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Original Research Article

THE ASSOCIATION BETWEEN PHYSICAL FITNESS, SPIROMETRIC INDICES, AND COGNITIVE FUNCTION IN SCHOOL CHILDREN OF SUNSARI DISTRICT, NEPAL

Khirendra Choudhary[1], Lalit Narayan Chaudhary[2], Prabha Nanda Chaudhary[3], Uttam Khadka[4]

[1]Department of Physiology, B&C Medical College Teaching Hospital and Research Center, Birtamod, Jhapa, Nepal, [2]Department of Biochemistry, B&C Medical College Teaching Hospital and Research Center, Birtamod, Jhapa, Nepal, [3]Department of Anatomy, B&C Medical College Teaching Hospital and Research Center, Birtamod, Jhapa, Nepal,[4] Department of Pharmacology, B&C Medical College Teaching Hospital and Research Center, Birtamod, Jhapa, Nepal,

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ABSTRACT

Background

Physical fitness and lung function affect cognitive development in children. This study investigates relationships between cardiovascular fitness, spirometric indices, and cognitive function among school children in Sunsari District, Nepal.

Objectives

The objectives of the study were to determine the association between cardiovascular fitness and cognitive function, examine the relationship between spirometric parameters and cognitive performance, identify the strongest predictors of cognitive outcomes, and explore differences in these variables across gender, school type, and different age groups.

Methods

A cross-sectional study of 120 children aged 12-16 years from government and private schools in Sunsari District was conducted. Physical fitness was assessed using YMCA 3-minute step test, lung function via spirometry, and cognitive function using Trail Making Test and Digit Span tests.

Results

Lower recovery heart rates and higher fitness index correlated significantly with better cognitive scores ($r = -0.34$, $p < 0.01$). Spirometric variables showed mild positive associations with cognitive performance ($r = 0.13$-0.18). Physical fitness ($\beta = 0.418$, $p < 0.001$) and digit span backward ($\beta = 0.375$, $p < 0.001$) were strongest predictors, explaining 28.4% of variance ($R^2 = 0.284$, $F = 11.41$, $p < 0.001$).

Conclusions

Cardiopulmonary fitness and lung function significantly associate with executive and memory functions in adolescents. School-based physical activity interventions may enhance cognitive outcomes and academic performance.

Keywords: *Physical fitness, spirometry, cognitive function, school children*

***Corresponding Author**
Khirendra Choudhary
Email: khirendrachoudhary@hotmail.com
ORCID: https://orcid.org/0009-0004-3227-6906

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INTRODUCTION

Cognitive development in children depends on biological, environmental, and behavioral factors. Recent research shows physical fitness, particularly cardiovascular and respiratory health, influences memory, attention, and executive function [1,2]. Meta-analyses support that fitness interventions benefit children's cognitive functioning, with small to moderate effects [1-3].

Aerobic fitness links to increased prefrontal cortex activation, critical for executive functioning and working memory [4]. Proposed mechanisms include improved cerebral blood flow, increased brain-derived neurotrophic factor (BDNF), enhanced neuroplasticity, and improved neurovascular coupling [4-6]. Longitudinal studies demonstrate cardiovascular fitness improvements predict enhanced cognitive performance [7].

Spirometric indices like FVC and FEV_1 may support cognitive development through systemic oxygenation and neurovascular coupling [8,9]. While established in adults [10,11], research in healthy children remains limited.

Despite global evidence, South Asian studies, particularly from Nepal, are scarce. This study examines relationships between physical fitness, lung function, and cognitive performance among school children in Sunsari District, Nepal.

METHODS

A cross-sectional study was conducted from March 18 – May 31, 2025 among 120 school children aged 12-16 years from Sunsari District. Participants were recruited by stratified random sampling from 8 schools (5 government, 3 private) conveniently. Sample size calculation assumed moderate correlation (r=0.30), α=0.05, power=0.80, yielding minimum n=84.

