Research Square

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A mediation model of physical activity levels and cardiorespiratory fitness: The role of sleep quality and stress

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Abstract

Purpose- Physical activity (PA) is a key determinant of cardiorespiratory fitness (CRF), reflecting the efficiency of the cardiovascular, respiratory, and muscular systems during sustained activity, while also enhancing sleep quality (SQ) by reducing sleep latency and promoting circadian rhythm regulation. Chronic stress is associated with poor SQ lower participation in health-promoting behaviors, and adverse physiological responses that may reduce the CRF. Therefore, this study aimed to investigate whether the relationship between physical activity and cardiorespiratory fitness in young adults is mediated by sleep quality and perceived stress.

Methods- A cross-sectional study was conducted with 300 participants to examine the relationships between SQ, perceived stress, PA, and CRF. Sleep quality, perceived stress, and PA were assessed using the Pittsburgh Sleep Quality Index (PSQI), Perceived Stress Scale 10 (PSS), and International Physical Activity Questionnaire (IPAQ) respectively. CRF was evaluated using the McArdle Step Test.

Results- The findings revealed both direct and indirect pathways linking PA, CRF, stress, and SQ. Furthermore, the significant serial mediation effect underscores the interconnected influence of SQ and psychological well-being on fitness outcomes in young adults.

Conclusion- These results suggest that SQ and stress levels do mediate the association between physical activity and cardiorespiratory fitness, both independently and collectively.

Introduction

Insufficient physical activity remains prevalent globally, with nearly 80% of adolescents and one-third of adults not meeting the recommended guidelines [1]. Indian epidemiological studies have reported a high prevalence of physical inactivity, especially among urban adults who often fail to meet the recommended activity guidelines [2]. Regular moderate-to-vigorous physical activity is well established as a primary determinant of cardiorespiratory fitness (CRF) [3]. Cardiorespiratory fitness, commonly assessed through maximal oxygen uptake (VO_2 max), represents the integrated capacity of the cardiovascular, respiratory, and muscular systems to supply and utilize oxygen during sustained physical activity. Thus, we hypothesize the following-

Hypothesis 1

Higher physical activity levels positively affect cardiorespiratory fitness in young adults.

Consistent physical activity optimizes sleep quality by facilitating faster sleep initiation and promoting deeper slow-wave sleep stages [4]. Poor sleep may lead to daytime fatigue and reduced participation in physical activity, thereby limiting improvements in CRF. Sedentary behavior is significantly associated with an elevated prevalence of sleep-related disturbances [5–7]. In young adults, inadequate sleep duration coupled with reduced physical activity may substantially affect cardiorespiratory fitness (CRF) [8]. Regular exercise stimulates physiological changes such as improved cardiovascular function,

hormonal regulation (e.g., melatonin), and vagal tone, which can promote better sleep quality [9]. Recent evidence supports the concept of a bidirectional relationship between sleep quality and cardiorespiratory fitness (CRF). Better CRF is associated with improved sleep quality, whereas poor sleep may impair physiological recovery, exercise performance, and long-term fitness adaptations [10]. Regular engagement in physical activity has been shown to improve sleep quality through mechanisms involving enhanced circadian rhythm regulation, reduced sleep latency, and increased slow-wave sleep, thereby promoting restorative physiological processes and recovery [11]. Regular exercise can mitigate the negative effects of poor sleep quality on metabolism [12]. However, the pathways linking sleep quality and CRF are unlikely to be direct and may operate through intermediary behavioral and psychological mechanisms. Therefore, we formulated the following hypothesis-

Hypothesis 2

Increased physical activity levels positively affect the quality of sleep in young adults, which in turn, anticipates cardiorespiratory fitness.

Chronic stress is associated with poor sleep and reduced engagement in health-promoting behaviors, including physical activity [13]. In turn, diminished physical activity and sustained physiological stress responses may adversely affect the CRF [14]. Therefore, stress may function as both an independent determinant and mediator of the sleep–fitness relationship. Thus, we propose the following hypothesis-

Hypothesis 3

Higher stress levels are negatively associated with cardiorespiratory fitness (CRF) in young adults. While physically active people tend to have a stress-free life.

