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Post-Exercise Physiological Recovery and Academic Achievement in Adolescents: The Role of Autonomic Regulation

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Abstract

Background. Physical education represents a regular physiological stimulus within the school day, yet little is known about autonomic recovery following curricular lessons and its relationship with academic achievement.

Objectives. To compare post-exercise autonomic recovery following a regular physical education lesson with a time-matched control condition and to determine whether autonomic recovery is associated with academic achievement in adolescents.

Materials and Methods. Ninety-two adolescents completed both a physical education condition and a time-matched control condition using a within-participant repeated-measures design. Heart rate variability was recorded before and after each condition, and the root mean square of successive differences was analyzed after natural logarithmic transformation (lnRMSSD). Academic achievement was assessed using the official grade point average.

Results. A significant Condition × Time interaction was observed for lnRMSSD ($F(1,91)=4.06$, $p=0.047$, partial $\eta^2=0.043$). Post hoc analyses demonstrated a significant increase in lnRMSSD following physical education ($p=0.003$), whereas no significant change occurred during the control condition ($p=0.292$). Autonomic recovery following physical education was positively associated with academic achievement ($r=0.52$, $p<0.001$). Linear regression analysis showed that autonomic recovery explained 27.5% of the variance in academic achievement ($R^2=0.275$, $p<0.001$).

Conclusions. A regular physical education lesson elicited significantly different autonomic responses compared with a time-matched control condition. Adolescents exhibiting greater post-exercise parasympathetic recovery achieved higher academic performance. These findings indicate that autonomic recovery following physical education may represent a meaningful physiological correlate of scholastic achievement and support further longitudinal and intervention-based research examining the role of autonomic regulation in educational outcomes.

Keywords: heart rate variability, cardiac vagal modulation, school performance, parasympathetic reactivation, exercise physiology, secondary school students.

Introduction

Academic achievement represents a central indicator of educational success and a major determinant of subsequent opportunities across the course of life (Steinmayr et al., 2014). Although academic outcomes are commonly expressed through grades, examination scores, or standardized assessments, scholastic performance emerges from the interaction of cognitive, behavioral, social, and physiological processes (Osman et al., 2021). Attention, working memory, executive control, emotional regulation, motivation, and the capacity to adapt to environmental demands all contribute to students' ability to engage effectively with learning tasks. Consequently, increasing attention has been directed toward factors that extend beyond conventional instructional practices and may support the conditions under which learning occurs (Alfonsi et al., 2020). Within this perspective, physical activity and school based physical education have gained considerable relevance because of their potential contribution not only to physical health

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and motor development, but also to cognitive functioning, psychological well-being, and educational outcomes.

The relationship between physical activity and academic achievement has been examined extensively in children and adolescents. A substantial body of evidence suggests that regular participation in physical activity is positively associated with cognitive performance and may support selected dimensions of academic attainment. Several mechanisms have been proposed to explain these relationships (Latino et al., 2025a,b). From a neurobiological perspective, physical exercise may influence cerebral blood flow, neurotrophic signaling, synaptic plasticity, and the functional efficiency of neural networks involved in executive control and memory. At the behavioral level, physically active students may benefit from improved emotional regulation, reduced psychological distress, enhanced classroom engagement, and more effective management of academic demands. However, the magnitude and consistency of the observed associations vary across studies, suggesting that the relationship between movement behaviors and scholastic outcomes cannot be explained exclusively by the amount of physical activity performed. The physiological responses elicited by exercise and the capacity to recover after physical exertion may provide an additional perspective through which this relationship can be investigated (James et al., 2023).

Physical education occupies a distinctive position within this field. Unlike extracurricular sport or voluntary physical activity, physical education is embedded within the educational curriculum and reaches students with heterogeneous levels of fitness, motor competence, and previous sport experience (Canli et al., 2024). Its educational purpose extends beyond the promotion of physical fitness and includes the development of motor competence, self-regulation, cooperation, decision making, and positive attitudes toward active lifestyles. In adolescence, diversified physical activity programs have also been associated with favorable changes in body related perceptions, supporting the broader developmental relevance of structured motor experiences during this stage of life (Latino et al., 2025). At the same time, each physical education lesson constitutes an acute physiological stimulus that temporarily alters cardiovascular and autonomic function. The transition from exercise to subsequent recovery therefore represents a potentially informative phase, particularly within the school setting, where students are generally expected to return to cognitively demanding academic activities shortly after the conclusion of the lesson (Martín-Rodríguez et al., 2024).

The acute physiological consequences of exercise are not limited to changes in heart rate and energy expenditure. Physical exertion produces a dynamic reorganization of autonomic regulation characterized by parasympathetic withdrawal and increased sympathetic influence during exercise, followed by progressive vagal reactivation during recovery (Marschin, & Herbert, 2026). The speed and magnitude of this post exercise autonomic restoration reflect the capacity of the organism to transition from physiological activation toward a more regulated state. This process is particularly relevant during adolescence, a developmental period characterized by substantial changes in cardiovascular regulation, emotional reactivity, executive functioning, and sensitivity to social and academic stressors. Individual differences in autonomic regulation may therefore contribute to variations in how students respond to and recover from the demands of both physical and educational environments (López-Bueno et al., 2025).

Heart rate variability, HRV, provides a non-invasive method for examining cardiac autonomic modulation through the analysis of beat-to-beat variations in heart rate. Among the available HRV indices, the root mean square of successive differences, RMSSD, is widely used in exercise and psychophysiological research because it predominantly reflects parasympathetic modulation and can be obtained through relatively short recordings under standardized conditions (Soares-Miranda et al., 2014). Higher vagally mediated HRV at rest has frequently been interpreted as an indicator of greater autonomic flexibility and adaptive capacity, although HRV should always be considered within the specific physiological and contextual conditions in which it is measured. In young populations, HRV has been investigated in relation to physical fitness, psychological stress, emotional regulation, and cognitive functioning. Nevertheless, its potential relevance to academic achievement remains comparatively underexplored, particularly when HRV is examined dynamically rather than exclusively through a single resting measurement (El-Malahi et al., 2024).

