% to 32%.[2,3] Data from a national survey in China observed that

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the prevalence of childhood asthma was significantly rising in most of areas within recent 20 years.[4] AR and asthma can present at any age but usually become manifest older than 2 years of age, with incremental increases during childhood and adolescence.[5] Therefore, identifying risk factors so as to make targeted intervention strategy is of great significance for the control of asthma/AR. There is convincing evidence that the development of AR and asthma is mediated by genetic and environmental factors.[6,7] In recent years, most studies have focused on the effects of age, gender, genetic variations and environmental exposures on childhood AR and asthma.[8,9] Nevertheless, compared with relatively stable genetic factors and demographic characteristics, individual behavior and lifestyle may also have direct and/or indirect effects on asthma/AR manifestations.

Almost half of children worldwide are affected by sleep problems.[10] Systematically reviewer provided evidence that sleep impairment, including decreased sleep duration, poor sleep quality, and sleep-related disorders, was associated with a higher risk of AR.[11] Moreover, a study found that children with AR and attention deficit hyperactivity disorder exhibited a strong correlation between AR symptoms and attention deficit hyperactivity disorder severity, highlighting the potential impact of AR on neuropsychiatric system which could, in turn, contribute to disruptions in sleep quality.[12] Several cross-sectional studies suggested that poor sleep is associated with an ascending prevalence of asthma, and insufficient sleep duration and sleep-disordered breathing increased the risk of new-onset asthma.[13,14] And an 11-year prospective cohort study that recruited 17,927 individuals further discovered that the cumulation of sleep problems was associated with an additional increase in the risk of incident asthma following a dose-dependent manner.[15]

Regular physical activity has been strongly recommended as one of the most effective means of preventing chronic disease and maintaining good health.[16] However, studies looking at physical activity and asthma/ AR yielded mixed results. Most data suggested that a physically active lifestyle was negatively correlated with the risk of AR and asthma,[17–23] but a few studies linked moderate to severe physical activity to an increased risk of asthma and AR.[24–26] In addition, the fact that physical activity and sleep were considered separately from each other is concerning since evidence has revealed that individual behaviors are codependent and should be taken into account simultaneously.[27,28]

To our knowledge, only two studies have simultaneously collected information on sleep characteristics and physical activity and then analyzed their associations with asthma and/or AR. In which, a cross-sectional study in 53,769 adolescents found that high physical activity and short sleep duration were individually associated with asthma and AR after mutual adjustment in the respective multivariate models, but the study did not analyze them jointly. The other study, by adopting a randomized controlled clinical trial, showed that physical activity can improve sleep quality and asthma symptoms, and the improvement of sleep quality may play a modified effect on the melioration of asthma symptoms.[29] Despite the reported associations, the combined effects of physical activity and sleep quality on the prevalence of asthma and AR in children have not been studied. Previous research suggested that outdoor activity and sleep duration have declined substantially over the last few decades,[30,31] emphasizing a focus on them simultaneously. So far gaps remain in understanding how the lifestyle behavior combination impact allergic diseases in children. The importance of this study lies in its potential implications for holistic health strategies targeting both sleep and activity behaviors in childhood, which could ultimately support the prevention and management of allergic diseases.

In this study, we conducted a large population study covering 31 kindergartens and 17 primary schools in 13 districts of Shanghai to examine whether there are combined effects of sleep quality and outdoor activities on childhood asthma and AR.

Materials and Methods

Study Participants

This cross-sectional study was conducted from April 12 to June 1, 2019, using a multistage and multi-layer sampling method. Overall, seven urban districts (Xuhui, Huangpu, Hongkou, Putuo, Changning, Yangpu, and Pudong New Area) and six suburban/rural areas (Minhang, Jinshan, Qingpu, Songjiang, Baoshan, and Chongming) were randomly sampled among the nine urban districts and eight suburban/rural districts in Shanghai. Within these districts, 31 kindergartens and 17 primary schools were randomly sampled; then children were recruited and their caregivers were invited to participate in the project. All caregivers received an informed consent form, a completion guide, and a link to a digital questionnaire.

