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Difference in out-of-school physical activity patterns, sedentary behavior, and health-related fitness in relation to mathematics achievement among school-aged children: a cross-sectional study

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Aim: This study examined differences in health-related fitness, physical activity patterns, and sedentary behavior among Qatari schoolchildren, classified by their mathematics achievement levels.

Methods: Ninety-eight schoolchildren (age: 12.1 ± 0.5 years; height: 1.58 ± 0.9 m; body mass: 50.5 ± 13.6 kg; Body mass index: 20.6 ± 4.7 kg/m^2) participated in this cross-sectional study. Based on their mathematics grade point average (GPA), participants were classified into two achievement levels Excellent level in mathematics (90–100; n = 49), and Good level in mathematics (70–79; n = 49). Assessments included anthropometric measurements, physical performance tests (medicine ball throw, postural stability, and handgrip strength), and out-of-school physical activity levels measured using the International Physical Activity Questionnaire-Short Form.

Results: Significant differences between the achievement levels were detected in postural stability ($p < 0.001$, $\eta_p^2 = 0.137$), with excellent pupils demonstrating better balance (boys: 2.09 ± 0.36 s, girls: 2.05 ± 0.45 s) versus good level pupils (boys: 1.71 ± 0.55 s, girls: 1.69 ± 0.51 s). Total physical activity levels displayed substantial sex-based variations ($p < 0.001$, $\eta_p^2 = 0.188$), with boys showing higher activity levels across achievement groups. Sedentary behavior also differed significantly between achievement levels ($p < 0.001$, $\eta_p^2 = 0.166$), with lower-achieving students accumulating more sitting time. Mathematics achievement level predicted 23.7% of the variance in sedentary behavior ($R^2 = 0.237$, $p = 0.002$).

Conclusion: The findings demonstrate significant associations between mathematics achievement level, health-related fitness, and activity patterns among Qatari schoolchildren. The strong relationship between postural stability and mathematics performance, along with the inverse association between sedentary behavior and mathematics achievement level, suggests the presence of shared underlying mechanisms and cognitive abilities that may influence both physical and academic outcomes.

KEYWORDS

anthropometry, cognitive performance, exercise testing, motor control, sedentary behavior, sex characteristics

1 Introduction

Increasing sedentary behavior and decreasing physical activity levels among adolescents and children represent a significant and growing public health concern (Wu et al., 2017; Zhang et al., 2020). An increasing number of young people are not meeting the recommended levels of physical activity (Guthold et al., 2020). According to a World Health Organization's survey of 72,845 schoolchildren across 34 countries, a significant number of children are not engaging in sufficient physical activity, with nearly one-third leading sedentary lifestyles (Guthold et al., 2010). Physical activity plays a crucial role in promoting individual wellbeing and health. Regular participation in physical activity offers numerous advantages, such as reducing anxiety and depression levels and lowering the risk of non-communicable diseases. Additionally, there is a widely held belief in the literature that a positive correlation exists between academic achievement and physical activity levels. This notion is supported by research indicating a beneficial relationship between physical activity during school hours and physical activity. Furthermore, higher levels of physical fitness have been linked to better academic achievement. However, it is important to acknowledge that previous studies in this field have produced mixed results (Shan et al., 2010; Weiss et al., 2013). In light of these concerns, promoting physical activity and reducing sedentary behavior are crucial strategies for improving both the physical and mental health of children and adolescents. This can offer several health benefits for children and teenagers.

Physical activity is a protective factor against systemic and non-communicable chronic diseases, contributes to body weight control, and enhances physiological capacities such as strength and endurance (Wu et al., 2017; Zhang et al., 2020). Furthermore, regular engagement in high levels of physical activity and a reduction in sedentary behavior are associated with cognitive benefits, and improved mental health (Carson et al., 2016; Wu et al., 2017). According to previous research, physical activity influences neurological processes related to increased concentration, thereby supporting overall development, enhancing emotional regulation, and improving academic performance (Padulo et al., 2019; Barbosa et al., 2020). Research indicates that the potential benefits of physical activity on cognitive performance, executive functions, learning, brain structure, and brain function may form the basis for improved academic performance (Donnelly and Lambourne, 2011; Álvarez-Bueno et al., 2017; De Greeff et al., 2018; Ishihara et al., 2018; Ben Ezzdine et al., 2025). However, this relationship is not a simple causal link and can be influenced by various factors (Lagerberg, 2005). While research has focused on the impact of physical activity on various academic areas such as language, reading, and science, the connection with mathematics achievement level has received particular attention, with findings showing both positive associations and varying results (Sibley and Etnier, 2003; Esteban-Cornejo et al., 2015; De Greeff et al., 2018; Bedard et al., 2019; Barbosa et al., 2020).

