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Original Article

Association of Cardiorespiratory Fitness and Quality of Sleep among Adolescents in Lahore: A Cross-Sectional Study

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ABSTRACT

Background: Cardiorespiratory fitness and sleep are modifiable determinants of health during childhood and adolescence, yet their direct relationship remains inconsistent and is understudied in South Asian school populations. Objective: To examine the association of sleep duration and sleep disturbance with field-estimated cardiorespiratory fitness among school-going participants aged 10–15 years in Lahore, Pakistan. Methods: A cross-sectional observational study was conducted in schools in Lahore using stratified random sampling. Sleep was assessed using reported sleep duration and the parent-reported Children's Sleep Habits Questionnaire (CSHQ), while cardiorespiratory fitness was assessed using the 20-m multistage shuttle run test and estimated VO_2max. Descriptive statistics, Spearman's rank correlations, and Kruskal–Wallis tests were applied according to data distribution. Results: Mean sleep duration across age strata ranged from 7.84 to 8.14 hours, while mean CSHQ scores ranged from 43.82 to 46.22. Shuttle-run performance increased with age, from 2.43 ± 1.01 stages at age 10 to 6.86 ± 1.70 stages at age 15. No consistent statistically significant association was observed between sleep duration and estimated VO_2max or between CSHQ score and estimated VO_2max. Estimated cardiorespiratory fitness also did not differ significantly across study-defined sleep categories. Conclusion: Short or borderline sleep duration and elevated sleep-disturbance scores were common; however, sleep characteristics were not consistently associated with estimated cardiorespiratory fitness. Sleep health and physical fitness should therefore be considered important but independently relevant targets for adolescent health promotion. Keywords: adolescents; cardiorespiratory fitness; sleep quality; sleep duration; CSHQ; 20-m shuttle run; VO_2max; Pakistan

INTRODUCTION

Cardiorespiratory fitness (CRF) represents the integrated capacity of the cardiovascular, respiratory, and skeletal-muscle systems to transport and utilize oxygen during sustained physical activity. In children and adolescents, CRF is increasingly recognized as an important indicator of health rather than merely a measure of sporting ability. Evidence synthesizing more than 125,000 pediatric observations demonstrates favorable associations between higher CRF and several health domains, including body composition, cardiometabolic status, vascular health, and mental well-being, although certainty differs across outcomes (1). Identification of behavioral factors potentially related to CRF is therefore important for preventive health strategies during childhood and adolescence.

Sleep is another fundamental component of healthy growth and development. Adequate sleep contributes to cognitive functioning, emotional regulation, memory consolidation, metabolic homeostasis, immune function, physical recovery, and psychological health. Recommended sleep duration varies according to age. Children aged 6–12 years are generally advised to obtain 9–12 hours of sleep per 24 hours, whereas adolescents aged 13–18 years are advised to obtain 8–10 hours regularly (2). Insufficient sleep during these developmental stages has been associated with adverse attention, learning, behavioral, metabolic, cardiovascular, and mental-health outcomes.

The biological relationship between sleep and physical fitness is plausible but multifactorial. Adequate sleep supports autonomic recovery, hormonal regulation, energy metabolism, glucose homeostasis, muscle recovery, and adaptation to repeated exercise. Conversely, inadequate or fragmented sleep may reduce perceived energy, impair recovery, and decrease motivation to participate in physical activity. A systematic review examining sleep and health-related physical fitness among children and adolescents found that longer sleep duration and better sleep quality were generally associated with more favorable fitness indicators, although the available evidence was heterogeneous and relatively limited (3).

Longitudinal findings further suggest that sleep may influence subsequent CRF. Sousa-Sá et al. followed 734 adolescents and reported that participants with short sleep duration at baseline had lower odds of demonstrating healthy CRF at follow-up than those meeting recommended sleep duration (4). The relationship appeared particularly important among girls, whereas comparable statistically significant associations were not identified among boys. Such findings indicate that sex, maturation, physical activity, and behavioral patterns may modify associations between sleep and fitness. Sleep health also extends beyond the total number of hours slept. Sleep timing, regularity, chronotype, circadian alignment, nocturnal awakenings, and differences between weekday and weekend schedules may influence physiological recovery. Chen et al. reported associations between greater CRF and more favorable circadian characteristics among adolescents, including greater sleep-timing consistency and differences in circadian activity patterns (5). Therefore, two adolescents obtaining similar total sleep duration may have substantially different sleep quality and physiological recovery.