Ethical approval was obtained from the ethics committee of Shanghai Jiao Tong University School of Medicine (Ethics Approval Number: SJUPN-201717) in accordance with the Declaration of Helsinki. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cross-sectional studies was followed.

Determination of Allergic Rhinitis and Asthma

As shown in previous studies by our group,[32,33] the International Asthma and Allergy Study in Childhood (ISAAC) questionnaire, which is commonly used in preschool and school-age children, was used to assess asthma and AR in children.[34,35] The Cronbach-α coefficient for the ISAAC questionnaire in our sampled children was 0.94 and the validity determined by the Kaiser-Meyer-Olkin method was 0.94.

Asthma and AR were defined by means of questions in relation to diagnosis history and current symptoms. Those children who were ever diagnosed with asthma or AR and still had typical symptoms (eg, whistling in the chest, sneezing, runny nose, and other non-cold symptoms) were classified as having either allergic disease. We excluded children with other allergic diseases, mainly atopic dermatitis and eczema The final analysis included children aged 3–12 years, among whom there were 1367 with asthma (11.4%), 2554 with allergic rhinitis (9.2%), and 11,982 with none of them.

Determination of Sleep Quality

The Chinese version of the Children's Sleep Habit Questionnaire (CSHQ) was used to assess the characteristics of children's sleep quality.[36] The internal consistency, test-retest reliability, content validity and structural validity of the overall questionnaire have been well recognized.[37] The CSHQ 33 items covering 8 subscales (bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night waking, parasomnias, sleep disordered breathing, and daytime sleepiness), adopting 3-point scale response to collect the average frequency of sleep problem symptoms per week: usually (5–7 times/week), sometimes (2–4 times/week), and rarely (0–1 time/week), based on which the higher the score, the worse the sleep quality. For the 8 subscales, parasomnias and daytime sleepiness were defined as two related symptoms occurring at least twice a week, and other sleep problems were defined as one related symptom occurring at least twice a week. The total number of sleep problems in children was counted and divided into two groups: 0–2 sleep problems vs 3–8 sleep problems.

Determination of Outdoor Activity

Outdoor activity was assessed by a question: "How often does your child usually participate in moderate outdoor activities (eg, walking in the park, playing games, etc). lasting more than 10 minutes?" and the rating options are shown as "None/occasionally (less than 1 day/week)", "Sometimes (1–2 days/week)", "Often (3–4 days/week)", "Almost every day (5 days/week and above)". The categories were further classified into two groups: less than 3 times/week vs 3 times/week and above.[38]

Assessment of Covariates

The covariates selected in this study were based on scientific plausibility and the association between exposures (sleep, physical activity) and the incidence of asthma and AR,[13,26] which included child age (continuous), gender (male/female), overweight/obesity (defined according to standard age- and sex-specific percentile[39]), parents' education level (Junior high or below, Senior high, College or above), premature birth (yes/no), delivery mode(Natural delivery, Cesarean delivery), breastfeeding (yes/no), family income (<3999, 4000–7999, >8000 RMB per month), average sleep duration (<10 h, ≥10 h), parents' history of sleep disorders (yes/no), and family history of allergies (yes/no).

Statistical Analysis

Descriptive statistics (means and standard deviations) have been used to describe continuous variables and absolute frequencies and proportions to describe categorical variables. The none-allergic group was defined as those children without symptoms of AR or asthma, meanwhile, drug allergy and food allergy were also considered for exclusion.