Beyond physical activity and sedentary behavior, other components of health-related fitness, such as muscular strength, power, and agility, are vital indicators of overall health and wellbeing in children and adolescents (Prince et al., 2020). While much of the research has focused on the relationship between physical activity or cardiorespiratory fitness and academic success (Donnelly and Lambourne, 2011; Esteban-Cornejo et al., 2015), the potential role of muscular fitness in supporting cognitive and academic performance has received less attention (Donnelly and Lambourne, 2011). Recent studies, such as those by Kao et al. (2017), have emphasized the need for further research into the role of muscular strength and power in supporting cognitive health and academic achievement.

In recent years, over 200 studies have investigated the link between physical activity and academic success in school-aged children. These studies collectively suggest a significant positive relationship between physical activity and cognitive functioning in children. Among various subjects, the connection between physical activity and mathematics has garnered the most attention (Barbosa et al., 2020). This focus is understandable, given mathematics' crucial role as a fundamental discipline. Mathematics is a mandatory subject from grades 1–12 and is essential for college and senior high school entrance exams. It also underpins other science and engineering disciplines and subsequent learning activities. Consequently, researchers have concentrated more on mathematics when examining the relationship between physical activity and academic performance (Fedewa and Ahn, 2011). Most studies have found that physical activity positively impacts mathematics performance (Ericsson and Karlsson, 2014; Mullender-Wijnsma et al., 2015).

Therefore, this study aims to investigate the differences in health-related fitness, physical activity patterns, and sedentary behavior among Qatari schoolchildren classified by their mathematics achievement levels. By exploring the associations between physical performance and academic achievement, particularly in mathematics, this research seeks to highlight potential shared mechanisms that may explain how physical health impacts cognitive performance. Through comprehensive assessments of anthropometric measurements, physical fitness tests, and out-of-school physical activity levels, this study contributes valuable data to the growing body of literature on the interplay between physical health and academic success in schoolchildren. In detail, we hypothesized *a priori* that significant differences exist in health-related fitness, physical activity patterns, and sedentary behavior among Qatari schoolchildren when classified by their mathematics achievement levels. Specifically, we expect that schoolchildren with higher mathematics achievement levels will demonstrate better health-related fitness, more favorable physical activity patterns, and lower levels of sedentary behavior compared to their peers with lower mathematics achievement levels.

2 Methods

2.1 Study design

This cross-sectional study employed convenience sampling, selecting participants from a single urban school in the Doha Community (Qatar).

2.2 Subjects

Sample size estimation was performed using G*Power (version 3.1.2; Heinrich Heine University, Dusseldorf, Germany). Based on an anticipated effect size of η_p^2 = 0.14 (large), α = 0.05, power (1-β) = 0.80, and two groups, a minimum total sample size of 94 participants was required. A total of 98 school children (age: 12.1 ± 0.5 years; height: 1.58 ± 0.9 m; body mass: 50.5 ± 13.6 kg; Body mass index (BMI): 20.6 ± 4.7 kg/m^2, seat height: 1.21 ± 0.09 cm; arm span: 1.56 ± 0.10 cm) participated in this study. Participants were recruited from one of the schools in Doha, Qatar. This active school was selected for this study in accordance with the active school policy formulated by the Ministry of Education and Higher Education, Doha. In the school, in accordance with this policy, it was required to provide two physical education classes per week with 50-min sessions. The school management team and physical education teachers were informed about the study plan and objectives. Children were eligible if they: (1) provided written informed consent from a parent/guardian and themselves, (2) were in good health with no contraindications to participation in physical activity, (3) had no physical limitations to exercise, and (4) were 10–13 years of age. Children were excluded if they: (1) had been diagnosed with a psychological disorder, such as depression, attention deficit disorder, and anxiety; (2) were taking medications for nervous system disorders or antidepressants; (3) did not provide signed informed consent from their legal guardians; or (4) did not participate in regular physical education classes.

