

A Serial Mediation Study of Physical Activity Frequency, Sleep Duration, and Academic Achievement among Adolescents Based on YRBS Data

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Abstract: Investigating the relationship between physical activity frequency, sleep duration, and academic achievement among adolescents carries considerable importance. This study, based on data from the 2023 Youth Risk Behavior Survey (YRBS) in the United States, employed correlation analysis, regression models, and the PROCESS macro (Model 4) to test mediating effects, with gender, grade, and race selected as control variables. Employing the Bootstrap method, repeat sampling was conducted 5,000 times to estimate the 95% confidence interval for the indirect effect. The results showed that there were significant positive correlations between all three variables—physical activity frequency, sleep duration, and academic achievement—in every pair. Sleep duration mediated 15.98% of the total effect between physical activity frequency and academic achievement. It is one of the key mechanisms explaining the relationship between physical activity and academic achievement, but it is not the only explanatory pathway. The study suggests that both schools and families should focus on adolescents' physical activity and sleep health in order to work together to improve their academic performance.

1. Introduction

Adolescence represents the vulnerable period in the development of the human body and psyche as well as the acquisition of learning skills. It has been experimentally confirmed that academic success and physical activity are linked together, but the underlying mechanisms of this relationship remain to be further explored.

According to a study by Howie and Pated, physical activity can improve cognitive functioning and academic performance^[1]. Following the baseline information of the study on CEPS 2013-2014 and threshold regression model of Hansen, Xiang et al. examined the relationship between physical activity after school and academic performance among teenagers and discovered that there is a strong positive correlation between after-school physical activity and academic performance suggesting the existence of an inverse U-shaped relationship between the two variables^[2]. To investigate the underlying mechanisms that connect both academic achievement and physical activity, Tomporowski et al. created a systematic theoretical model. It indicates that physical activity affects the academic

performance of adolescents in three significant areas namely physical fitness, physical health, and psychosocial factors^[3]. Presented theoretical framework provides an important theoretical foundation for the present research. By using random sampling, Zhang et al. interviewed 224 high school students in Xinjiang. The findings indicated that sleep quality partially mediated the relationship between physical activity and academic performance and mediating effect was only 21.75 percent of the overall effect^[4].

In relation to other important mechanisms, researchers have discovered that academic executive functions and associated psychosocial variables act as intermediaries between physical activity and academic achievement, meaning that physical activity has an effect on academic achievement in various ways and on different levels.^{[5][6]}

Subsequently, the current paper is supposed to employ the regression analysis and mediation analysis as the methods of studying the correlation between the quantity of sleep and the rate of physical activity amongst adolescents and their academic performance.

2. Research Methods

2.1 Research Hypotheses

The present research provides three hypotheses that are based on the literature review and theoretical framework mentioned above:

H1: The frequency of physical activity significantly and positively influences adolescents' academic achievement.

H2: The frequency of physical activity significantly influences adolescents' sleep duration.

H3: Sleep duration significantly and positively predicts adolescents' academic achievement.

H4: Sleep plays a mediating role in the association between the amount of physical activities and academic performance.

2.2 Data Sources and Processing

The data used in this research will be based on the 2023 Youth Risk Behavior Surveillance System (YRBSS) survey performed by the U.S. Centers for Disease Control and Prevention (CDC)^[7]. Three-stage cluster sampling method employed to select the survey sample was a high school student in grades 9-12 selected in each of the U.S. states, resulting in 20,103 usable responses. Physical activity frequency is one of three major variables and three control variables in the current study, and sleep duration and academic performance are two other ones.

2.3 Measurement of Variables

The last analytic sample consisted of 13800 people after the exclusion of all cases that had missing values in the key variables (physical activity, sleep duration and academic achievement). Control variables were gender, grade and race. To examine if the duration of sleep may be viewed as a mediator between physical activity and academic achievement, a mediation model was drawn in which physical activity predicted sleep duration (which in turn predicted academic achievement) and covariates of gender, grade, and race were accounted to test this hypothesis. Table 1 gives the definition of variables.

Table 1 Variable Definitions

Variable Name	Data Type	Range	Notation
Physical activity frequency	Numeric	[0,7]	X_1
Sleep duration	Numeric	[4,10]	M
Academic achievement	Numeric	[1,5]	Y
Gender	Categorical	0=Male; 1=Female	X_2
Grade	Categorical	1 = Grade 9; 2 = Grade 10; 3 = Grade 11; 4 = Grade 12	X_3
Race	Categorical	1 = White; 2 = Black; 3 = Hispanic; 4 = Other/Multiracial	X_4

2.4 Analytical Methods

The research project has implemented statistics by means of SPSS 27.0 and its PROCESS v5.0 macro. To investigate the total impact of physical activity on academic performance, two regression models have been constructed in this paper. Model 1 will be a bivariate regression between physical activity frequency and academic achievement because it allows comparing the changes of coefficients in an intuitive fashion before and after adding control variables, which will allow concluding that there is no confounding bias. Model equation is presented as:

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon \quad (1)$$

The second model is the extension of the first one which adds gender, grade level and race as the control variables and performs a multiple regression analysis. In order to get a better estimate of how physical training influences general academic performance, the model equation has the form $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$. In which symbol β_0 represents the intercept, and symbol β_1 - β_4 are the regression coefficients of every variable, and symbol ε is the error term.