This distinction is important because resting HRV and post exercise autonomic recovery provide related but conceptually different information. A resting measurement describes cardiac autonomic modulation under relatively stable conditions, whereas recovery assessment captures the organism's response following a defined physiological challenge. From this perspective, autonomic recovery may represent a functional characteristic of regulatory capacity rather than merely a static physiological state. Two students with comparable resting values may exhibit different recovery trajectories after the same educationally embedded physical activity. Such differences may reflect variation in physical conditioning, stress responsiveness, autonomic flexibility, or the efficiency with which physiological systems return toward baseline conditions. Examining this recovery process may therefore provide information that cannot be obtained from resting HRV alone (Dong, 2016).

The possible connection between autonomic regulation and academic achievement is supported by broader psychophysiological models linking vagal function with cognitive and emotional self-regulation. Successful participation in school requires students to sustain attention, inhibit irrelevant responses, adapt behavior to changing demands, manage frustration, and maintain goal directed engagement (Yoo et al., 2021). These processes depend on coordinated regulatory mechanisms involving interactions between central and peripheral systems. Cardiac autonomic regulation has been associated with executive functioning, attentional control, and the capacity to respond adaptively to environmental challenges. Accordingly, students who demonstrate more efficient autonomic recovery following physical exertion may also possess physiological regulatory characteristics that support adaptation to academic demands. This proposition does not imply that autonomic recovery directly determines academic achievement. Rather, it suggests that physiological flexibility may constitute one component within the broader network of individual characteristics associated with successful functioning in educational contexts (Mendoza-Castejón, & Clemente-Suárez, 2020).

Despite increasing interest in the cognitive and academic implications of physical activity, research conducted in schools has predominantly focused on chronic interventions, fitness levels, habitual activity, or comparisons between physically active and inactive students (Trudeau, & Shephard, 2008). These approaches have provided valuable evidence but have often treated physiological adaptation as an inferred mechanism rather than a directly measured process. Furthermore, studies examining acute exercise have generally concentrated on immediate cognitive outcomes, including attention, inhibition, and working memory, while comparatively less consideration has been given to autonomic recovery following ordinary physical education lessons (Yan et al., 2025). This represents a relevant gap because school-based physical education differs from laboratory exercise protocols. Lessons occur within authentic educational schedules, involve naturally heterogeneous groups of students, and are followed by a return to classroom activities. Understanding physiological recovery in this ecological context may therefore contribute to a more integrated interpretation of the relationship between physical education and educational functioning.

Another methodological consideration concerns the interpretation of autonomic changes across the school day. HRV is sensitive to multiple influences, including time of day, posture, recent physical activity, respiration, psychological stress, and environmental conditions. A decrease or increase observed after physical education cannot be interpreted adequately without considering the changes that might occur during a comparable period without exercise (Tornberg et al., 2019). For this reason, the inclusion of a minimally intrusive control condition, in which the same students are assessed at corresponding time points during a school day without physical education, may strengthen the interpretation of post lesson autonomic responses. A within participant approach also reduces the influence of stable interindividual characteristics and is particularly suitable for school-based research, where the creation of separate experimental groups may be impractical or educationally inappropriate.

The investigation of academic achievement alongside autonomic recovery may also help bridge a persistent conceptual separation between exercise physiology and educational research. Physical education is frequently evaluated through motor, fitness, or behavioral outcomes, whereas academic research often examines scholastic performance without direct consideration of physiological regulation. Integrating these domains does not require complex experimental protocols or extensive batteries of psychological assessments (Frank et al., 2020). A focused examination of autonomic recovery and academic achievement may provide an initial empirical basis for understanding whether physiological responsiveness to a routine physical education lesson is related to broader educational outcomes. Such an approach is particularly relevant in adolescence, when increasing academic demands coexist with changes in physical activity patterns, physiological maturation, and heightened exposure to school related stress (Wang et al., 2025).

Accordingly, the present study aimed to examine autonomic recovery following a regular physical education lesson and its association with academic achievement in adolescents. Using a within participant design, HRV responses were assessed across a physical education condition and a time matched control condition without structured physical activity. Academic achievement was evaluated through students' scholastic performance. It was hypothesized that the physical education condition would produce a distinct pattern of autonomic change compared with the control condition, reflecting the physiological activation and subsequent recovery associated with the lesson. It was further hypothesized that more favorable post exercise autonomic recovery would be positively associated with higher academic achievement. By examining a naturally occurring component of the school curriculum through a psychophysiological perspective, the study seeks to clarify whether individual differences in autonomic recovery are meaningfully related to educational performance during adolescence.

Materials and Methods

Study Design

This study adopted a within participant repeated measures design to examine cardiac autonomic responses following a regular physical education lesson and their association with academic achievement in adolescents. Each participant was assessed under two conditions, a physical education condition and a time matched control condition, thereby allowing each student to serve as his or her own control. The two assessment sessions were conducted on separate school days within the same week and at comparable times of day to minimize the potential influence of circadian variation on heart rate variability, HRV. During the physical education condition, HRV was recorded before the beginning of the lesson and during a standardized recovery period following its completion. During the control condition, HRV was recorded at corresponding time points, while students followed their usual academic schedule without engaging in structured physical activity between measurements.

The study was conducted in accordance with the principles of the Declaration of Helsinki and received approval from the competent institutional ethics committee. Before data collection, written informed consent was obtained from the parents or legal guardians of all participants, while students provided their assent to participate. Participation was voluntary, and students were informed that withdrawal from the study was possible at any time without consequences for their school activities or academic evaluation. The study was conducted between September 2025 and January 2026.

Participants

Participants were recruited from a secondary school and included male and female students. Recruitment was conducted through school-based information sessions in which students and their families received a detailed explanation of the study aims and assessment procedures. The study was designed to include adolescents attending regular curricular physical education lessons, independently of their participation in extracurricular sport, in order to preserve the ecological characteristics of the school population.

The inclusion criteria were enrollment in the participating secondary school, age between 14 and 18 years, regular attendance at curricular physical education lessons,

eligibility to participate in school based physical activity according to school regulations, and provision of written parental or guardian consent and student assent. Students were required to complete both experimental conditions and to have valid HRV recordings at all assessment time points.