2.3 Ethical clearance

The study protocol was approved by the institutional review board of Qatar University (QU-IRB 1544-FBA/21- Date of approval: 20 May 2021 and renewed on May 16, 2024), the Ministry of Education and Higher Education of Qatar (REF: 18/2021) and was conducted in accordance with the Declaration of Helsinki. The study design and objectives were communicated to the school administration and physical education teachers. Before the study began, students and their parents or legal guardians received information about the study objectives and procedures and gave their written informed consent.

2.4 Research protocol

The experimental protocol was divided into four test days that were conducted in an indoor room during the same period from 08:00 to 10:00 under the same environmental conditions: temperature of 24.5 ± 0.5°C and relative humidity of 65 ± 5%. During these test days, children were instructed to abstain from strenuous exercise and maintain a regular food diary devoid of ergogenic products (e.g., caffeine, vitamins) 24 h before the test. Anthropometric parameters were measured on the first day. Stork static balance test was performed on the second day and medicine ball throw test was performed on the third day. On the last day, children completed a physical activity questionnaire. Two weeks after the first test phase, test days 1 to 3 were repeated and test–retest reliability was measured. Values obtained from the second day of testing were used in the analysis.

2.5 Measurement

2.5.1 Anthropometry

Body mass was measured to the nearest 0.1 kg using an electronic scale (Tanita, model TBF 105, Tanita Corporation of America, Inc., Arlington Heights, Illinois). Also, Height was measured to the nearest 0.5 cm with a measuring tape fixed to the wall. Body mass index was calculated using the following formula: BMI = Body mass (kg)/body height^2 (m).

2.5.2 Stork balance test

The participants were instructed to stand on one leg, place their hands on their hips, and placing the sole of the opposite foot against the inside of the knee of the standing leg. The lifted foot should be flat against the knee, and the knee of the standing leg should be slightly bent (Miller et al., 2002). The participants had to maintain this position as long as, while avoiding touching the ground. The timer was started when the heel was lifted off the ground and stops when the heel touches the ground or when balance is lost. The total time in seconds is recorded. Each participant performed three repetitions, with the best score being recorded.

2.5.3 Medicine ball throw

Participants were positioned behind a line and instructed to throw a 3 kg medicine ball, with a diameter of 21.5 cm, as far as possible using an overhead throw (Negrete et al., 2010). The throwing distance was measured from the line to the point where the ball landed, using a measuring tape. Three trials were conducted, and the farthest throw was recorded.

2.5.4 Hand grip strength test

Hand grip strength of the dominant hand was measured using a digital hand grip dynamometer (T. K. K. 5,401, Tokyo, Japan) with a sensitivity of 10 N. Detailed descriptions of all the physical performance tests employed can be found in prior literature (Hermassi et al., 2023).

2.5.5 Academic performance

The grade point average (GPA) and percentage scores of the participants in mathematics for the academic years 2021–2022 present the academic performance of the students. The grading categories included: Excellence in mathematics, from 90 to 100: n = 49; and Good in the mathematics category, scores ranged from 70 to 79: n = 49. The students' performance was measured by three assessments: oral exam, written exam, and final exam. The final grade was calculated from these assessments using a grade weighting of each assessment. The reason for including only mathematics was our interest in science-related subjects. Academic achievement has been reported to depend on the academic subject, with physical fitness being particularly beneficial for subjects that rely more on executive cognition, such as mathematics (Hsieh and Chen, 2019).

2.5.6 Physical activity questionnaire

Physical activity was measured using the International Physical Activity Questionnaire-Short Form (IPAQ-SF). The administration and scoring procedures of the IPAQ-SF are described elsewhere (Craig et al., 2003). The reliability and validity of the IPAQ-SF have been reported in different study populations and countries (Craig et al., 2003; Zhang et al., 2020). The result was used to quantify the daily amount of physical activity, expressed as metabolic equivalent of task-minutes per day (MET-min/day). Physical activity was classified into three intensities based on the IPAQ-SF scoring protocol (Craig et al., 2003): moderate (4 METs), vigorous (8 METs), and walking (3.3 METs) (Craig et al., 2003; Stierlin et al., 2015). Total physical activity was calculated from the sum of the three intensities. Sitting time was also determined to quantify sedentary behaviors (Craig et al., 2003).