Moreover, the fact that the independent variables affect the dependent variable via a mediating variable has been addressed by developing a mediation model to indicate whether sleep duration serves as a mediator in the connection between physical activity and academic performance, and therefore explain the processes involved in this link.

3. Results and Discussion

3.1 Correlation Analysis of Core Variables

Before investigating mediating effects, this paper initially measured the three main variables, namely, X_1 , M and Y , using Pearson correlation analysis. The findings showed that X_1 strongly positively correlated with M ($r=0.145$, $p<0.001$), X_1 strongly positively correlated with Y ($r=0.124$, $p<0.001$) and M strongly positively correlated with Y ($r=0.182$, $p<0.001$). These are the required conditions to carry out mediating analysis in the present study.

3.2 Baseline Model

To test the total effect of physical activity frequency on academic achievement and to control for the influence of demographic variables on the study, this study conducted a bivariate regression and a multiple regression incorporating control variables. The regression results are shown in Table 2.

Table 2 Baseline Regression Model of Physical activity on Academic Achievement

Variable	Model 1	Model 2
Frequency of physical activity	0.124 ^a	0.153 ^a
Gender (Male = Ref)		0.141 ^a
Grade		0.058 ^a
Race/Ethnicity		-0.018 ^b
R ²	0.015	0.038

Note: a: $p^* < 0.001$, b: $p^* < 0.05$; values are standardized regression coefficients (Beta).

The results show that the frequency of physical activity is a significant predictor of academic achievement, explaining 1.5% of the variance. After controlling for covariates, the model's explanatory power increased to 3.8% ($\Delta R^2 = 0.023$). In addition, gender and grade level also had significant positive effects on academic achievement, while the effect of race was relatively small but still significant. These results indicate that the positive correlation between the frequency of physical activity and academic achievement remains robust even after controlling for demographic variables.

3.3 Testing the Mediating Effect

In this study, after controlling for gender, grade level, and race, we tested the mediating effect of sleep duration on the relationship between physical activity and academic achievement. The results are shown in Table 3; the overall effect of physical activity on academic achievement was significant.

Table 3 Decomposition of Mediation Effects

Effect Type	Coefficient (B)	Standard Error (SE)	p-value	95% Confidence Interval	Proportion of Effect (%)
Total Effect (c)	0.0651	0.0037	<.001	[0.0580, 0.0723]	100.00
Direct Effect (c')	0.0548	0.0036	<.001	[0.0476, 0.0619]	84.02
Indirect Effect (ab)	0.0104	0.0009*	—	[0.0087, 0.0121]	15.98

Note: The standard error for the indirect effect is the bootstrap standard error (BootSE); the confidence interval is the bias-corrected bootstrap confidence interval. The asterisk (*) indicates that the SE is bootstrapped.

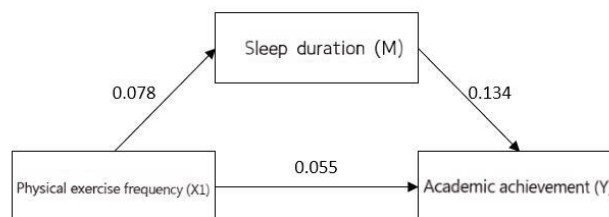


Figure 1: Mediation Model Diagram

Mediation model is presented in Figure 1. Incorporating sleep duration as a mediator revealed that frequency of physical activity positively predicted sleep duration and sleep duration positively predicted academic performance. The mediated effect of sleep duration can be said to be statistically significant because the Bootstrap confidence interval of the indirect effect did not contain 0. The direct effect is still significant, that is, sleep duration does not completely mediate the connection between physical activity and academic achievement and mediation explains 15.98 percent of the

overall effect. This finding suggests that all four hypotheses of the current research were empirically proven.

There is a positive correlation between physical activity and sleep duration, which is in line with prior literature. The quality of sleep will be enhanced by regular physical activity which means that the duration of sleep will also be increased. Thirdly, the relationship between sleep duration and academic performance has also gained significant attention. Students who have adequate sleep tend to focus better and enhance their consolidation of memory and executive functioning which leads to better academic performance. According to the results of the mediation analysis of this paper, the mediation effect contributes to 15.98% of the overall effect, meaning that despite the fact that sleep duration is the most critical mediating factor through which physical activity impacts academic achievement, it should not be the only pathway; physical activity can influence academic achievement through other mechanisms.

4. Conclusion

The investigation performed by analyzing 2023 YRBS data has shown that physical activity positively predicts academic achievement and exerts an indirect effect on academic achievement through sleep duration, which is partially intervening variable in the relationship between the frequency of physical activity and academic achievement (15.98). Based on this research paper, schools and families ought to concentrate on physical activity and amount of sleep during the adolescence healthy development, to ensure that physical activity and sleep duration work synergistically to support their academic development. One of the limitations of the existing study is that it has not implemented weighting in its sampling procedure, therefore, the results are not representative of all high school students in the United States. Future studies may use statistics software packages that facilitate complex sampling strategies. These results indicate the relationships among the three variables which might serve as the theory base of the subsequent research.

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