Exclusion criteria included medical conditions contraindicating participation in regular physical education, acute illness or injury at the time of assessment, use of medications known to substantially influence cardiac autonomic regulation, inability to complete the physical education lesson, and HRV recordings of insufficient quality for analysis. Students were also excluded from the final analysis if they were absent from either assessment session or failed to comply with the standardized pre assessment instructions.

An a priori sample size calculation was conducted using G*Power software. The calculation was based on the primary correlational hypothesis concerning the association between autonomic recovery and academic achievement. Assuming a moderate expected correlation of $r = 0.30$, a two tailed significance level of $\alpha = 0.05$, and statistical power of 0.80, the minimum required sample size was 84 participants. To account for potential absences, incomplete assessments, and HRV recordings unsuitable for analysis, 92 students were targeted for initial recruitment. Therefore, the final sample consisted of 92 adolescents, with a mean age of 16.01 ± 1.02 years. The sample included 49 females, 53.3%, and 43 males, 46.7%. The mean academic achievement score, expressed as grade point average, was 7.39 ± 0.71.

Procedures

Data collection was carried out during the regular school timetable and within the students' usual educational environment. To reduce variability related to circadian influences, all HRV assessments were scheduled within the same morning time window. The two assessment conditions were completed within the same week whenever possible, with sufficient separation between sessions to avoid any immediate carryover effect.

Before the first assessment session, students received standardized instructions regarding behaviors that could acutely affect autonomic regulation. They were asked to avoid vigorous physical activity for 24 hours before testing and to refrain from consuming caffeinated beverages or other stimulants on the morning of assessment. Students were also instructed to maintain their usual sleep and eating habits and to report any acute illness or unusual condition that could interfere with participation.

In the physical education condition, participants completed an initial five-minute seated stabilization period in a quiet environment, followed by a five-minute HRV recording. Students then participated in their regularly scheduled physical education lessons. Immediately after the lesson, participants returned to the assessment area and assumed the same seated position used during the baseline recording. Following a standardized five-minute transition period, a second five-minute HRV recording was obtained to characterize early post exercise autonomic recovery.

The control condition followed the same temporal structure. Participants underwent the initial stabilization and HRV recording procedures at a time corresponding to the pre lesson assessment of the physical education condition. They then continued their regular classroom activities without structured physical exercise. After a time, interval corresponding to the duration of the physical education lesson, the second HRV recording was conducted using the same stabilization period, body position, equipment, and environmental procedures applied in the physical education condition.

Whenever organizationally feasible, the order of the two conditions was counterbalanced across participants to reduce potential order effects. All measurements were conducted by trained researchers using standardized verbal instructions and identical recording procedures.

Physical Education Condition

The physical education condition consisted of a regular curricular lesson conducted by the school physical education teacher according to the planned educational program. The lesson lasted approximately 60 minutes and reflected the typical structure of secondary school physical education. It included an initial warm up phase, a central phase involving motor and sport-based activities, and a final phase characterized by progressively reduced exercise intensity.

The lesson was not designed as a laboratory-based exercise protocol or as a specific training intervention. Rather, it was intentionally embedded within ordinary school practice to examine autonomic recovery under ecologically valid educational conditions. The central phase included continuous and intermittent physical activities, coordination tasks, and participation in individual or group motor and sport activities. The same lesson structure and organizational procedures were maintained for all participating students within each class.

The control condition consisted of the students' normal classroom schedule and did not include structured physical activity during the period corresponding to the physical education lesson. Students remained engaged in their usual academic activities and were instructed not to participate in vigorous movement or organized exercise before the second HRV assessment. The control condition was designed to provide a minimally intrusive time matched comparison and to account for autonomic changes potentially associated with the passage of time and the ordinary school environment.

Measures

Heart Rate Variability

Cardiac autonomic modulation was assessed through short term HRV recordings (Brage et al., 2007). Heart rate data were collected using a Polar H10 (Polar Electro Oy, Kempele, Finland) heart rate sensor, which records R to R intervals and has been widely used in field based physiological research. Recordings were performed for five minutes with participants in a seated position, with their feet placed on the floor and hands resting comfortably on their thighs. Students were instructed to remain still, avoid speaking, and breathe spontaneously throughout the recording period.

The root mean square of successive differences between normal heartbeats, RMSSD, was selected as the primary HRV outcome because of its established sensitivity to vagally

mediated cardiac autonomic modulation and its suitability for short term recordings. The same recording duration, posture, equipment, and environmental conditions were maintained across all assessment sessions.

Autonomic change during early recovery was operationalized as the difference in RMSSD between the pre lesson recording and the standardized post lesson recovery recording, calculated as post minus pre. The corresponding change observed during the control condition was calculated using the same procedure. This index was used to characterize the direction and magnitude of autonomic change during the defined early recovery window rather than the complete temporal kinetics of post exercise autonomic recovery.

All R-to-R interval recordings were visually inspected for artifacts and ectopic beats before analysis. Recordings that did not meet predetermined quality criteria were excluded from the final analysis. Where required by the distribution of the data, RMSSD values were natural logarithm transformed before inferential statistical analyses.

Academic Achievement

Academic achievement was assessed using students' official school grades obtained from school records. Academic achievement was expressed as the grade point average calculated from the official grades obtained across all curricular subjects during the first semester of the academic year. The use of official grades was selected to provide an ecologically valid indicator of students' educational performance and to avoid the potential biases associated with self-reported academic achievement.

Academic data were collected only after the necessary institutional and parental permissions had been obtained. Individual records were anonymized before statistical analysis, and academic information was matched with physiological data through coded identifiers.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 30.0. Before inferential analyses, data were screened for completeness, potential outliers, and distributional assumptions. Continuous variables were summarized using means and standard deviations, while categorical variables were reported as frequencies and percentages. The normality of continuous variables was assessed using the Shapiro Wilk test and visual inspection of histograms and Q Q plots. HRV data were inspected for distributional characteristics, and RMSSD values were natural logarithm transformed, lnRMSSD, before inferential analyses to reduce distributional skewness and improve conformity with parametric assumptions.