Differences in descriptive data between asthma, AR, and non-allergic groups were assessed using the Chi-square test and Student's *t*-test when appropriate. To estimate the joint effect of sleep quality and outdoor activity, we created a four-classification variable as good sleep quality and high outdoor activity frequency (Good SQ & high OA), good sleep quality and low outdoor activity frequency (Good SQ & low OA), poor sleep quality and high outdoor activity frequency (Poor SQ & high OA), and poor sleep quality and low outdoor activity frequency (Poor SQ & low OA). Both crude and adjusted logistic regressions were performed to assess the association of sleep quality, outdoor activity, and the combination with asthma and AR, respectively. And crude odds ratio and adjusted odds ratio and their 95% confidence intervals (95% CIs) were reported, respectively. Covariates included in the adjustment model were as follows: child's age, gender, parental educational level, delivery mode, family history of allergy, parents' sleep disorder history, overweight/obesity, premature birth, breastfeeding, average sleep duration and family income. We then conducted a stratified analysis according to gender (male vs female), average sleep duration (<10h vs ≥10h), family history of allergy (yes vs no) and premature birth (yes vs no).

Analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, NY, USA) and R-4.1.2 software (R Foundation for Statistical Computing, Vienna, Austria). And two-sided P values < 0.05 were considered statistically significant.

Results

Characteristics of the Study Population

The description of asthma and AR was presented in Table 1. Of the 16,936 children included in the analysis, the prevalence rates of the allergies were 11.4% for asthma and 21.3% for AR. Overall, the prevalence of asthma and AR was higher among boys, high-income families, having family history of allergic diseases, higher parents' education level, and parents having sleep disorder history. (all p < 0.001) Additionally, compared to the non-allergic group, participants with premature birth had a higher incidence of asthma, but not allergic rhinitis. Breastfeeding and average sleep duration were associated with allergic rhinitis, but not with asthma (all $p < 0.001$).

Description of Sleep Quality, Outdoor Activity and Their Combination According to Asthma and AR

Table 2 reports the differences of sleep quality and outdoor activity between groups with and without asthma or AR. Participants with asthma were more likely to have poor sleep quality (86.7 vs 80.1%, $p < 0.001$) and low outdoor activity frequency (73.4 vs 68.8%, $p < 0.001$). Those with AR had low outdoor activity frequency (74.4 vs 68.8%, $p < 0.001$), but non-significance difference in terms of sleep quality. When sleep quality and outdoor activity were combined, the proportions of asthma and AR, in order, are as follows: Poor SQ & low OA (asthma:63.6%, AR:60.2%), followed by the Poor SQ & high OA (asthma:23.0%, AR:21.3%), Good SQ & low OA (asthma:9.8%, AR:14.2%), and Good SQ & high OA groups (asthma:3.5%, AR:4.3%) (all $p < 0.001$).

Relationships of Sleep Quality and Outdoor Activity with Asthma and AR

Table 3 demonstrated the association of sleep quality, outdoor activity and their combination with childhood asthma and AR. Sleep quality was associated with an increased risk of asthma (OR: 1.62, 95% CI: 1.37–1.90) but not AR in univariable analyses. After adjustment for confounding factors, sleep quality was significantly associated with increased risk of both asthma and AR (aOR: 1.45, 95% CI: 1.23–1.73 & aOR: 1.16, 95% CI: 1.03–1.31). With regard to outdoor activity, it was demonstrated that, compared with frequently outdoor activity, less frequent outdoor activity was linked with a higher risk of asthma and AR in both univariable (OR: 1.26, 95% CI: 1.11–1.43 & OR: 1.32, 95% CI:1.20–1.45) and multivariable analysis (aOR:1.30, 95% CI: 1.14–1.49 & aOR:1.18, 95% CI:1.07–1.32). Regarding the joint effects of sleep quality and outdoor activity on asthma, poor SQ & low OA was associated with an increased risk of asthma (aOR: 1.76, 95% CI: 1.30–2.39). For AR, compared to Good SQ & high OA, the adjust OR (95% CI) for Poor SQ & high OA, Good SQ & low OA, and Poor SQ & low OA groups were 1.27 (1.01–1.60), 1.31 (1.03–1.67), and 1.46 (1.17–1.82), respectively.