The relationship between PA and cardiorespiratory fitness (CRF) may be influenced by behavioral and psychosocial factors, particularly sleep quality and perceived stress. Due to the prognostic importance of CRF, pinpointing changeable behavioral and psychosocial elements that affect CRF has emerged as a key focus in the fields of preventive medicine and public health research. Thus, physical activity may serve as a medium that influences sleep quality and helps reduce stress levels [15]. Stress levels are another important pathway. Adequate sleep is essential for reducing stress levels in people with insomnia [16]. Accordingly, this study advances the following hypothesis-

Hypothesis 4

Sleep quality and perceived stress mediate the relationship between physical activity and cardiorespiratory fitness, such that higher physical activity levels are associated with improved sleep quality and reduced stress, which subsequently contribute to enhanced cardiorespiratory fitness among young adults.

Despite many studies on physical activity and cardiorespiratory fitness, none have simultaneously examined sleep and stress as mediating variables within a unified conceptual framework. Understanding

these mechanisms is essential for designing integrated behavioral interventions aimed at optimizing both physical activity and cardiorespiratory fitness. Accordingly, the present study investigated whether the relationship between physical activity and cardiorespiratory fitness is mediated by sleep quality and perceived stress. By elucidating these interrelationships, this study seeks to contribute to a more comprehensive behavioral model linking sleep, psychological well-being, physical activity, and cardiorespiratory fitness.

Methodology

2.1 Study design

A cross-sectional study was conducted to elucidate the underlying mechanisms connecting physical activity with cardiorespiratory fitness (CRF). The analysis further incorporated sleep quality and perceived stress as mediating variables to identify possible indirect associations.

2.2 Participants

Subjects aged 18–28 years were recruited via institutional and community advertisements, resulting in a sample of 300 subjects selected through convenience sampling. Asymptomatic healthy participants with no medical or surgical history were included in the study. The exclusion criteria encompassed a diagnosis of sleep disorders (e.g. obstructive sleep apnea), cardiopulmonary disease, musculoskeletal disease, psychiatric disease, and the use of medications known to affect sleep or autonomic function.

2.3 Measures and instruments

2.3.1 Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) is a globally accepted test to assess sleep quality, with scores ranging from 0 to 21. The test has good test-retest reliability (0.85), with a specificity and sensitivity of 86.5% and 89.6%, respectively [17]. Whereas a score of more than five indicates sleep disturbances, while a score less than 6 indicates good sleep quality.

2.3.2 Cardiorespiratory fitness

The McArdle Step Test is an economical and practical tool for predicting cardiorespiratory fitness (CRF) levels by measuring Heart Rate (HR) response at the end of three minutes of post-exercise recovery HR at. This test requires participants to step up and down on a stepper at a rate of 22 steps per minute for women and 24 steps per minute for men for three minutes. This test was used to estimate VO2max using a reference equation that utilized the heart rate of the subject at the end of the test. Different equations were used for men and women. The equations for men and women are 111.33 –(0.42* heart Rate) and 65.81-(0.18*heart rate), respectively.

2.3.3 Perceived stress scale (PSS 10)

The PSS 10 is a widely utilized instrument that assesses the extent of stress levels in an individual. It is a self-administered measure with acceptable internal consistency and Cronbach's alphas of 0.86 and 0.79, respectively [18]. The Hindi version of PSS 10 has also been validated in the Indian population [19].

2.3.4 International Physical Activity Questionnaire long form (IPAQ)

The International Physical Activity Questionnaire–Long Form (IPAQ-LF) is a standardized self-report instrument developed to assess habitual physical activity among adults aged 15–69 years across multiple domains of daily life. The questionnaire evaluates physical activity performed during the preceding seven days in four domains: occupational activity, transportation, domestic/household activities, and leisure-time physical activity, while also recording sedentary behaviour through sitting time. Activities were categorized according to intensity (walking, moderate, and vigorous), and total physical activity was measured in Metabolic Equivalent Task minutes per week (MET-min/week). A study on Indian participants reported excellent test–retest reliability (ICC = 0.963), along with high reliability for occupational (ICC = 0.923), transportation (ICC = 0.839), domestic (ICC = 0.862), and leisure-time activity (ICC = 0.939) [20].