Changes in cardiac autonomic modulation were examined using a 2 × 2 repeated measures analysis of variance, ANOVA. The model included Condition, physical education and control, and Time, pre and post, as within participant factors. The Condition × Time interaction was considered the primary effect of interest, as it indicated whether the temporal change in lnRMSSD differed between the physical education and control conditions. Main effects of Condition and Time were also examined. Because within participant factors included only two levels, the assumption of sphericity was inherently satisfied. Effect sizes for ANOVA results were expressed as partial eta squared, ηp^2. Baseline lnRMSSD values between the physical education and control conditions were compared using a paired samples to test to identify potential precondition differences.

When a significant Condition × Time interaction was identified, paired samples t tests were conducted as post hoc comparisons to examine pre to post changes separately within the physical education and control conditions. Cohen's dz was calculated to quantify the magnitude of within participant differences. All post hoc comparisons were interpreted in relation to the interaction effect and were not considered independent primary hypothesis tests.

Autonomic change during early recovery following physical education was operationalized as the difference in lnRMSSD between the pre lesson assessment and the standardized post lesson recovery assessment, calculated as post minus pre. The association between PE Δ lnRMSSD and academic achievement was examined using Pearson's product moment correlation coefficient. The correlation coefficient was reported together with its 95% confidence interval. The direction and magnitude of the association were interpreted according to the absolute value of the correlation coefficient.

A simple linear regression analysis was subsequently conducted to examine the association between autonomic recovery following physical education and academic achievement. Academic achievement was entered as the dependent variable, while PE Δ lnRMSSD was entered as the independent variable. The regression model was evaluated using the F statistic, coefficient of determination, R^2, adjusted R^2, unstandardized regression coefficient, B, standard error, standardized regression coefficient, β, and corresponding t and p values. The assumptions of linearity, normality of residuals, homoscedasticity, and the absence of excessively influential observations were assessed before interpretation of the model. All statistical tests were two tailed, and statistical significance was set at $p < 0.05$.

Results

Participant Characteristics and Descriptive Statistics

Descriptive statistics for HRV across the physical education and control conditions are presented in Table 1. In the physical education condition, mean lnRMSSD increased from 3.60 ± 0.43 before the lesson to 3.67 ± 0.52 during the post lesson recovery assessment. In the control condition, lnRMSSD showed only a limited variation, from 3.48 ± 0.42 at the first assessment to 3.50 ± 0.44 at the corresponding second assessment. The mean change in lnRMSSD was 0.07 ± 0.23 for the physical education condition and 0.02 ± 0.17 for the control condition.

Autonomic Responses Across Physical Education and Control Conditions

A 2 × 2 repeated measures analysis of variance was conducted to examine changes in cardiac autonomic modulation across conditions. The analysis included Condition, physical education and control, and Time, pre and post, as within participant factors.

Table 1. Descriptive statistics for the main study variables

Variable	Mean	SD
Age, years	16.01	1.02
Academic achievement, GPA	7.39	0.71
PE pre lnRMSSD	3.60	0.43
PE post recovery lnRMSSD	3.67	0.52
PE Δ lnRMSSD	0.07	0.23
Control pre lnRMSSD	3.48	0.42
Control post lnRMSSD	3.50	0.44
Control Δ lnRMSSD	0.02	0.17

The analysis revealed a significant main effect of Time, $F_{(1, 91)} = 8.47$, $p = 0.005$, partial $\eta^2 = 0.085$, indicating that lnRMSSD values changed across the two assessment time points when both conditions were considered. A significant main effect of Condition was also observed, $F_{(1, 91)} = 5.62$, $p = 0.020$, partial $\eta^2 = 0.058$, reflecting differences in mean lnRMSSD values between the physical education and control conditions.

More importantly, the Condition × Time interaction was statistically significant, $F_{(1, 91)} = 4.06$, $p = 0.047$, partial $\eta^2 = 0.043$. This interaction indicated that the pattern of change in lnRMSSD across time differed between physical education and control conditions.

Post hoc comparisons were subsequently conducted to examine significant interaction. In the physical education condition, lnRMSSD increased significantly from the pre lesson assessment, 3.60 ± 0.43, to the post lesson recovery assessment, 3.67 ± 0.52, $t_{(91)} = 3.06$, $p = 0.003$, Cohen's dz = 0.32. Conversely, the control condition showed no statistically significant change between the first assessment, 3.48 ± 0.42, and the second assessment, 3.50 ± 0.44, $t_{(91)} = 1.06$, $p = 0.292$, Cohen's dz = 0.11.

The significant interaction, together with the post hoc comparisons, indicates that autonomic modulation followed a different temporal pattern after the physical education lesson compared with the corresponding period of a regular school day without structured physical activity. Specifically, the physical education condition was characterized by a significant increase in vagally mediated HRV during the standardized post lesson recovery assessment, whereas no comparable change was observed in the control condition.

Table 2. Repeated measures ANOVA for lnRMSSD

Effect	F	df	p value	Partial η^2
Condition	5.62	1, 91	0.020	0.058
Time	8.47	1, 91	0.005	0.085
Condition × Time	4.06	1, 91	0.047	0.043

Association Between Autonomic Recovery and Academic Achievement

Pearson's product moment correlation coefficient was calculated to examine the association between autonomic recovery following physical education and academic achievement. Autonomic recovery was operationalized as the change in lnRMSSD between the pre lesson assessment and the post lesson recovery assessment in the physical education condition.

The analysis revealed a statistically significant positive correlation between PE Δ lnRMSSD and academic achievement, $r = 0.52$, $p < 0.001$. Students who displayed greater increases in lnRMSSD during the recovery period following physical education tended to have higher grade point averages. The magnitude of the correlation indicated a moderate positive association between autonomic recovery and scholastic performance.

The squared correlation coefficient was approximately 0.27, indicating that the two variables shared approximately 27% of their variance. Although this relationship does not imply a causal connection between autonomic recovery and academic performance, it suggests that individual differences in post exercise autonomic regulation are meaningfully associated with educational achievement.