All tests were conducted 9:00 AM-12:00 PM with standardized protocols. Physical fitness was assessed using YMCA 3-minute step test with fitness index: (Duration in seconds × 100) ÷ (2 × sum of three 30-second pulse counts) [12]. Spirometry was performed using calibrated Spiro Excel spirometer following ATS guidelines [13], measuring FVC, FEV_1, and FEV_1/FVC ratio using absolute values (liters for FVC and FEV_1; ratio for FEV_1/FVC), with results additionally expressed as z-scores derived from GLI 2012 South Asian reference equations [14]. Z-scores were used for classification of lung function status (normal: z-score > −1.645), while absolute values were used in correlation and regression analyses to preserve physiological variability in this healthy sample. Cognitive function was evaluated using Trail Making Test (TMT A & B) [15] and Digit Span tests [16]. "A Cognitive Composite Score ranging from 0 to 100 was computed for each participant using the following formula: Cognitive Composite Score = (Digit Span Forward × 5) + (Digit Span Backward × 5) + (100 − TMT-A) × 0.2 + (150 − TMT-B) × 0.1, where higher scores indicate better overall cognitive performance." This composite formula integrates working memory (digit span) and executive processing speed (TMT) into a single index. While a formal psychometric validation of this specific formula was beyond the scope of the present study, each component test (TMT and Digit Span) is individually well-validated and widely used in pediatric cognitive assessment research [15,16]. The composite formula was adapted from prior published methodology combining speed and memory indices [17,1]. and its internal consistency in the present sample was acceptable (Cronbach's $\alpha = 0.74$).

Data were analyzed using SPSS 21. Normality was assessed via Shapiro-Wilk tests. Pearson correlations examined bivariate relationships. Stepwise multiple regression identified independent predictors. Independent t-tests and ANOVA compared subgroups with Bonferroni correction (α=0.005). Significance was set at $p<0.05$.

The study was approved by B&C Medical College Teaching Hospital and Research Center IRC (00242025, March 13, 2025). Data collection commenced on March 18, 2025, strictly after receipt of the IRC approval certificate. Written parental consent and child assentent were obtatined. The five-day interval between approval (March 13, 2025) and commencement of data collection (March 18, 2025) allowed for finalizing logistics and obtaining school permissions. All study activities, including participant recruitment, testing, and data collection, were conducted exclusively within the approved period (March–May 2025). No data were collected prior to IRC clearance.

RESULTS

Table 1: Participant Demographics and Baseline Characteristics (N=120)

Characteristic	Value
Mean Age (years)	14.2 ± 1.3 (Range: 12-16)
Gender	Male: 65 (54.2%), Female: 55 (45.8%)
School Type	Government: 72 (60.0%), Private: 48 (40.0%)
Location	Urban: 72 (60.0%), Semi-urban: 48 (40.0%)

Table 1: The study included 120 school children from Sunsari District, Nepal, with a mean age of 14.2

years (SD = 1.3), representing mid-adolescence when significant cognitive and physiological development occurs. The gender distribution was relatively balanced (54.2% male, 45.8% female), allowing for meaningful gender-based subgroup analyses. The sample was stratified by school type, with 60% from government schools and 40% from private schools. All participants were from urban (60%) and semi-urban (40%) areas.

Table 2: Descriptive Statistics of All Measured Variables (N=120)

Variable	Mean ± SD	Median	Range	25th Percentile	75th Percentile	Normal Range*
YMCA Recovery HR (bpm)	93.7 ± 9.3	92.5	78-115	87.0	99.0	85-100
Fitness Index	181.7 ± 30.4	178.0	125-245	158.0	203.0	150-200
FVC (L)	3.51 ± 0.55	3.48	2.45-4.68	3.12	3.89	3.2-4.2
FEV_1 (L)	3.03 ± 0.53	2.98	2.10-4.15	2.68	3.38	2.7-3.6
FEV_1/FVC Ratio	0.84 ± 0.05	0.84	0.72-0.94	0.81	0.87	0.80-0.90
TMT-A (seconds)	40.1 ± 8.5	38.5	25-62	34.0	45.0	30-50
TMT-B (seconds)	90.6 ± 14.2	88.0	65-125	81.0	98.0	75-120
Digit Span Forward	6.1 ± 1.4	6.0	4-9	5.0	7.0	5-7
Digit Span Backward	5.1 ± 1.3	5.0	3-8	4.0	6.0	4-6
Cognitive Composite Score	72.3 ± 12.8	71.5	48-98	63.0	81.0	60-85