2.4 Procedure

The research protocol was approval by the Ethical Committee of the Delhi Pharmaceutical Sciences and Research University (DPSRU), Delhi. The study was prospectively registered with the Clinical Trials Registry–India (CTRI) under the registration number REF/2024/08/090640). Following institutional permissions, recruitment notices were displayed on the notice boards of various institutions and community centers. These notices outlined the study objectives, detailed the assessment procedures to be conducted, and informed potential participants of the possible personal benefits associated with participation. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and received approval from the Ethical Committee of Delhi Pharmaceutical Sciences and Research University (DPSRU). Participants were informed in detail about the study objectives and procedures, following which written informed consent was obtained from those willing to participate. Eligible participants were recruited using a convenience sampling approach. The inclusion criteria encompassed individuals of either sex aged between 18 and 28 years. Additionally, participants diagnosed with musculoskeletal, neurological, or psychological disorders that could potentially influence the study outcomes were not considered for inclusion. The variables included sleep quality measured using the Pittsburgh Sleep Quality Index (PSQI), PA measured via the International Physical Activity Questionnaire (IPAQ) long form (expressed in MET-min/week), perceived stress assessed using the Perceived Stress Scale (PSS- 10), and predicted cardiorespiratory fitness quantified using the McArdle step test.

3 Data Analysis

Data were analyzed using IBM SPSS Statistics Version 26.0 (IBM Corp., NY, USA). Descriptive statistics (mean and standard deviation) were computed to summarize the participants' characteristics. Pearson's correlation analysis was conducted to examine the bivariate relationships between these variables. Statistical significance was set at $p < 0.05$ for all analyses.

To examine the hypothesized mediation framework, a serial multiple mediation analysis was conducted using Model 6 of the PROCESS Macro developed by Hayes. In this model, estimated VO_2 max was entered as the independent variable, physical activity (IPAQ scores) as the dependent variable, and sleep quality (PSQI score) and perceived stress (PSS scores) were included as sequential mediators. Indirect effects were evaluated using a bias-corrected bootstrapping procedure with 5,000 resamples to generate 95% confidence intervals (CIs). Mediation was considered statistically significant if the confidence intervals did not include the zero. The specific indirect pathways assessed were as follows- (i) physical activity → sleep quality → stress → cardiorespiratory fitness, (ii) physical activity → perceived stress → cardiorespiratory fitness, and (iii) the serial pathway sleep quality → physical activity → sleep quality → cardiorespiratory fitness.

Result

4.1 Descriptive statistics

After screening for inclusion and exclusion criteria, 300 participants were recruited for the study. The descriptive statistics of the sample and Pearson's correlation coefficients for the study are presented (Table 1). The mean age of the participants was 21.39 years (SD = 2.19). The mean body mass index (BMI) was 22.38 kg/m² (SD = 2.65), indicating that the majority of the subjects were within the normal weight range. The mean cardiorespiratory fitness (VO_2max) was 45.41 mL·kg⁻¹·min⁻¹ (SD = 7.34), while the mean sleep quality score measured using the Pittsburgh Sleep Quality Index (PSQI) was 5.19 (SD = 2.27), suggesting mild sleep disturbances. The average perceived stress score evaluated using the Perceived Stress Scale (PSS) was 9.71 (SD = 5.25), and the mean physical activity level measured using the International Physical Activity Questionnaire (IPAQ) was 928.37 MET-min/week (SD = 547.31).

4.2 Correlation among variables

The correlations among the key measures are listed in Table 1. There was a significant correlation between sleep quality and stress levels (r = 0.50**), and between physical activity (IPAQ) and CRF (r = 0.42**). It was also reported that CRF is negatively correlated with sleep (r = − .43**) and stress levels (r = − .44**). Similarly, the IPAQ was negatively correlated with sleep (r = − .32**) and stress levels (r = − .41**). All the above values were significant at p < 0.05.

Table 1
Descriptive statistics and correlations among variables.