Table 4. Pearson correlation between autonomic recovery and academic achievement

Variables	r	p value	95% CI
PE Δ lnRMSSD and academic achievement	0.52	<0.001	0.35 to 0.66

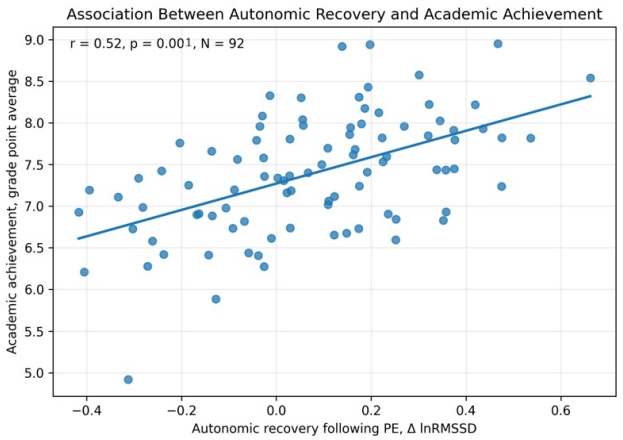

Fig. 1. Association between autonomic recovery following physical education and academic achievement in adolescents. Note: The scatterplot illustrates the positive relationship between the change in lnRMSSD from pre lesson assessment to post lesson recovery, PE Δ lnRMSSD, and academic achievement expressed as grade point average, GPA. The solid line represents the linear regression fit, $r = 0.52$, $p < 0.001$.

Linear Regression Analysis

A simple linear regression analysis was conducted to further examine the association between autonomic recovery

Table 3. Post hoc comparisons of lnRMSSD changes within conditions

Condition	Pre, Mean ± SD	Post, Mean ± SD	Mean change	t	p value	Cohen's dz
Physical education	3.60 ± 0.43	3.67 ± 0.52	0.07	3.06	0.003	0.32
Control	3.48 ± 0.42	3.50 ± 0.44	0.02	1.06	0.292	0.11

following physical education and academic achievement. Academic achievement was entered as the dependent variable, while PE Δ lnRMSSD was entered as the predictor.

The regression model was statistically significant, $F_{(1, 90)} = 34.18$, $p < 0.001$, and accounted for 27.5% of the variance in academic achievement, $R^2 = 0.275$, adjusted $R^2 = 0.267$. Autonomic recovery following physical education was significantly and positively associated with academic achievement, B = 1.58, SE = 0.27, β = 0.52, t = 5.85, $p < 0.001$.

The positive regression coefficient indicates that greater increases in lnRMSSD during the post physical education recovery period were associated with higher academic achievement scores. According to the estimated model, a one unit increase in PE Δ lnRMSSD corresponded to an expected increase of 1.58 units in grade point average. Given the observed range of lnRMSSD change scores, the coefficient should be interpreted in relation to the scale and variability of the physiological measure rather than as evidence of a causal effect.

Visual inspection of residual plots and examination of standardized residuals did not indicate substantial violations of linearity, normality, or homoscedasticity assumptions. No observations exerted excessive influence on the regression estimates.

Table 5. Simple linear regression analysis for academic achievement

Predictor	B	SE	β	t	p value
Constant	7.27	0.03		242.33	<0.001
PE Δ lnRMSSD	1.58	0.27	0.52	5.85	<0.001

Model statistics: $R^2 = 0.275$, adjusted $R^2 = 0.267$, $F(1, 90) = 34.18$, $p < 0.001$.

Discussion

The present study examined autonomic recovery following a regular physical education lesson and its association with academic achievement in adolescents. By comparing HRV responses across a physical education condition and a time-contained control condition, the study sought to determine whether autonomic modulation followed a distinct temporal pattern after curricular physical activity and whether individual differences in this response were associated with scholastic performance. The findings showed a significant Condition × Time interaction for lnRMSSD, characterized by an increase during the post lesson recovery assessment in the physical education condition and no significant change across the corresponding time interval in the control condition. In addition, greater PE related changes in lnRMSSD were positively associated with academic achievement, and the regression analysis confirmed a significant relationship between autonomic recovery and grade point average.

The first relevant finding was the different temporal pattern of lnRMSSD observed across the two conditions. The significant Condition × Time interaction indicates that the autonomic change occurring after the physical education lesson differed from the variation observed during a comparable period without structured physical activity. More specifically, lnRMSSD increased significantly from the pre lesson assessment to the standardized recovery measurement following physical education, whereas no significant variation emerged in the control condition. This pattern suggests that the post lesson assessment captured a condition specific change in vagally mediated cardiac modulation rather than a fluctuation attributable solely to the passage of time during the school morning (May et al., 2017). The small magnitude of the interaction effect, however, indicates that this difference should be interpreted as a modest physiological response rather than a pronounced autonomic alteration.

This finding is consistent with the physiological framework of post exercise autonomic regulation. Physical exercise induces a marked reorganization of cardiac autonomic control, while the period following exercise cessation is characterized by progressive parasympathetic reactivation (Yue et al., 2025). RMSSD is commonly used to describe vagally mediated HRV, and its behavior during recovery provides information concerning the restoration of parasympathetic influence after physical exertion. Previous investigations of post exercise autonomic recovery have shown that parasympathetic reactivation contributes substantially to cardiovascular adjustment following exercise cessation, although its time course varies according to exercise characteristics and individual factors. Research specifically examining young populations has also identified age related characteristics in post exercise parasympathetic reactivation, supporting the relevance of studying recovery responses within developmentally defined groups rather than extrapolating directly from adult samples (Medeiros et al., 2021).

The present findings also extend previous evidence concerning exercise and autonomic modulation in children and adolescents. Existing research has primarily examined the effects of repeated exercise exposure or structured training programs on HRV. Systematic evidence suggests that exercise interventions can improve indices of autonomic modulation in young populations, although considerable heterogeneity exists in exercise modalities, intervention duration, and HRV assessment procedures. The current study addresses a different aspect of this relationship by examining autonomic change following a routine curricular physical education lesson rather than adaptation to a prolonged exercise intervention. This distinction is relevant because the observed response occurred within the ordinary organization of the school day and was compared with a time matched condition involving the same participants (Speer et al., 2022).

The absence of a significant change in lnRMSSD during the control condition provides an important context for interpreting the physical education response. HRV is sensitive to measurement conditions, including posture, time of assessment, recent activity, and contextual influences (Makivić et al., 2013). Consequently, interpreting changes recorded at different points of a school day without a corresponding comparison condition could lead to uncertainty regarding whether the observed variation is related to physical activity or to temporal variability. In the present study, the stability of lnRMSSD across the control period, together with the significant interaction effect, supports the interpretation that the pattern observed

after physical education was distinguishable from ordinary variation across the corresponding time interval. This methodological consideration is particularly relevant in educational research, where HRV assessment is increasingly used but substantial variability remains in recording and analytical procedures. A recent systematic review of HRV applications in educational research emphasized the importance of standardized measurement conditions and careful interpretation of physiological data within the specific context in which recordings are obtained (May et al., 2017).