2.6 Statistical analysis

All statistical analyses were performed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA). Prior to inferential analyses, all variables were tested for normality using the Shapiro–Wilk test and homogeneity of variances using Levene's test. Descriptive statistics are presented as mean ± standard deviation (SD), along with 95% confidence intervals (95% CI). A two-way analysis of variance (ANOVA) was employed to examine the effects of mathematics achievement level (excellent vs. good) and sex (boy vs. girl) on anthropometric characteristics, physical performance parameters, and physical activity patterns. Effect sizes were calculated using partial eta squared (η_p^2), with values interpreted as: small (0.01–0.05), medium (0.06–0.13), and large (≥0.14). For pairwise comparisons between groups, Cohen's d effect sizes were calculated with 95% confidence intervals. The magnitude of Cohen's d effect sizes was interpreted as: trivial (<0.2), small (0.2–0.5), moderate (0.5–0.8), and large (>0.8). For non-parametric effect sizes (r), thresholds were interpreted as: small (0.1–0.3), medium (0.3–0.5), and large (>0.5) in accordance with established guidelines (Cohen, 2013). Multiple linear regression analyses were conducted to develop predictive equations for physical activity parameters, with sex and mathematics achievement level as independent variables. The coefficient of determination (R^2) was calculated to assess the proportion of variance explained by each model. Statistical significance was set at $p < 0.05$.

3 Results

3.1 Normal distribution and variance homogeneity

A power analysis confirmed that our sample size provided adequate statistical power (>0.80) for detecting meaningful differences between groups with medium to large effect sizes. Prior to conducting the main analyses, all variables were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. Only three variables (height: $p = 0.078$; agility: $p = 0.150$; arm span: $p = 0.279$) demonstrated normal distribution. For non-normally distributed variables, non-parametric statistical methods were employed. Specifically, Mann–Whitney U tests were utilized to examine between-group differences (mathematics achievement levels and sex) for these variables, while Spearman's rank correlation coefficients were calculated to assess relationships between non-normally distributed variables. For consistency in reporting across all variables, both parametric and non-parametric effect sizes were calculated. For normally distributed variables, Cohen's d and partial eta squared (η_p^2) were used, while for non-normally distributed variables, we calculated $r = Z/\sqrt{N}$ for Mann–Whitney U tests and used Spearman's rho values directly as effect size measures.

Regarding variance homogeneity, postural stability demonstrated significant heterogeneity ($p < 0.001$). For this variable, Welch's ANOVA was employed as a robust alternative to the standard ANOVA to account for unequal variances. All other variables exhibited variance homogeneity with p-values exceeding 0.061 (with BMI at the lower threshold), indicating that standard parametric tests were appropriate for these variables when they also met normality assumptions.

3.2 Anthropometric characteristics

When comparing anthropometric characteristics between mathematics achievement level groups statistical significance were observed (height: $p = 0.003$, $\eta_p^2 = 0.09$; body mass: $p = 0.033$, $\eta_p^2 = 0.05$, Table 1). For height, both excellent-level boys (1.54 ± 0.87 m) and girls (1.56 ± 0.78 m) were shorter than good-level boys (1.59 ± 0.93 m) and girls (1.61 ± 0.82 m). Similarly, for body mass, both excellent-level students (boys: 45.24 ± 12.23 kg, girls: 49.92 ± 9.32 kg) weighed less than good-level students (boys: 52.84 ± 16.23 kg, girls: 53.95 ± 14.40 kg, Table 1).

3.3 Physical performance parameters

Physical performance analysis demonstrated significant differences in postural stability between mathematics achievement levels ($p < 0.001$, $\eta_p^2 = 0.137$), representing a large effect size according to established thresholds. Excellent students maintained better balance (2.09 ± 0.36 s males, 2.05 ± 0.45 s females) compared to good-level students (1.71 ± 0.55 s males, 1.69 ± 0.51 s females). Medicine ball throwing displayed a significant gender effect ($p = 0.001$, $\eta_p^2 = 0.106$), indicating a medium-to-large effect size, with males achieving greater distances across both mathematics achievement levels (Table 2).