Table 2: Descriptive statistics revealed that the study sample demonstrated physical fitness and cognitive performance parameters within expected ranges for healthy adolescents. The mean YMCA (Young Men's Christian Association.) recovery heart rate (93.7 ± 9.3 bpm) indicated moderate cardiovascular fitness, with the majority of participants (IQR: 87.0-99.0 bpm) falling within or near the normal range (85-100 bpm). Spirometric values showed adequate lung function, with mean FVC (3.51 ± 0.55 L) and FEV_1 (3.03 ± 0.53 L) corresponding to approximately 98% of predicted values based on GLI 2012 South Asian reference standards. The mean FEV_1/FVC ratio (0.84 ± 0.05) was within normal limits, indicating absence of obstructive airway disease in this healthy sample. Cognitive performance measures showed considerable variability: TMT-A completion time (40.1 ± 8.5 seconds) and TMT-B (90.6 ± 14.2 seconds) reflected typical adolescent processing speed and executive function, while digit span scores (forward: 6.1 ± 1.4; backward: 5.1 ± 1.3) were consistent with published normative data for this age group. The cognitive composite score (72.3 ± 12.8) demonstrated substantial individual variation (range: 48-98), providing adequate variance for correlation and regression analyses.

Table 3: Correlation Matrix - Pearson Correlation Coefficients

Variable	1	2	3	4	5	6	7	8	9	10
1. Recovery HR	1.000									
2. Fitness Index	-0.781**	1.000								
3. FVC (L)	-0.234*	0.282**	1.000							
4. FEV_1 (L)	-0.213*	0.265*	0.923**	1.000						
5. FEV_1/FVC Ratio	0.082	-0.124	-0.152	0.184	1.000					
6. TMT-A (sec)	0.312**	-0.347**	-0.162	-0.145	0.053	1.000				
7. TMT-B (sec)	0.285**	-0.324**	-0.178	-0.156	0.078	0.738**	1.000			
8. Digit Span Forward	-0.253*	0.294**	0.152	0.133	0.118	-0.423**	-0.384**	1.000		
9. Digit Span Backward	-0.315**	0.364**	0.184	0.163	0.142	-0.478**	-0.452**	0.682**	1.000	
10. Cognitive Composite	-0.342**	0.398**	0.182	0.154	0.132	-0.821**	-0.874**	0.784**	0.847**	1.000

Table 3: Pearson correlation analysis revealed several statistically significant relationships supporting the study hypotheses. The strongest correlation was between recovery heart rate and fitness index ($r = -0.781$, $p < 0.01$), which is expected given that fitness index is mathematically derived from recovery heart rate measurements; this high collinearity was appropriately managed in subsequent regression analysis by retaining only one measure. Physical fitness variables showed moderate negative correlations with recovery heart rate and positive correlations with cognitive composite score (fitness index: $r = 0.398$, $p < 0.01$; recovery HR: $r = -0.342$, $p < 0.01$), indicating that better cardiovascular fitness was associated with superior cognitive performance. Spirometric indices demonstrated weaker but meaningful associations: FVC and FEV_1 showed mild positive correlations with fitness index ($r = 0.282$, $r = 0.265$ respectively, $p < 0.05$) and trends with cognitive composite score ($r = 0.182$, $r = 0.154$). The FEV_1/FVC ratio showed minimal correlations with all variables ($r = -0.15$ to 0.18), which is physiologically appropriate in this healthy sample. Among cognitive measures, Trail Making Tests showed strong intercorrelation ($r = 0.738$, $p < 0.01$), and digit span backward demonstrated stronger associations with fitness variables and overall cognitive composite, supporting its inclusion as the primary working memory predictor in regression modeling.

Table 4: Multiple Linear Regression Analysis - Predictors of Cognitive Composite Score

Predictor	B	SE B	β	t	p	95% CI	VIF
Constant	45.23	8.92	-	5.07	<0.001	27.61–62.85	-
Fitness Index	0.175	0.035	0.418	5.02	<0.001	0.106–0.244	1.23
Digit Span Backward	3.68	0.78	0.375	4.72	<0.001	2.14–5.22	1.18
FVC (L)	4.12	1.85	0.178	2.23	0.028	0.46–7.78	1.15
Age (years)	2.31	0.89	0.235	2.59	0.011	0.54–4.08	1.09

Table 4: Stepwise multiple regression identified four significant predictors of cognitive composite score. Fitness index emerged as the strongest predictor (β = 0.418), followed by digit span backward (β = 0.375), FVC (β = 0.178), and age (β = 0.235). The model explained 28.4% of variance in cognitive performance, with adjusted R^2 of 0.259 accounting for the number of predictors. All VIF (Variance Inflation Factor) values were below 1.5, indicating no multicollinearity concerns. For practical interpretation, a 10-point increase in fitness index predicts a 1.75-point improvement in cognitive composite score, while each additional year of age predicts a 2.31-point increase.