Table 1 Baseline Characteristics of the Study Participants

		(I)	(II)	(II vs I)		(III)	(III vs I)	
		Neither symptom (n=11982)	**Asthma (n=1367)**	***t*/x^2**	***p*-value**	**AR (n=2554)**	***t*/x^2**	***p*-value**
Age		7.71 (2.35)	7.40 (2.36)	4.588	**<0.001**	7.96 (2.28)	−4.904	**<0.001**
Gender	Male	5950 (49.7)	762 (55.7)	18.172	**<0.001**	1485 (58.1)	60.678	**<0.001**
	Female	6032 (50.3)	605 (44.3)			1069 (41.9)		
Overweight/obesity	No	8266 (70.2)	888 (66.2)	9.278	**<0.001**	1800 (71.7)	2.193	0.142
	Yes	3509 (29.8)	454 (33.8)			711 (28.3)		
Mother's education level	Junior high or below	2207 (18.4)	218 (15.9)	32.437	**<0.001**	192 (7.5)	215.048	**<0.001**
	Senior high	7681 (64.1)	978 (71.5)			366 (14.3)		
	College or above	1687 (14.1)	151 (11.0)			1996 (78.2)		
Father's education level	Junior high or below	2549 (21.3)	250 (18.3)	20.226	**<0.001**	148 (5.8)	199.180	**<0.001**
	Senior high	7746 (64.6)	966 (70.7)			411 (16.1)		
	College or above	958 (8.1)	154 (11.3)			1995 (78.1)		
Premature birth	No	10897 (91.9)	1203 (88.7)	16.866	**<0.001**	2327 (91.7)	0.108	0.751
	Yes	958 (8.1)	154 (11.3)			210 (8.3)		
Delivery mode	Natural delivery	6562 (54.8)	805 (58.9)	8.432	**<0.001**	1064 (41.7)	10.886	**<0.001**
	Cesarean delivery	1772 (14.8)	182 (13.3)			1490 (58.3)		
Breastfeeding	No	1988 (11.7)	161 (11.8)	0.422	0.529	350 (13.7)	12.925	**<0.001**
	Yes	14948 (88.3)	1206 (88.2)			2204 (86.3)		
Family income	<4000	4810 (40.1)	517 (37.8)	7.379	**<0.001**	206 (8.1)	122.348	**<0.001**
	4000–8000	5400 (45.1)	668 (48.9)			938 (36.7)		
	>8000	2001 (16.7)	459 (33.6)			1410 (55.2)		
Family history of allergy	No	9981 (83.3)	908 (66.4)	232.499	**<0.001**	1436 (56.2)	915.685	**<0.001**
	Yes	2001 (16.7)	459 (33.6)			1118 (43.8)		
Parents' sleep disorder history	No	9586 (80.0)	949 (69.4)	82.577	**<0.001**	1856 (72.7)	67.568	**<0.001**
	Yes	2396 (20.0)	418 (30.6)			698 (27.3)		
Average sleep duration	≥10h	3153(26.5)	335(24.7)	2.077	0.153	563(22.1)	20.461	**<0.001**
	<10h	8760(73.5)	1024(75.3)			1979(77.9)		

Notes: Bold values indicate $p < 0.05$.

Table 2 Sleep Quality, Outdoor Activity and Their Combination According to Asthma and AR

	Neither symptom (n=11982)	**Asthma (n=1367)**	**x^2**	***p*-value**	**AR (n=2554)**	**x^2**	***p*-value**
Sleep quality index			34.165	**<0.001**		2.642	0.110
0–2 sleep problems (good)	2383 (19.9)	182 (13.3)			472 (18.5)		
3–8 sleep problems (poor)	9599 (80.1)	1185 (86.7)			2082 (81.5)		
Outdoor activity index			12.640	**<0.001**		31.203	**<0.001**
(≥ 3 times/ week) high	3743 (31.2)	363 (26.6)			655 (25.6)		
(< 3 times/ week) low	8239 (68.8)	1004 (73.4)			1899 (74.4)		
Sleep quality and outdoor activity[a]			46.696	**<0.001**		35.189	**<0.001**
Good SQ& high OA	754 (6.3)	48 (3.5)			110 (4.3)		
Poor SQ& high OA	2989 (24.9)	315 (23.0)			545 (21.3)		
Good SQ& low OA	1629 (13.6)	134 (9.8)			362 (14.2)		
Poor SQ& low OA	6610 (55.2)	870 (63.6)			1537 (60.2)		

Notes: a: Participants were assigned good sleep quality if they had 0–2 sleep problems on the sleep quality index and poor sleep quality if they had 3–8 sleep problems. Participants were assigned high outdoor activity frequency if the outdoor activity index was ≥3 times/week and low outdoor activity frequency if it was < 3 times/ week. Bold values indicate $p < 0.05$.