Modern pediatric health research increasingly considers sleep, physical activity, and sedentary behavior as interdependent components of a 24-hour movement-behavior continuum. Costa et al. identified distinct behavioral clusters among adolescents and reported higher CRF among those characterized by greater moderate-to-vigorous physical activity, lower screen exposure, and adequate sleep compared with adolescents displaying less favorable movement patterns (6). International surveillance studies also demonstrate that a considerable proportion of children and adolescents fail to simultaneously meet recommendations for physical activity, screen time, and sleep (7,8). The clustering of these behaviors complicates interpretation of direct sleep–fitness associations. Physical inactivity, sedentary behavior, prolonged screen exposure, and insufficient sleep frequently coexist, making it difficult to distinguish the independent contribution of each behavior. A systematic review of immigrant children and adolescents demonstrated substantial variation in physical activity, sedentary behavior, and sleep patterns across populations and highlighted the importance of sociocultural context (9).

Objective studies of 24-hour behavior also support the interrelationship between sleep and broader health characteristics. Beunders et al. reported associations between sleep, daily activity rhythms, and cardiometabolic risk factors among school-aged children (10). These findings reinforce the concept that sleep should be interpreted as one component of a larger behavioral and physiological system rather than as an isolated determinant. Body composition represents another potentially important influence. Excess body weight may affect sleep characteristics and weight-bearing exercise performance. Adiposity increases the energetic cost of locomotion and may decrease relative oxygen-uptake estimates expressed per kilogram of body mass. Exercise interventions among children and adolescents with overweight and obesity have demonstrated improvements in CRF, including maximal or peak oxygen-uptake measures (11). Sleep profiles have also been associated with adiposity and CRF in adolescent populations (12).

Recent research continues to demonstrate variability in the sleep–fitness relationship. Hong et al. investigated joint associations among sleep quality, moderate-to-vigorous physical activity, CRF, and working memory among adolescents, emphasizing interactions among behavioral and physiological variables (13). Muñoz-Pardeza et al. similarly found that greater overall physical fitness was associated with lower odds of sleep-related problems among adolescents, although individual fitness components did not show uniform associations with all sleep domains (14). Studies among adults also support a potential relationship between fitness and sleep, although findings cannot be directly generalized to adolescents. Osailan et al. reported associations among CRF, physical activity, and sleep quality in apparently healthy adults (15), while Callow et al. found that sleep quality modified associations between CRF and selected brain-volume measures among middle-aged and older adults (16). Developmental differences in sleep architecture, puberty, educational schedules, habitual activity, and social behavior nevertheless make adolescent-specific investigation essential.

Physical activity itself may influence sleep and potentially mediate the sleep–fitness relationship. Reviews examining early childhood describe reciprocal associations between physical activity and sleep (17), while exercise interventions among adolescents have demonstrated improvements in sleep quality (18). Higher CRF may therefore reflect habitual activity patterns that also promote healthier sleep, rather than sleep independently determining aerobic fitness. Schools represent an important setting for addressing both behaviors. Sleep-education interventions have demonstrated improvements in sleep-related knowledge and selected behavioral outcomes among children (19). School schedules, academic demands, physical-education opportunities, commuting patterns, and extracurricular activities can influence both sleep opportunity and physical activity.

Accurate interpretation also depends on measurement methodology. The Children's Sleep Habits Questionnaire (CSHQ) was developed as a parent-report screening instrument for sleep behaviors and sleep problems in school-aged children. Its original validation demonstrated acceptable reliability and discriminative validity, with a total score greater than 41 providing useful sensitivity and specificity for identifying clinically relevant sleep problems (20). Higher scores indicate greater sleep disturbance. However, the original validation population consisted mainly of younger school-aged children, which requires caution when applying the same threshold to older adolescents. Parent-reported sleep may also differ from objectively measured sleep. Actigraphy provides estimates of sleep timing, duration, movement, and sleep–wake patterns across multiple nights and can identify discrepancies between perceived and objectively estimated sleep characteristics (21). Questionnaire-based sleep assessment nevertheless remains practical for school-based epidemiological studies because it does not require laboratory facilities or specialized equipment.