The second principal finding was the positive association between autonomic recovery following physical education and academic achievement. Students who exhibited greater increases in lnRMSSD from the pre lesson assessment to the post lesson recovery period tended to have higher grade point averages. The correlation was moderate in magnitude, indicating a meaningful association while also demonstrating that the two constructs remain clearly distinct. This result should therefore be interpreted as evidence of covariation between the physiological response observed after physical education and scholastic performance, rather than as evidence that either variable determines the other (Buchheit et al., 2007).

One possible interpretation, restricted to the variables assessed in the present study, is that academic achievement differs systematically in relation to individual variability in autonomic recovery following physical exertion. The result indicates that students were not homogeneous in their post lesson HRV responses and that part of this interindividual variation was associated with differences in grade point average. Importantly, the present data do not identify the processes underlying this association. The study did not assess cognitive performance, psychological stress, classroom behavior, or other potential explanatory variables, and these mechanisms therefore cannot be inferred from the observed relationship. The finding instead establishes a direct empirical association between a physiological recovery index and an educational outcome, providing a focused basis for subsequent investigation (Chen et al., 2022).

The relationship observed in the present study can be situated within the emerging use of HRV in educational research (Kim et al., 2024). The literature in this area remains comparatively limited and has focused predominantly on physiological responses to stress and on university populations, while studies involving school aged participants and educational outcomes are less represented. The growing interest in HRV within educational contexts reflects the possibility of integrating objective physiological measures with conventional indicators of educational functioning. At the same time, current methodological reviews emphasize that the validity of HRV interpretation depends on the research question, recording context, and analytical approach. The present findings contribute to this developing field by showing that a dynamically derived HRV measure, obtained in relation to a naturally occurring physical education lesson, was associated with official academic performance in adolescents (Silva et al., 2022).

The positive correlation between PE Δ lnRMSSD and academic achievement was further supported by the regression analysis. Autonomic recovery was significantly associated with grade point average, with the model accounting for approximately 27.5% of the variance in academic achievement. This proportion indicates that the association was statistically meaningful within the present sample, while leaving most of the variability in academic performance unexplained. Such a pattern is consistent with the multifactorial nature of scholastic achievement and reinforces the need for a circumscribed interpretation of the regression model. The regression analysis confirmed the statistical association between autonomic change during early recovery and academic achievement. However, given the concurrent nature of this association, the model should not be interpreted as evidence of prospective prediction or causality (Ketelhut et al., 2024).

Taken together, the findings provide two complementary observations. First, autonomic modulation differed across the physical education and control conditions, with a modest but statistically significant condition dependent on temporal response. Second, individual differences in the HRV change observed following physical education were positively associated with academic achievement. These results connect an acute physiological response to a routine component of the school curriculum with an objective indicator of scholastic performance, while preserving a clear distinction between association and causation. The findings are particularly relevant because physical education was examined within its ordinary curricular context rather than through an externally imposed laboratory exercise protocol.

Several strengths of the study should be acknowledged. The within participant design allowed each student to serve as his or her own control, thereby reducing the influence of stable interindividual differences when comparing the physical education and control conditions. The inclusion of a time matched control condition strengthened the interpretation of temporal changes in HRV and reduced the possibility of attributing ordinary within day variation to the physical education lesson. The use of standardized recording procedures, a single prespecified HRV index, and official school grades limited measurement complexity and ensured direct alignment between the study aims, physiological assessment, and educational outcome. Furthermore, conducting the study during regular school activities increased ecological validity and allowed autonomic responses to be examined within the context in which physical education ordinarily occurs.

The study also presents limitations. First, although the repeated measures design supports comparison between conditions, the association between autonomic recovery and academic achievement remains observational and does not permit causal inference. Second, autonomic recovery was assessed through a single standardized post lesson HRV recording. Consequently, the study captured autonomic status during a defined recovery window rather than the complete temporal trajectory of parasympathetic restoration. Future research could incorporate repeated post exercise measurements to characterize the recovery curve more comprehensively. Third, the study relied on grade point average as the sole indicator of academic achievement. Although official grades provide an ecologically meaningful measure of school performance, the findings cannot be generalized to other educational outcomes that were not assessed. Fourth, the study was conducted within a specific school context, which may limit the generalizability of the

findings to educational systems with different curricular structures or physical education practices. Finally, the regression model included autonomic recovery as a single predictor and was intentionally designed to examine a focused bivariate relationship. The proportion of unexplained variance confirms that the model should not be interpreted as a comprehensive account of academic achievement, but as an examination of the specific association between post physical education autonomic recovery and scholastic performance.

Conclusions

The present study showed that cardiac autonomic modulation followed a different temporal pattern after a regular physical education lesson compared with a time matched control condition. The increase in lnRMSSD observed during the post lesson recovery period, together with the significant Condition × Time interaction, indicates that curricular physical education was followed by a distinct autonomic response within the school day. Furthermore, greater autonomic recovery following physical education was positively associated with academic achievement, and this relationship was supported by both correlation and regression analyses. These findings provide evidence of a meaningful association between post exercise autonomic regulation and scholastic performance in adolescents, while the observational nature of the relationship precludes causal interpretation. Assessing HRV responses to physical education within authentic school settings may offer a useful physiological perspective for research examining the relationship between curricular physical activity and educational outcomes. Future studies should investigate autonomic recovery across multiple post exercise time points and in larger and more diverse school populations to determine the consistency and temporal characteristics of the observed association.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Naples Parthenope, Department of Medical, Motor and Wellness Sciences (DiSMMeB Prot. No. 88592/2024).

Informed Consent Statement

Informed consent was obtained from all participants prior to participatioin the study. For participants under 18 years of age, written informed consent was n additionally obtained from parents or legal guardians.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy restrictions.