Abbreviations: AR, allergic rhinitis; SQ, sleep quality; OA, outdoor activity frequency.

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Table 3 Sleep Quality, Outdoor Activity, and Their Combination with Asthma & AR, Stratified Analysis

	Asthma		AR	
	OR (95% CI)	aOR (95% CI)	OR (95% CI)	aOR (95% CI)
All				
Sleep quality (poor vs good)	**1.62(1.37, 0.90)**	**1.45(1.23, 1.73)**	1.10(0.98, 1.22)	**1.16(1.03, 1.31)**
Outdoor activity (low vs high)	**1.26(1.11, 1.43)**	**1.30(1.14, 1.49)**	**1.32(1.20, 1.45)**	**1.18(1.07, 1.32)**
Sleep quality and outdoor activity				
Good SQ &high OA	Ref	Ref	Ref	Ref
Poor SQ &high OA	**1.66(1.21, 2.27)**	1.35(0.98, 1.87)	**1.25(1.00, 1.56)**	**1.27(1.01, 1.60)**
Good SQ &low OA	1.29(0.91, 1.82)	1.20(0.85, 1.70)	**1.52(1.21, 1.92)**	**1.31(1.03, 1.67)**
Poor SQ &low OA	**2.07(1.53, 2.79)**	**1.76(1.30, 2.39)**	**1.59(1.30, 1.96)**	**1.46(1.17, 1.82)**
Stratified analysis				
Average sleep duration <10h				
Sleep quality (poor vs good)	**1.57(1.31, 1.89)**	**1.39(1.15, 1.69)**	1.11(0.98, 1.26)	**1.15(1.01, 1.32)**
Outdoor activity (low vs high)	**1.21(1.05, 1.41)**	**1.24(1.06, 1.46)**	**1.29(1.15, 1.45)**	**1.18(1.05, 1.33)**
Sleep quality and outdoor activity				
Good SQ &high OA	Ref	Ref	Ref	Ref
Poor SQ &high OA	1.42(0.99, 2.03)	1.17(0.81, 1.69)	1.17(0.91, 1.52)	1.22(0.93, 1.60)
Good SQ &low OA	1.08(0.73, 1.59)	1.02(0.69, 1.51)	**1.37(1.05, 1.79)**	1.25(0.95, 1.65)
Poor SQ &low OA	**1.76(1.25, 2.47)**	**1.49(1.06, 2.11)**	**1.50(1.17, 1.91)**	**1.41(1.09, 1.81)**
Average sleep duration ≥10h				
Sleep quality (poor vs good)	**1.79(1.26, 2.54)**	**1.67(1.16, 2.40)**	1.06(0.84, 1.34)	1.17(0.91, 1.51)
Outdoor activity (low vs high)	**1.37(1.08, 1.74)**	**1.47(1.14, 1.90)**	**1.30(1.08, 1.58)**	1.19(0.97, 1.46)
Sleep quality and outdoor activity				
Good SQ &high OA	Ref	Ref	Ref	Ref
Poor SQ &high OA	**2.49(1.28, 4.84)**	**2.02(1.03, 3.97)**	1.45(0.95, 2.22)	1.41(0.90, 1.22)
Good SQ &low OA	**2.10(1.00, 4.40)**	1.91(0.90, 4.04)	**1.93(1.21, 3.07)**	1.51(0.92, 2.48)
Poor SQ &low OA	**3.18(1.66, 6.09)**	**2.82(1.46, 5.41)**	**1.73(1.15, 2.61)**	**1.59(1.03, 2.44)**

Notes: Adjusted models were controlled for gender, age, parental educational level, delivery mode, family history of allergy, parents' sleep disorder history, overweight/obesity, premature birth, breastfeeding, average sleep duration and family income. Bold values indicate $p < 0.05$.
Abbreviations: AR, allergic rhinitis; OR, odds ratios; CI, confidence interval; SQ, sleep quality; OA, outdoor activity frequency.