S no	Variable	Mean	SD	CRF	SQ	PSS	IPAQ
1	Age	21.39	2.19				
2	Height	162.75	8.46				
3	Weight	58.00	9.26				
4	BMI	22.38	2.65				
5	CRF	45.41	7.34	1			
6	PSQI	5.19	2.27	− .43**	1		
7	PSS	9.71	5.25	− .44**	.50**	1	
8	IPAQ	928.37	547.30	.42**	− .32	− .41**	1

4.3 Mediating effect of stress levels and sleep quality on cardiorespiratory fitness and physical activity

To examine the relationship between stress levels and physical activity, a mediation model was performed using Hayes' Process Model 6 macros. The direct, indirect, and total effects of the variables are presented in Table 2. First, the direct effect of physical activity level on cardiorespiratory fitness was analyzed. Indirect effects of sleep quality and stress levels were evaluated.

4.4 Regression and mediation analyses

Regression analysis demonstrated a positive direct association between physical activity (PA) and cardiorespiratory fitness (CRF) ($\beta = 0.0035$, $t = 4.7835$, $p < 0.001$, 95% CI: 0.0029–0.0049), indicating that higher levels of physical activity were associated with better CRF outcomes. Similarly, the total effect of PA on CRF remained statistically significant ($\beta = 0.0056$, $t = 8.0090$, $p < 0.001$, 95% CI: 0.0043–0.0070), suggesting both direct and indirect pathways linking PA and CRF.

Regarding intermediary variables, physical activity was significantly negatively associated with sleep quality scores ($\beta = -0.3171$, $t = -5.7713$, $p < 0.001$). Given that higher sleep quality scores generally indicate poorer sleep quality in instruments such as the PSQI, this finding suggests that greater physical activity is associated with improved sleep quality in young adults. Physical activity also demonstrated a significant inverse association with perceived stress ($\beta = -0.4140$, $t = -5.6400$, $p < 0.001$), indicating lower stress levels among individuals who reported higher physical activity participation.

Sleep quality was significantly positively correlated with perceived stress ($\beta = 0.4997$, $t = 8.1315$, $p < 0.001$), suggesting that poorer sleep quality was associated with increased perceived stress. Furthermore, sleep quality was negatively associated with CRF ($\beta = -0.4292$, $t = -4.3050$, $p < 0.001$), indicating that poor sleep may adversely affect cardiorespiratory fitness. Perceived stress was also

significantly related to CRF (β = − 0.4367, t = − 3.5398, p = 0.0005), supporting an inverse relationship between stress level and cardiorespiratory fitness.

Mediation analysis revealed statistically significant indirect effects through all examined pathways, as none of the bootstrap confidence intervals included zero (Table 3). Sleep quality independently mediated the association between PA and CRF (indirect effect = 0.0010; Boot SE = 0.0003; 95% CI: 0.0006–0.0017). Similarly, perceived stress independently mediated the relationship between PA and CRF (indirect effect = 0.0008; Bootstrapped SE = 0.0002; 95% CI: 0.0004–0.0013). Importantly, a sequential mediation pathway involving sleep quality followed by perceived stress was also significant (PA → SQ → PS → CRF: indirect effect = 0.0004; Boot SE = 0.0001; 95% CI: 0.0002–0.0006).

Collectively, these findings indicate that the beneficial effect of physical activity on cardiorespiratory fitness operates not only through a direct mechanism but also indirectly through improvements in sleep quality and reductions in perceived stress. The significance of the serial mediation pathway further suggests that sleep quality and perceived stress may function as interconnected behavioral mechanisms linking physical activity with CRF outcomes.

Table 2 Analysis of direct, indirect, and total effects.

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Effect	Item	Effect	SE	t	p	LLCI	ULCI
Direct effect	PA → CRF	.0035	.0007	4.7835	.0000	.0029	.0049
Indirect effect	PA → SQ	.3171	.0002	-5.7713	.0000	-.0018	-.0009
	PA → PS	-4140	.0005	- 5.6400	.0000	-.0037	-.0018
	SQ → PS	.4997	.1164	8.1315	.0000	.7177	1.1759
	SQ → CRF	.4292	.1829	-4.3050	.0000	-1.1470	-.4273
	PS → CRF	.4367	.0824	-3.5398	.0005	-.4539	-.1295
Total effect	PA→ CRF	.0056	.0007	8.0090	.0000	.0043	.0070

Table 3
Mediating effect of sleep quality and perceived stress

Path	Effect	Boot SE	95% Confidence Interval	
			Lower limit	Upper Limit
PA → SQ → CRF	.0010	.0003	.0006	.0017
PA → PS → CRF	.0008	.0002	.0004	.0013
PA → SQ → PS → CRF	.0004	.0001	.0002	.0006

Discussion

This study examined the direct and indirect associations between physical activity (PA) and cardiorespiratory fitness (CRF), focusing on the mediating roles of sleep quality and perceived stress. The findings demonstrated that higher physical activity was positively associated with CRF, both directly and indirectly, through improved sleep quality and reduced perceived stress. Moreover, the observed serial mediation pathway suggests that sleep and stress may act as interconnected mechanisms linking habitual physical activity to cardiorespiratory fitness in young adults.