Assessment of CRF presents comparable challenges. The 20-m multistage shuttle run test (20mSRT) is a progressive field test in which participants repeatedly run between two points separated by 20 m in response to standardized audio signals delivered at progressively increasing speeds. The test is widely used because it is inexpensive, scalable, feasible in school environments, and demonstrates generally high reliability for the assessment of aerobic exercise capacity (22). The 20mSRT measures field performance rather than respiratory gas exchange. Estimated VO_2max derived from shuttle-run performance should therefore be distinguished from directly measured VO_2peak or VO_2max obtained during cardiopulmonary exercise testing. Welsman and Armstrong demonstrated considerable disagreement between shuttle-run-predicted and directly measured oxygen uptake in boys aged 11–14 years and cautioned against treating predicted VO_2 values as precise individual physiological measurements (23).

Sleep-related breathing disorders illustrate further interaction among sleep, body composition, physical activity, and fitness. Torres-Lopez et al. reported relationships among sedentary behavior, physical activity, CRF, body composition, and risk of sleep-related breathing disorders among children with overweight or obesity (24). These observations demonstrate why both sleep and physical fitness require interpretation within the broader context of body composition and habitual activity. Not all multivariable studies identify sleep as an independent determinant after adjustment for other lifestyle behaviors. Castro et al. examined fitness, physical activity, sedentary behavior, nutrition, and sleep simultaneously and found that CRF and sedentary time were associated with cardiometabolic risk, whereas sleep did not demonstrate an independent association in the adjusted analysis (25). A statistically weak direct relationship between sleep and CRF therefore does not imply that sleep is unimportant to health.

Despite growing international evidence, research directly examining sleep characteristics and CRF among school-going populations in Pakistan remains limited. Social schedules, educational demands, socioeconomic conditions, environmental characteristics, recreational opportunities, and patterns of sedentary behavior may differ from populations represented in much of the existing literature. Locally generated evidence is therefore required. The present study aimed to examine the association of sleep duration and sleep disturbance with cardiorespiratory fitness among school-going participants aged 10–15 years in Lahore, Pakistan. Sleep was evaluated using reported sleep duration and the CSHQ, whereas cardiorespiratory fitness was assessed using the 20-m multistage shuttle run test and estimated VO_2max. It was hypothesized that longer sleep duration and lower sleep-disturbance scores would be associated with more favorable cardiorespiratory fitness.

MATERIALS AND METHODS

A cross-sectional observational study was conducted among school-going boys and girls aged 10–15 years from participating schools in Lahore, Pakistan, with data collection undertaken from December 2025 to April 2026. Participants were generally healthy and capable of completing both the questionnaire-based sleep assessment and the field-based cardiorespiratory fitness test. The planned sample size was 250 participants and was calculated using Rao sample-size software. Stratified random sampling was used for recruitment from participating schools to obtain representation across the included age range.

Participants were eligible if they were 10–15 years of age, enrolled in a participating school, generally healthy, able to understand the assessment procedures, and physically capable of completing the 20-m multistage shuttle run test. Participants with known sleep disorders, neurological disorders, relevant physiological conditions, musculoskeletal problems that could limit exercise performance, endocrine disease, or medication use likely to substantially influence sleep or physical performance were excluded. Participants with incomplete sleep or fitness assessments were also excluded from the relevant analyses.

Sleep was assessed using reported nightly sleep duration and the Children's Sleep Habits Questionnaire (CSHQ). The CSHQ is a parent-reported instrument developed to evaluate sleep behaviors and common sleep problems among school-aged children (20). It assesses domains including bedtime resistance, sleep-onset delay, sleep duration, sleep anxiety, nocturnal awakenings, parasomnias, sleep-disordered breathing, and daytime sleepiness, with higher total scores indicating greater sleep disturbance. A total score greater than 41 has traditionally been used as a screening threshold for clinically relevant sleep problems (20). Because the study included participants up to 15 years of age, continuous CSHQ scores were considered particularly important for interpretation. Reported nightly sleep duration was recorded in hours and interpreted according to age-specific recommendations of 9–12 hours per 24 hours for children aged 6–12 years and 8–10 hours for adolescents aged 13–18 years (2).