According to the stratified analysis of average sleep duration, the associations were independent of sleep duration. Notably, the subgroup of long sleepers (≥10 h per day) had higher odds of asthma and AR in some cases. In addition, we investigated whether the relationship was modified by gender, premature birth, and family history of allergy. It was shown that the associations were most pronounced in males (Figure 1A and Supplementary Table 1) and those children with premature birth (Figure 1B and Supplementary Table 2), but only demonstrated significance in participants without a family history of allergies (Figure 1C and Supplementary Table 3).

Discussion

To the best of our knowledge, this is the first large-scale epidemiological study examining the joint effects of sleep quality and outdoor activity on asthma and AR in children. The findings revealed that poor sleep quality and low outdoor activity were separately positively associated with increased risks of childhood asthma and AR, and there is a combined effect that the overlaying of poor sleep quality and less outdoor activity contributed to a much stronger effect. In addition, our findings did show evidence of effect modification by certain covariates that the associations were stronger in males and participants born prematurely, and only in children with a family history of allergy. Our study emphasizes the combination of individual behaviors with their health impacts, which should be given consideration in designing lifestyle interventions for the prevention of asthma and AR.

The relationship of sleep quality with asthma and AR has been evaluated in a few studies, with most identifying sleep quality as a key determinant of asthma control across different populations.[40–43] A previous cohort study among Australian teenagers aged 14–21 years found that poor sleep quality was associated with asthma,[44] while another reported that it predicts