Table 5: Subgroup Analysis by Gender

Variable	Males (n=65)	Females (n=55)	p-value	Cohen's d	Sig.
Recovery HR (bpm)	91.2 ± 8.7	96.8 ± 9.1	0.001	0.63	*
Fitness Index	188.4 ± 28.9	173.6 ± 30.2	0.006	0.50	-
FVC (L)	3.71 ± 0.52	3.27 ± 0.51	<0.001	0.85	*
FEV_1 (L)	3.21 ± 0.49	2.82 ± 0.48	<0.001	0.80	*
FEV_1/FVC Ratio	0.85 ± 0.04	0.84 ± 0.05	0.289	0.22	-
TMT-A (sec)	38.7 ± 8.1	41.9 ± 8.7	0.034	0.38	-
TMT-B (sec)	87.3 ± 13.2	94.6 ± 14.5	0.004	0.53	*
Digit Span Forward	6.3 ± 1.3	5.8 ± 1.4	0.048	0.37	-
Digit Span Backward	5.4 ± 1.2	4.7 ± 1.3	0.003	0.56	*
Cognitive Composite	75.1 ± 11.9	68.9 ± 13.2	0.007	0.49	-

Table 5: Significant gender differences were observed across most variables. Males demonstrated superior cardiovascular fitness (lower recovery HR, higher fitness index) and lung function (FVC, FEV_1), with large effect sizes reflecting physiological sex differences in adolescent development. Males also showed better cognitive performance with medium effect sizes, particularly in executive function (TMT-B, d = 0.53) and working memory (Digit Span Backward, d = 0.56). These differences likely reflect both biological factors and sociocultural influences on physical activity participation. Seven variables remained significant after Bonferroni correction (α = 0.005), indicating robust gender differences.

Table 6: Subgroup Analysis by School Type

Variable	Government (n=72)	Private (n=48)	p-value	Cohen's d	Sig.
Recovery HR (bpm)	95.3 ± 9.8	91.4 ± 8.2	0.024	0.43	-
Fitness Index	176.2 ± 31.2	189.8 ± 27.9	0.017	0.46	-
FVC (L)	3.43 ± 0.57	3.63 ± 0.51	0.049	0.37	-
FEV_1 (L)	2.96 ± 0.55	3.14 ± 0.49	0.072	0.34	-
FEV_1/FVC Ratio	0.84 ± 0.05	0.85 ± 0.04	0.198	0.22	-
TMT-A (sec)	42.1 ± 8.9	37.2 ± 7.4	0.002	0.59	*
TMT-B (sec)	93.8 ± 14.8	86.1 ± 12.4	0.003	0.56	*
Digit Span Forward	5.8 ± 1.4	6.5 ± 1.3	0.008	0.52	-
Digit Span Backward	4.8 ± 1.3	5.5 ± 1.2	0.004	0.56	*
Cognitive Composite	69.2 ± 13.4	76.8 ± 11.2	0.001	0.61	*

Table 6: Private school students demonstrated superior performance across most measures. Cognitive differences were particularly pronounced (cognitive composite: d = 0.61, medium-to-large effect), with private school students showing faster processing speed (TMT-A, TMT-B) and better working memory (both digit span measures). Physical fitness and lung function differences were smaller (d = 0.37-0.46), suggesting the cognitive advantages may reflect broader socioeconomic factors beyond physical health alone.

Table 7: Age-Stratified Analysis

Variable	12-13 yrs (n=35)	14-15 yrs (n=52)	16 yrs (n=33)	p-value	ηp^2
Recovery HR (bpm)	96.8 ± 8.9	92.7 ± 9.1	91.2 ± 9.8	0.019	0.080
Fitness Index	169.2 ± 28.7	185.3 ± 29.8	189.4 ± 32.1	0.008	0.080
FVC (L)	3.21 ± 0.48	3.58 ± 0.52	3.74 ± 0.58	<0.001	0.149
FEV_1 (L)	2.78 ± 0.45	3.08 ± 0.49	3.25 ± 0.56	<0.001	0.129
FEV_1/FVC Ratio	0.84 ± 0.05	0.84 ± 0.05	0.85 ± 0.05	0.412	0.018
TMT-A (sec)	41.2 ± 8.8	39.8 ± 8.5	39.3 ± 8.2	0.558	0.010
TMT-B (sec)	92.8 ± 15.1	90.1 ± 13.8	88.4 ± 13.9	0.374	0.020
Digit Span Forward	5.9 ± 1.4	6.1 ± 1.3	6.4 ± 1.5	0.291	0.025
Digit Span Backward	4.7 ± 1.2	5.1 ± 1.3	5.6 ± 1.3	0.018	0.077
Cognitive Composite	68.3 ± 13.2	72.9 ± 12.3	75.8 ± 12.5	0.032	0.055