Cardiorespiratory fitness was assessed using the 20-m multistage shuttle run test (20mSRT). Participants repeatedly ran between two points positioned 20 m apart while following standardized audio signals, with running speed increasing progressively according to the test protocol until the participant could no longer maintain the required pace. The 20mSRT is widely used for school-based assessment of aerobic fitness because of its practicality, scalability, and reliability (22). Shuttle-run performance was recorded according to the stage attained. Estimated VO_2max values used in the statistical analyses were derived from shuttle-run performance and were therefore interpreted as estimates rather than direct measurements of maximal oxygen uptake. Field-based prediction was not considered equivalent to direct cardiopulmonary exercise testing (23), and shuttle-run stages and laps were treated as distinct units rather than used interchangeably.

Demographic and anthropometric information included age, sex, school-related information, exercise participation, height, weight, body mass index (BMI), and relevant medical history where available. BMI was considered a potentially important covariate because body composition may influence both sleep characteristics and weight-bearing cardiorespiratory exercise performance. Permission was obtained from participating schools before data collection. Participants were instructed regarding the assessment procedures before fitness testing. The 20mSRT was conducted over a standardized 20-m running distance, and participants continued to follow the progressively paced audio signals until they could no longer maintain the prescribed speed. Sleep-related and demographic information was collected during the same study period, and the CSHQ was administered as a parent-report measure in accordance with its established format (20).

Data were analyzed using IBM SPSS Statistics version 25.0. Categorical variables were summarized using frequencies and percentages, whereas continuous variables were summarized using means and standard deviations. Distributional characteristics were examined before inferential analysis. Estimated VO_2max in the age-10 subgroup showed a significant departure from normality according to both Kolmogorov–Smirnov and Shapiro–Wilk tests; therefore, non-parametric methods were used for the principal age-specific analyses. Spearman's rank correlation coefficient (ρ) was used to assess associations among sleep duration, CSHQ score, BMI, and estimated

VO_2max where appropriate, while Kruskal–Wallis H tests were used to compare estimated VO_2max across the study-defined sleep categories. Statistical significance was set at $p<0.05$. CSHQ total score and sleep categories derived from sleep-quality information were not interpreted simultaneously as independent predictors because of conceptual overlap. Similarly, regression models incorporating BMI together with height and weight were not used as the primary basis for inference because BMI is mathematically derived from height and weight, and simultaneous inclusion of these variables may introduce multicollinearity.

RESULTS

The age-stratified descriptive characteristics are presented in Table 1. Mean reported sleep duration was relatively similar across age groups, ranging from 7.84 ± 0.71 hours at age 13 to 8.14 ± 0.75 hours at age 11. Mean CSHQ scores ranged from 43.82 ± 4.86 to 46.22 ± 4.75, with mean values exceeding the commonly used screening threshold of 41 in every age group. Shuttle-run performance increased progressively with age. Mean performance increased from 2.43 ± 1.01 stages among participants aged 10 years to 6.86 ± 1.70 stages among those aged 15 years. Estimated VO_2max values available for participants aged 10–12 years were broadly comparable, ranging from 43.78 ± 1.99 to 44.92 ± 2.42 mL/kg/min.

Table 1. Age-Stratified Sleep and Cardiorespiratory Fitness Characteristics

Age, years	n	Sleep duration, h, mean ± SD	CSHQ score, mean ± SD	Shuttle run, stages, mean ± SD	Estimated VO_2max, mL/kg/min, mean ± SD
10	50	7.94 ± 0.80	43.94 ± 5.10	2.43 ± 1.01	44.92 ± 2.42
11	50	8.14 ± 0.75	46.22 ± 4.75	2.68 ± 0.81	43.78 ± 1.99
12	50	8.08 ± 0.56	44.18 ± 5.13	3.43 ± 1.14	43.95 ± 2.90
13	50	7.84 ± 0.71	44.32 ± 5.61	4.65 ± 1.68	
14	50	7.97 ± 0.74	45.22 ± 5.23	5.29 ± 1.90	
15	50	7.89 ± 0.85	43.82 ± 4.86	6.86 ± 1.70	