AI Transparency Statement

The authors declare that artificial intelligence (AI)-assisted tools were used exclusively to improve the linguistic quality, grammar, readability, and formatting of the manuscript. AI tools were not used to generate, analyze, interpret, or manipulate the research data, statistical analyses, results, or scientific conclusions. All study design, data collection, data analysis, interpretation of findings, and final scientific content were developed, verified, and approved by the authors. The authors accept full responsibility for the accuracy, integrity, and originality of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Steinmayr, R., Meißner, A., Weidinger, A.F., & Wirthwein, L. (2014). *Academic achievement.* In T. Teo (Ed.), Encyclopedia of Critical Psychology. Oxford University Press. https://doi.org/10.1093/obo/9780199756810-0108

Osman, A., Ydhag, C.C., & Månsson, N. (2021). Recipe for educational success: A study of successful school performance of students from low social cultural background. *International Studies in Sociology of Education, 30*(4), 422–439. https://doi.org/10.1080/09620214.2020.1764379

Alfonsi, V., Palmizio, R., Rubino, A., Scarpelli, S., Gorgoni, M., D'Atri, A., ... & De Gennaro, L. (2020). The association between school start time and sleep duration, sustained attention, and academic performance. *Nature and Science of Sleep,* 12, 1161–1172. https://doi.org/10.2147/NSS.S273875

Latino, F., Tafuri, F., Maisuradze, M., & Tafuri, M.G. (2025a). Enhancing Academic Performance, Cognitive Functions, and Mental Well-Being Through Active Breaks: Evidence from a Pilot Study with University Student Sample. *International Journal of Environmental Research and Public Health, 22*(11), 1605. https://doi.org/10.3390/ijerph22111605

Latino, F., Tafuri, F., Maisuradze, M., & Tafuri, M.G. (2025b). School-Based Physical Activity, Cognitive Performance and Circadian Rhythms: Rethinking the Timing of Movement in Education. *Children, 12*(10), 1324. https://doi.org/10.3390/children12101324

James, J., Pringle, A., Mourton, S., & Roscoe, C.M.P. (2023). The effects of physical activity on academic performance in school-aged children: A systematic review. *Children, 10*(6), 1019. https://doi.org/10.3390/children10061019

Canli, U., Aldhahi, M.I., & Küçük, H. (2024). Association of physiological performance, physical fitness, and academic achievement in secondary school students. *Children, 11*(4), 396. https://doi.org/10.3390/children11040396

Latino, F., Tafuri, F., Maisuradze, M., & Tafuri, M.G. (2025). Complex Motor Schemes and Executive Functions: A School-Based Dual-Challenge Intervention to Enhance Cognitive Performance and Academic Success in Early Adolescence. *Journal of Intelligence, 13*(11), 151. https://doi.org/10.3390/jintelligence13110151

Martín-Rodríguez, A., Gostian-Ropotin, L.A., Beltrán-Velasco, A.I., Belando-Pedreño, N., Simón, J.A., López-Mora, C., ... & Clemente-Suárez, V.J. (2024). Sporting mind: The interplay of physical activity and psychological health. *Sports, 12*(1), 37. https://doi.org/10.3390/sports12010037

Marschin, V., & Herbert, C. (2026). Physical activity's impact on cardiac activity and autonomic regulation in university students: A baseline study. *International Journal of Psychophysiology,* 226, 113415. https://doi.org/10.1016/j.ijpsycho.2026.113415

López-Bueno, R., Núñez-Cortés, R., Calatayud, J., Andersen, L.L., del Pozo Cruz, B., & Petermann-Rocha, F. (2025). The triad of physical activity: An optimal combination for cardiovascular health. *Trends in Cardiovascular Medicine, 35*(4), 232–240. https://doi.org/10.1016/j.tcm.2024.12.008

Soares-Miranda, L., Sattelmair, J., Chaves, P., Duncan, G.E., Siscovick, D.S., Stein, P.K., & Mozaffarian, D. (2014). Physical activity and heart rate variability in older adults: The Cardiovascular Health Study. *Circulation, 129*(21), 2100–2110. https://doi.org/10.1161/CIRCULATIONAHA.113.005361

El-Malahi, O., Mohajeri, D., Mincu, R., Bäuerle, A., Rothenaicher, K., Knuschke, R., ... & Lortz, J. (2024). Beneficial impacts of physical activity on heart rate variability: A systematic review and meta-analysis. *PLoS ONE, 19*(4), e0299793. https://doi.org/10.1371/journal.pone.0299793

Dong, J.G. (2016). The role of heart rate variability in sports physiology. *Experimental and Therapeutic Medicine, 11*(5), 1531–1536. https://doi.org/10.3892/etm.2016.3104

Yoo, H.H., Yune, S.J., Im, S.J., Kam, B.S., & Lee, S.Y. (2021). Heart rate variability-measured stress and academic achievement in medical students. *Medical Principles and Practice, 30*(2), 193–200. https://doi.org/10.1159/000513781

Mendoza-Castejón, D., & Clemente-Suárez, V.J. (2020). Autonomic profile, physical activity, body mass index and academic performance of school students. *Sustainability, 12*(17), 6718. https://doi.org/10.3390/su12176718

Trudeau, F., & Shephard, R.J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity,* 5, 10. https://doi.org/10.1186/1479-5868-5-10

Yan, J., Lyu, D., Morgan, P.J., Cicchella, A., Li, M., & Eather, N. (2025). Does perceived physical literacy relate to academic achievement in Chinese university students? Insights from a cross-sectional study. *Physical Education and Sport Pedagogy,* 1–18. https://doi.org/10.1080/17408989.2025.2603985

Tornberg, J., Ikäheimo, T.M., Kiviniemi, A., Pyky, R., Hautala, A., Mäntysaari, M., ... & Korpelainen, R. (2019). Physical activity is associated with cardiac autonomic function in adolescent men. *PLoS ONE, 14*(9), e0222121. https://doi.org/10.1371/journal.pone.0222121

Frank, J., Seifert, G., Schroeder, R., Gruhn, B., Stritter, W., Jeitler, M., ... & Voss, A. (2020). Yoga in school sports improves functioning of autonomic nervous system in young adults: A non-randomized controlled pilot study. *PLoS ONE, 15*(4), e0231299. https://doi.org/10.1371/journal.pone.0231299