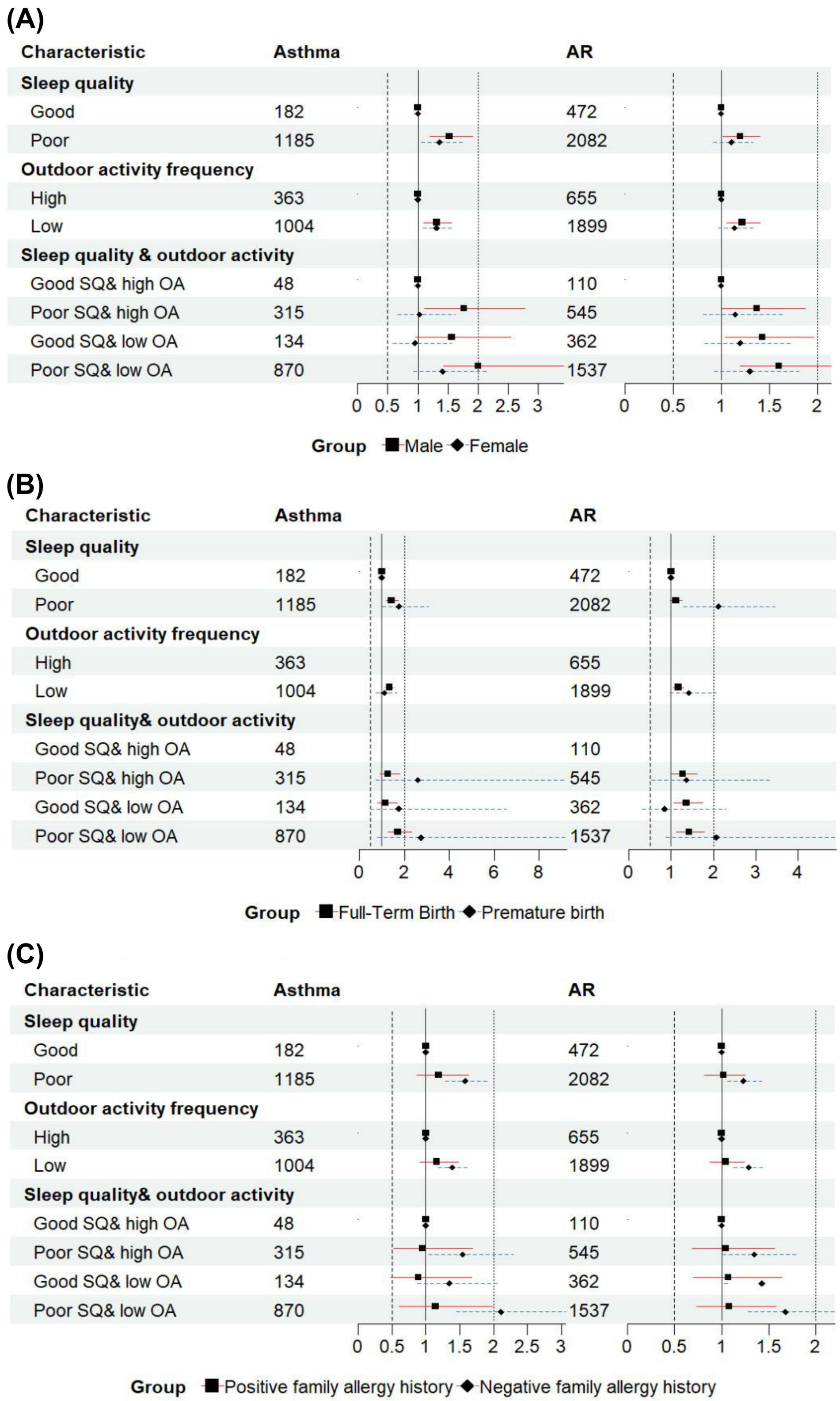

Figure 1 Sleep quality, outdoor activity and their combination with asthma and AR, stratified by gender (**A**), premature birth (**B**), family allergy history (**C**).

Notes: The mode was adjusted for gender (if not stratified variable), age, parental educational level, delivery mode, family history of allergy (if not stratified variable), parents' sleep disorder history, overweight/obesity, premature birth (if not stratified variable), breastfeeding, average sleep duration (if not stratified variable) and family income.

Abbreviations: AR, allergic rhinitis; SQ, sleep quality; OA, outdoor activity frequency.

worse asthma symptoms the following day, documenting that poor sleep quality precedes increased symptom severity.[45] Additionally, experimental studies showed that sleep deprivation exacerbated lung inflammation.[46] In Chinese children, poor sleep quality, including shorter sleep duration and frequent nocturnal awakenings, was associated with an increased risk of AR.[47,48] The converse is also true; a recent case-control study assessed sleep quality in asthmatic children using the Pediatric Sleep Questionnaire and found that, compared to healthy children, asthmatic children scored higher on indices of snoring, sleepiness, and inattention.[49] Consistent with previous findings, our study suggested that poor sleep quality is associated with asthma and AR in children. The evidence on physical activity and its association with asthma and AR in school-aged children is mixed. A meta-analysis of five longitudinal studies, involving 85,117 participants over follow-up duration ranging from 5 to 10 years, indicated that physical activity is a protective factor against the development of asthma.[50] Similarly, a cross-sectional study of Greek adolescents aged 13–14 years found significant inverse associations between a physically active lifestyle and current asthma and AR.[17] Our study also identified low outdoor activity as a risk factor for childhood asthma and AR. However, a cohort study of 18,894 adults did not observe significant associations of physical activity with incident asthma over an 11-year follow-up period.[51] These inconsistencies may be due to differences in populations, sample sizes, study designs, and how physical activity is categorized. Further research is needed to confirm our findings and establish the optimal timing and duration of outdoor activity.