CSHQ, Children's Sleep Habits Questionnaire; SD, standard deviation; VO_2max, maximal oxygen uptake estimated from shuttle-run performance. Higher CSHQ scores indicate greater sleep disturbance. Among participants aged 10 years, estimated VO_2max demonstrated significant departure from normality on both the Kolmogorov–Smirnov and Shapiro–Wilk tests (both $p<0.001$). Non-parametric analyses were therefore used for the principal age-specific association tests. Spearman correlation analyses for the age groups with complete correlation outputs are summarized in Table 2. Sleep duration was not significantly associated with estimated VO_2max at age 10 ($\rho=0.120$, $p=0.405$), age 11 ($\rho=0.246$, $p=0.085$), or age 12 ($\rho=0.089$, $p=0.539$). Similarly, CSHQ score was not significantly associated with estimated VO_2max at age 10 ($\rho=-0.188$, $p=0.192$), age 11 ($\rho=0.044$, $p=0.761$), or age 12 ($\rho=-0.016$, $p=0.914$). Among participants aged 10 years, longer sleep duration was significantly associated with a lower CSHQ score ($\rho=-0.301$, $p=0.033$), indicating fewer reported sleep disturbances among participants with longer sleep duration. In the age-11 subgroup, CSHQ score was inversely associated with BMI ($\rho=-0.304$, $p=0.032$). No other reported correlations reached statistical significance.

Table 2. Correlations Between Sleep Characteristics and Estimated Cardiorespiratory Fitness

Age, years	Variable pair	Spearman ρ	p value
10	Sleep duration vs estimated VO_2max	0.120	0.405
10	CSHQ score vs estimated VO_2max	−0.188	0.192
10	Sleep duration vs CSHQ score	−0.301	0.033
11	Sleep duration vs estimated VO_2max	0.246	0.085
11	CSHQ score vs estimated VO_2max	0.044	0.761
11	CSHQ score vs BMI	−0.304	0.032
12	Sleep duration vs estimated VO_2max	0.089	0.539
12	CSHQ score vs estimated VO_2max	−0.016	0.914

Statistical significance was defined as $p<0.05$.

Kruskal–Wallis analyses demonstrated no statistically significant differences in estimated VO_2max across the study-defined sleep categories in any age group. The smallest p value occurred among participants aged 13 years ($H=5.336$, $p=0.069$), but this remained above the prespecified significance threshold. The corresponding comparisons were also non-significant at age 10 ($p=0.484$), age 11 ($p=0.377$), age 12 ($p=0.124$), age 14 ($p=0.306$), and age 15 ($p=0.592$). Accordingly, the null hypothesis of no difference in estimated cardiorespiratory fitness across sleep categories was not rejected in any age-specific analysis.

Table 3. Comparison of Estimated VO_2max Across Study-Defined Sleep Categories

Age, years	Kruskal–Wallis H	df	p value
10	1.452	2	0.484
11	1.951	2	0.377
12	4.171	2	0.124
13	5.336	2	0.069
14	2.367	2	0.306
15	1.050	2	0.592

Overall, the age-specific analyses did not demonstrate a consistent statistically significant association between either sleep duration or CSHQ score and estimated cardiorespiratory fitness. Although shuttle-run performance increased substantially with age, variation in sleep characteristics did not correspond to statistically significant differences in estimated VO_2max within individual age groups.

DISCUSSION

The study has several strengths. It focuses on a school-going population from Lahore, adding evidence from a South Asian urban setting that remains comparatively underrepresented in the international literature. Sleep characteristics and cardiorespiratory exercise capacity were assessed within the same participants, allowing direct examination of their relationship, while inclusion of participants aged 10–15 years permitted age-specific evaluation of developmental patterns. The 20mSRT also offered important practical advantages for school-based fitness assessment because it can be implemented in relatively large groups without sophisticated laboratory equipment (22), whereas the CSHQ provided a structured and widely used framework for identifying parent-reported sleep disturbances (20). Nevertheless, several limitations should be considered when interpreting the findings. The cross-sectional design prevents determination of temporal direction or causality, and it therefore remains uncertain whether sleep influences fitness, fitness influences sleep, or both are shaped by common behavioral and physiological determinants. Sleep was assessed primarily through reported duration and a questionnaire rather than objective multi-night measurement, while the CSHQ was originally validated predominantly among younger school-aged children; consequently, application of its traditional screening threshold to participants in the older adolescent age range requires caution.