The significant positive association between physical activity and CRF observed in the current study is consistent with extensive evidence identifying regular physical activity as one of the strongest determinants of aerobic capacity and cardiovascular health. A recent systematic review reported that greater exercise intensity and training volume are linked to more pronounced increases in mitochondrial content and improvements in aerobic capacity [21]. The significant direct effect identified in the present analysis reinforces the established role of physical activity in maintaining and improving the aerobic fitness.

An important finding of this study was the mediating effect of sleep quality on the relationship between physical activity and CRF. Individuals who reported higher physical activity demonstrated better sleep outcomes, which subsequently contributed to improved CRF. Recent studies have revealed that various modes and doses of exercise training affect sleep quality [22]. Adequate sleep is essential for autonomic recovery, endocrine balance, tissue restoration, and cardiovascular regulation, all of which may support optimal physiological functioning and aerobic performance; therefore, the present findings support the proposition that sleep quality may partially explain how physically active individuals attain superior cardiorespiratory fitness.

The study further revealed a significant inverse relationship between physical activity and perceived stress, suggesting that participation in physical activity may contribute to lower psychological stress levels. A comprehensive systematic review identified stress, resilience, affect, and self-efficacy as mediators through which physical activity improves mental health outcomes, supporting the role of emotional regulation mechanisms. [23]. Lower stress levels may, in turn, facilitate healthier behavioral

patterns, improved recovery, and sustained engagement in physically active lifestyles. In contrast, a recent review pointed out that chronic stress affects autonomic cardiovascular regulation and HPA axis function, potentially impairing adaptive responses to exercise and overall physiological recovery [24].

Notably, perceived stress independently mediated the association between physical activity and CRF. A 2024 study found inverse correlations between psychological distress measures and improvements in VO_2max and exercise performance, indicating that higher distress is associated with poorer cardiorespiratory outcomes [25]. Chronic activation of stress pathways may adversely affect cardiovascular and metabolic functions, thereby limiting the physiological adaptations necessary for optimal CRF. This relationship highlights the importance of considering psychological well-being alongside behavioral factors when evaluating the determinants of cardiorespiratory fitness.

A particularly novel contribution of the present study is the identification of a significant serial mediation pathway involving sleep quality, followed by perceived stress. These findings suggest that physical activity may improve sleep quality, which subsequently lowers perceived stress and contributes to enhanced CRF. This sequential relationship is biologically plausible because inadequate sleep is associated with dysregulation of the hypothalamic–pituitary–adrenal axis and increased sympathetic activity, both of which contribute to elevated stress responses and poorer cardiovascular functioning [26]. Therefore, sleep and stress appear to function as interrelated mechanisms rather than as isolated determinants within the PA–CRF pathway.

Collectively, these findings underscore the multidimensional nature of cardiorespiratory fitness and indicate that behavioral and psychological factors may substantially influence its development. Interventions designed to improve CRF in young adults may benefit from approaches that extend beyond exercise promotion alone, incorporating strategies aimed at optimizing sleep quality and reducing perceived stress. Such integrated interventions may yield greater improvements in aerobic fitness and overall health outcomes.