Wang, Z., Jing, R., & Zhang, R. (2025). The impact of sports activities on the cardiac autonomic nervous system changes in college students and medical imaging analysis. *Journal of Radiation Research and Applied Sciences, 18*(2), 101376. https://doi.org/10.1016/j.jrras.2025.101376

Brage, S., Ekelund, U., Brage, N., Hennings, M.A., Froberg, K., Franks, P.W., & Wareham, N.J. (2007). Hierarchy of individual calibration levels for heart rate and accelerometry to measure physical activity. *Journal of Applied Physiology, 103*(2), 682–692. https://doi.org/10.1152/japplphysiol.00092.2006

May, R., McBerty, V., Zaky, A., & Gianotti, M. (2017). Vigorous physical activity predicts higher heart rate variability among younger adults. *Journal of Physiological Anthropology, 36*(1), 24. https://doi.org/10.1186/s40101-017-0140-z

Yue, T., Li, F., & Wang, Y. (2025). Effects of high-intensity interval training and moderate-intensity continuous training on the functioning of attentional networks and heart rate variability in healthy young adults. *Journal of Exercise Science & Fitness, 23*(3), 203–212. https://doi.org/10.1016/j.jesf.2025.04.003

Medeiros, A.R., Leicht, A.S., Michael, S., & Boullosa, D. (2021). Weekly vagal modulations and their associations with physical fitness and physical activity. *European Journal of Sport Science, 21*(9), 1326–1336. https://doi.org/10.1080/17461391.2020.1838619

Speer, K.E., McKune, A.J., Telford, R.M., Semple, S., Naumovski, N., Olive, L.S., & Telford, R.D. (2022). Heart rate variability improves in 3–5-year-old children following a 6-month physical activity-based intervention: The Active Early Learning (AEL) cluster randomised controlled trial. *Applied Physiology, Nutrition, and Metabolism, 47*(1), 51–59. https://doi.org/10.1139/apnm-2021-0207

Makivić, B., Nikić Djordjević, M., & Willis, M.S. (2013). Heart Rate Variability (HRV) as a Tool for Diagnostic and Monitoring Performance in Sport and Physical Activities. *Journal of Exercise Physiology Online, 16*(3).

Buchheit, M., Platat, C., Oujaa, M., & Simon, C. (2007). Habitual physical activity, physical fitness and heart rate variability in preadolescents. *International Journal of Sports Medicine, 28*(3), 204–210. https://doi.org/10.1055/s-2006-924296

Chen, H., Xu, J., Xie, H., Huang, Y., Shen, X., & Xu, F. (2022). Effects of physical activity on heart rate variability in children and adolescents: A systematic review and meta-analysis. *Ciência & Saúde Coletiva, 27*(5), 1827–1842. https://doi.org/10.1590/1413-81232022275.10402021

Kim, H.J., Park, Y., & Lee, J. (2024). The validity of heart rate variability (HRV) in educational research and a synthesis of recommendations. *Educational Psychology Review, 36*(2), 42. https://doi.org/10.1007/s10648-024-09921-1

Silva, J.K.T.D.N.F.D., Lins Filho, O.D.L., Germano-Soares, A.H., Ritti-Dias, R.M., & Farah, B.Q. (2022). Association between frequency of physical education classes and heart rate variability in adolescent boys: A cross-sectional study. *Journal of Physical Education,* 33, e3322. https://doi.org/10.4025/jphyseduc.v33i1.3322

Ketelhut, S., Ketelhut, K., Ketelhut, S.R., & Ketelhut, R.G. (2024). Effects of school-based high-intensity interval training on hemodynamic parameters and heart rate variability: A randomized controlled trial. *The Journal of Strength & Conditioning Research, 38*(6), 1033–1040. https://doi.org/10.1519/JSC.0000000000004873

Післянавантажувальне фізіологічне відновлення та академічна успішність підлітків: роль автономної регуляції

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 11 с., 5 табл., 1 рис., 32 джерела.

Передумови. Фізичне виховання є регулярним фізіологічним стимулом упродовж навчального дня, проте автономне відновлення після уроків фізичної культури та його зв'язок з академічною успішністю залишаються недостатньо вивченими.

Мета. Порівняти автономне відновлення після звичайного уроку фізичної культури з відповідною за тривалістю контрольною умовою та визначити, чи пов'язане автономне відновлення з академічною успішністю підлітків.

Матеріали та методи. Дев'яносто два підлітки взяли участь у дослідженні з повторними вимірюваннями, у якому виконували програму в умовах уроку фізичної культури та в контрольній умові аналогічної тривалості. Варіабельність серцевого ритму реєстрували до та після кожної умови, а квадратний корінь із середнього квадрата різниць між послідовними інтервалами аналізували після натурального логарифмічного перетворення (lnRMSSD). Академічну успішність оцінювали за офіційним середнім балом успішності.

Результати. Виявлено статистично значущу взаємодію «Умова × Час» для показника lnRMSSD, $F_{(1, 91)} = 4{,}06$, $p = 0{,}047$, часткова $\eta^2 = 0{,}043$. Апостеріорний аналіз показав статистично значуще підвищення lnRMSSD після уроку фізичної культури ($p = 0{,}003$), тоді як у контрольній умові статистично значущих змін не виявлено ($p = 0{,}292$). Автономне відновлення після уроку фізичної культури позитивно корелювало з академічною успішністю ($r = 0{,}52$, $p < 0{,}001$). Регресійна модель була статистично значущою та пояснювала 27,5 % варіації академічної успішності ($R^2 = 0{,}275$, $p < 0{,}001$).

Висновки. Автономна модуляція після уроку фізичної культури відрізнялася від такої після контрольної умови аналогічної тривалості, а більш виражене автономне відновлення після уроку було пов'язане з вищою академічною успішністю. Отримані результати свідчать, що автономне відновлення після уроку фізичної культури може бути важливим фізіологічним корелятом академічної успішності підлітків та підтверджують доцільність подальших лонгітюдних і інтервенційних досліджень ролі автономної регуляції в освітніх результатах.

Ключові слова: варіабельність серцевого ритму, кардіальна вагусна модуляція, академічна успішність, парасимпатична реактивація, фізіологія фізичних вправ, учні закладів загальної середньої освіти.

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