Cardiorespiratory fitness was assessed using a field-based shuttle-run test and estimated VO_2max rather than direct cardiopulmonary exercise testing, and prediction error may therefore have reduced the precision of individual fitness estimates. Objectively measured habitual physical activity and sedentary behavior were not comprehensively incorporated into the principal analyses, despite their potential importance as both confounding and mediating factors in the relationship between sleep and CRF. Additional variables, including screen exposure, pubertal maturation, dietary behavior, psychological stress, socioeconomic characteristics, organized sport participation, and environmental opportunities for physical activity, were also not comprehensively evaluated. The relatively modest age-specific subgroup sizes may have limited statistical power for detecting small associations, while repeated subgroup comparisons increase the possibility that isolated statistically significant findings occurred by chance. Furthermore, the originally specified multivariable models were not considered appropriate for primary interpretation when conceptually or mathematically overlapping predictors were entered simultaneously. Future analytical approaches should therefore prioritize continuous sleep-duration and CSHQ measures and use prespecified covariates selected on biological and statistical grounds, including age, sex, BMI, objectively measured physical activity, and other relevant confounders, while avoiding simultaneous inclusion of redundant variables.

These limitations provide a clear direction for subsequent research. Larger prospective cohorts with repeated measurements across school years would allow investigators to determine whether changes in sleep precede changes in CRF and whether the magnitude or direction of the association differs according to sex or developmental stage. Objective measurement should be incorporated wherever feasible, with wrist actigraphy used to characterize sleep duration, timing, regularity, efficiency, fragmentation, and night-to-night variability, and accelerometry used to quantify moderate-to-vigorous physical activity and sedentary behavior within the broader 24-hour movement-behavior framework. Such an approach would permit sleep to be interpreted alongside the other behaviors with which it naturally competes for time rather than as an isolated exposure. Direct cardiopulmonary exercise testing in a representative subsample could additionally provide criterion validation for field-estimated VO_2max and clarify the degree of measurement error associated with shuttle-run prediction.

Future studies should also be sufficiently powered for sex-stratified and developmental-stage analyses and should prospectively evaluate potentially important determinants such as BMI, screen exposure, pubertal maturation, psychological stress, diet, socioeconomic circumstances, and organized sport participation. Ultimately, intervention research will be required to establish whether deliberate improvement in sleep produces measurable changes in cardiorespiratory fitness.

Exercise interventions have already demonstrated beneficial effects on adolescent sleep quality (18), while school-based sleep education can influence sleep-related knowledge and behaviors (19). These findings support evaluation of multifactorial school-based interventions that combine sleep hygiene, regular physical activity, opportunities for active recreation, and reduction of excessive sedentary screen exposure rather than targeting a single behavior in isolation. From a public-health perspective, both healthy sleep and cardiorespiratory fitness remain independently important determinants of adolescent health even when a direct statistical association between them is not demonstrated. Accordingly, school health programs should promote age-appropriate sleep duration and regular sleep schedules alongside physical education and habitual physical activity. Overall, the present findings demonstrate that short or borderline sleep duration and elevated parent-reported sleep-disturbance scores were common among the studied participants, while shuttle-run performance increased with age. However, neither sleep duration nor CSHQ score demonstrated a consistent statistically significant association with estimated cardiorespiratory fitness. These results reinforce the need to consider sleep and fitness within the broader context of daily movement behaviors, body composition, maturation, and environmental influences rather than assuming a simple direct relationship.

CONCLUSION

School-going participants aged 10–15 years in Lahore commonly demonstrated short or borderline sleep duration and elevated parent-reported sleep-disturbance scores. Cardiorespiratory exercise performance assessed using the 20-m multistage shuttle run increased progressively with age. However, the available age-specific analyses did not demonstrate a consistent statistically significant association between sleep duration or CSHQ score and estimated cardiorespiratory fitness, and estimated VO_2max did not differ significantly across study-defined sleep categories. Sleep health and cardiorespiratory fitness should therefore be considered independently important dimensions of adolescent health. Larger longitudinal studies incorporating objective sleep, physical activity, body-composition, and cardiopulmonary measurements are required to clarify temporal and potentially age- or sex-specific relationships.

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