Despite these strengths, several limitations should be considered. The cross-sectional design precludes causal inference regarding the directionality of observed relationships. The narrow age range of the subjects in the study limits its applicability to middle-aged and elderly populations. The subjects were enrolled through convenience sampling, which represents a significant limitation of the study. Additionally, other confounding factors, such as caffeine intake, nutritional status, duration of mobile usage, and body composition, were not reported. Furthermore, self-reported measures of physical activity, sleep quality, and stress may be susceptible to recall bias. These measures are inherently subjective, and there is a lack of objective assessments, such as accelerometry, polysomnography, and cardiopulmonary exercise testing (CPET). We conducted McArdle step test to predict the maximal oxygen uptake; however, we are unable to calculate precise values. Future longitudinal and experimental studies incorporating objective measures such as accelerometery, actigraphy, and criterion-based assessment of CRF are warranted to confirm these pathways. While the serial mediation model was theoretically informed, the cross-sectional nature of the data prevents the verification of the temporal

order of sleep quality, perceived stress, and cardiorespiratory fitness. Equally plausible are alternative causal sequences .

Conclusion

In conclusion, the present findings indicate that physical activity positively influences cardiorespiratory fitness both directly and indirectly through improved sleep quality and lower perceived stress. The significant serial mediation effect further highlights the interconnected roles of sleep and psychological well-being in shaping fitness outcomes among young adults. These results suggest that the link between physical activity and cardiorespiratory fitness goes beyond direct physiological adaptation and may also function through interconnected behavioral and psychological pathways. Therefore, a holistic approach to improving cardiorespiratory fitness in young adults may involve promoting habitual physical activity in conjunction with sleep health and stress management.

Declarations

Conflict of Interest –

The authors hereby declare that there do not have any competing interests.

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The study have been accepted and approved by the Ethical Committee of DPSRU with **IEC Protocol No –** IEC/DPSRU/2024/05.

Author Contribution

H.V. designed the methodology, conceived the idea, and collected the data. A.D did data analysis. S.Z, H.V and R.H.R made significant contributions to drafting the manuscript. All authors reviewed the manuscript.

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Not applicable.

Data availability –

The datasets are not publicly available due to privacy of the subjects, but are available from the corresponding author on reasonable request.

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Figures

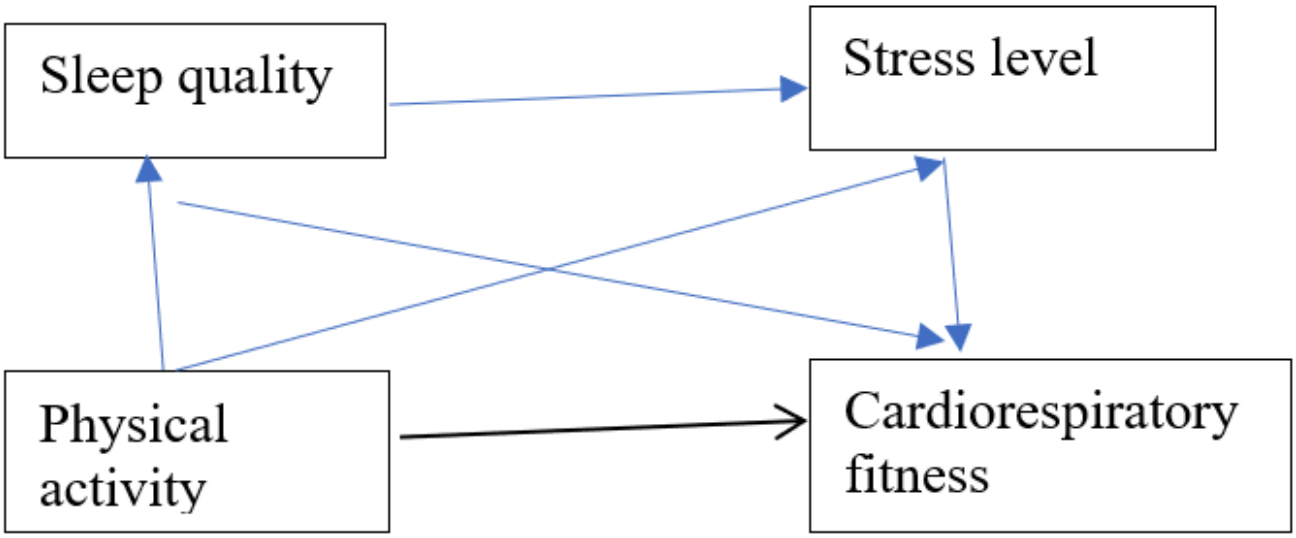

Figure 1

Proposed framework of the mediation effects of sleep quality and stress level.