Most existing studies on the combined effects of sleep and physical activity focused on metabolic,[52] cardiovascular,[53] and psychological outcomes.[54,55] However, the effects of their combined effects on asthma, AR, or other allergic diseases have not been studied. A narrative review found that sleep and physical activity influence cognition through shared cellular/molecular pathways.[56] And a 13-year cohort study involving 27 European countries observed that physical inactivity was involved in amplifying the association between poor sleep quality and depressive symptoms.[57] Consistent with the above studies, our study also suggested that sleep quality and physical activity jointly affect the risk of asthma and AR. Although the potential mechanisms behind this synergistic effect were not been elucidated, there are several possible explanations for our findings. Studies have demonstrated a bidirectional relationship between physical activity and sleep.[58] Physical activity can enhance sleep quality in children and adolescents,[59] meanwhile, sufficient sleep may mitigate physical inactivity by alleviating daytime fatigue and sleepiness.[60] Additionally, physical activity exerts anti-inflammatory effects, whereas poor sleep quality can promote inflammation.[61,62] Previous studies have shown that the anti-inflammatory effects of physical activity may be due to decreased levels of IL-4, IL-5, and IgE, as well as increased levels of anti-inflammatory cytokines.[61] However, sleep deprivation can lead to elevated levels of pro-inflammatory cytokines such as IL-1β, IL-6, and IL-12, and reduced levels of anti-inflammatory cytokines like IL-10.[62] Therefore, it seemed that the anti-inflammatory effects of physical activity may help counteract the pro-inflammatory impacts of poor sleep, while good sleep quality can enhance recovery from physical activity, supporting its anti-inflammatory benefits. Regarding immune function, poor sleep quality can result in immune system dysregulation, which in turn reduced the number and the activity of natural killer cells and T cells, thereby increasing an individual's susceptibility to allergens.[63,64] While physical activity was implicated in stimulating the continuous exchange of active immune cell subtypes between the blood and tissues, which would be of significance in enhancing immune defense.[65]

This study has several notable strengths, including the use of a large, representative sample obtained through a rigorous multi-stage and stratified random sampling method, which minimizes selection bias, and the findings were supported and validated by stratified analyses. However, this study has several limitations that should be considered. First, the data were collected from children in kindergartens and primary schools across 13 districts in Shanghai, a highly urbanized and densely populated city. This may limit the generalizability of the findings to other populations, particularly children living in rural areas. Second, physical activity and sleep quality were assessed based on parent-reports, and asthma and AR were not diagnosed by a physician. Therefore, information bias was inevitable Additionally, we did not assess the intensity of physical activity. Future research would benefit from evaluating the intensity and duration of outdoor activities to provide more detailed insights. Third, the study is subject to the inherent limitations of cross-sectional studies, including the potential for reverse causality. Although this is a cross-sectional study and our findings can only describe associations rather than causations between sleep, physical activity, and asthma as well as allergic rhinitis, understanding these associations is a crucial first step in identifying potential risk factors and establishing intervention targets. These findings can inform hypotheses for future longitudinal and interventional studies, which will ultimately help improve prevention and management strategies for asthma and AR.

Conclusion

This study is the first to emphasize the association between the overlaying of children's lifestyle factors and the risk of childhood allergies. Notably, there appears to be a significant synergistic effect, where the combined impact of sleep quality and physical activity is much stronger than their individual effects, and this impact is not influenced by sleep duration. Our findings suggest that targeted public health interventions to improve sleep quality and promote physical activity in children could help mitigate the risk of allergies, underscoring the importance of considering the potential interactions and syntheses among lifestyle factors when examining their associations with health outcomes.

Abbreviations

AR, Allergic Rhinitis; OR, Odds Ratios; CI, Confidence Intervals; PSS, Statistical Package for the Social Sciences; SQ, Sleep quality; OA, Outdoor activity.

Data Sharing Statement

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author. Data supporting the findings of this study are available in the main text and supplementary materials. Individual-level data can be obtained from the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

Ethical approval was obtained from the ethics committee of Shanghai Jiao Tong University School of Medicine (Ethics Approval Number: SJUPN-201717) in accordance with the Declaration of Helsinki. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cross-sectional studies was followed.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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