Table 7: Age-stratified analysis revealed significant developmental trajectories for physical fitness and lung function, consistent with normal adolescent growth. Lung function showed progressive improvements with large effect sizes (FVC: ηp^2 = 0.149; FEV_1: ηp^2 = 0.129), with FEV_1 showing significant differences across all three age groups, while FVC distinguished younger (12-13 years) from older children (14-15, 16 years). Cardiovascular fitness improved significantly (ηp^2 = 0.080), with 12–13-year-olds showing lower fitness than older groups. Executive function measures (TMT-A, TMT-B) showed non-significant age effects, possibly reflecting individual variability exceeding maturational changes in this age range. Working memory (Digit Span Backward) and overall cognitive composite scores showed medium effect sizes (ηp^2 = 0.055-0.077), with youngest children performing

significantly below 16-year-olds, consistent with continued prefrontal cortex maturation through mid-adolescence.

DISCUSSION

This cross-sectional study examined relationships between physical fitness, spirometric indices, and cognitive function in 120 Nepali school children aged 12-16 years, representing the first such investigation in Nepal.

Physical fitness emerged as the strongest predictor of cognitive outcomes ($\beta = 0.418$, $p < 0.001$), with fitness index, working memory, FVC, and age collectively explaining 28.4% of variance in cognitive performance. The negative correlation between recovery heart rate and cognitive composite score ($r = -0.342$, $p < 0.01$) suggests that children with better cardiovascular fitness tend to have better cognitive scores, consistent with international meta-analyses reporting moderate associations ($r = 0.25$-0.45) [1,2,3].

The modest but significant association between FVC and cognitive performance ($\beta = 0.178$, $p = 0.028$) suggests lung capacity contributes independently to cognitive function beyond cardiovascular fitness effects, aligning with literature linking pulmonary function to cognitive outcomes through improved cerebral oxygenation [8,9]. The non-significant FEV_1/FVC ratio associations are physiologically appropriate in healthy samples.

Working memory (digit span backward) proved highly predictive ($\beta = 0.375$, $p < 0.001$), highlighting its centrality to adolescent cognitive function. The retention of only backward digit span in regression suggests executive manipulation capacity holds greater functional significance than passive storage, consistent with academic achievement research [17,18].

Males demonstrated superior performance across physical fitness ($d = 0.50$) and cognitive measures ($d = 0.49$), reflecting both physiological sex differences in pulmonary development and sociocultural factors limiting girls' physical activity participation in Nepal [19,20]. Private school students showed significantly better outcomes ($d = 0.61$), likely reflecting socioeconomic advantages including better facilities and enhanced physical education programs [21]. Importantly, after controlling for fitness in regression, school type became non-significant ($p = 0.299$), suggesting performance differences are substantially mediated by modifiable factors.

The fitness-cognition relationship likely operates through multiple pathways: increased cerebral blood flow to prefrontal cortex and hippocampus, upregulation of BDNF promoting neuroplasticity, and optimization of dopaminergic neurotransmission supporting executive function [4-6,23]. These findings support the rationale for evaluating school-based physical activity interventions to potentially support cognitive and academic outcomes in Nepal, where government schools average only 1-2 physical education periods weekly [24,25].

The cross-sectional design precludes causal inference, and findings should be interpreted as associations rather than causal relationships, though longitudinal studies elsewhere support causality [7]. Several important confounders were not measured in this study, representing a key limitation. Nutritional status, socioeconomic status, and sleep quality are known modulators of both cognitive performance and physical fitness. These unmeasured variables likely account for a portion of the unexplained variance (71.6%) in our model. Future research employing longitudinal designs with comprehensive covariate measurement, including dietary assessment, household income indices, and sleep monitoring, would strengthen causal inference and improve model fit.

CONCLUSIONS

Cardiopulmonary fitness and lung function significantly associate with executive and memory functions in Nepali adolescents. Physical fitness emerged as the strongest modifiable predictor, supporting implementation of evidence-based school physical activity programs. The 28.4% explained variance suggests substantial room for multi-factorial interventions addressing fitness, education quality, and socioeconomic factors to optimize cognitive development in this population.

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