3.4 Physical activity patterns

Total MET values showed substantial sex differences ($p < 0.001$, $\eta_p^2 = 0.188$), representing a large effect size, with males demonstrating higher activity levels in both mathematics achievement level groups. Vigorous physical activity exhibited the largest sex-based difference ($p < 0.001$, $\eta_p^2 = 0.155$), also a large effect. Notably, sedentary behavior displayed significant differences between mathematics achievement levels ($p < 0.001$, $\eta_p^2 = 0.166$), constituting another large effect size, with good-level students spending more time sitting weekly than excellent level students (Table 3).

TABLE 1 Mean (±SD) anthropometric characteristics in relation to mathematics achievement level.

	Excellent level in mathematics		Good level in mathematics		Main effect		Interaction
	Boys (n = 25)	Girls (n = 24)	Boys (n = 25)	Girls (n = 24)	Sex	Mathematics achievement level	Sex* mathematics level
Body height (m)	1.54 ± 0.87	1.56 ± 0.78	1.59 ± 0.93	1.61 ± 0.82	p = 0.143 η_p^2 = 0.023	**p = 0.003** η_p^2 = 0.091	p = 0.871 η_p^2 = 0.001
Body mass (kg)	45.24 ± 12.23	49.92 ± 9.32	52.84 ± 16.23	53.95 ± 14.40	p = 0.284 η_p^2 = 0.012	**p = 0.033** η_p^2 = 0.047	p = 0.510 η_p^2 = 0.005
BMI (kg/m²)	18.91 ± 3.80	20.45 ± 3.83	20.55 ± 4.93	20.67 ± 5.24	p = 0.363 η_p^2 = 0.009	p = 0.311 η_p^2 = 0.011	p = 0.433 η_p^2 = 0.007
Seat height (cm)	119.40 ± 17.46	121.79 ± 3.27	119.32 ± 5.12	122.96 ± 3.52	p = 0.119 η_p^2 = 0.026	p = 0.778 η_p^2 = 0.001	p = 0.746 η_p^2 = 0.001
Arm span (cm)	149.40 ± 9.81*	158.13 ± 10.01#	158.48 ± 10.11	157.80 ± 9.63	**p = 0.031** η_p^2 = 0.048	**p = 0.047** η_p^2 = 0.041	p = **0.021** η_p^2 = **0.056**
Maturity (score)	−1.24 ± 0.58	−1.12 ± 0.48	−1.07 ± 0.54	−0.88 ± 0.51	p = 0.143 η_p^2 = 0.023	p = 0.054 η_p^2 = 0.039	p = 0.737 η_p^2 = 0.001

#Significant differences between sexes within each achievement level. *Significant differences between achievement levels by sex. η_p^2 = partial eta square. Bold values indicate statistical significance with $p < 0.005$.

TABLE 2 Mean (±SD) physical performance in relation to mathematics achievement level and sex.

	Excellent level in mathematics		Good level in mathematics		Main effect		Interaction
	Boys (n = 25)	Girls (n = 24)	Boys (n = 25)	Girls (n = 24)	Sex	Mathematics achievement level	Sex* mathematics level
Medicine ball throwing distance (m)	3.81 ± 0.77†	3.34 ± 0.49†	3.54 ± 0.77	3.11 ± 0.56	**p = 0.001** η_p^2 = 0.106	p = 0.063 η_p^2 = 0.036	p = 0.879 η_p^2 = 0.001
Postural stability (min)	2.09 ± 0.36*	2.05 ± 0.45*	1.71 ± 0.55	1.69 ± 0.51	p = 0.820 η_p^2 = 0.001	**p < 0.001** η_p^2 = 0.137	p = 0.924 η_p^2 = 0.001
Handgrip strength (N)	21.08 ± 2.76	19.90 ± 5.54	22.60 ± 7.13	20.34 ± 5.12	p = 0.117 η_p^2 = 0.026	p = 0.369 η_p^2 = 0.009	p = 0.618 η_p^2 = 0.003

η_p^2 = partial eta squared. *Significant differences between achievement levels. †Significant difference between sexes for this achievement level. Bold values indicate statistical significance with $p < 0.005$.

3.5 Predictive relationships

Regression analysis revealed that sex was the strongest predictor of total MET values ($R^2 = 0.181$, $p < 0.001$) and vigorous physical activity ($R^2 = 0.151$, $p < 0.001$). Mathematics achievement level significantly predicted sedentary behavior ($R^2 = 0.237$, $p = 0.002$), explaining 23.7% of the variance in sitting time (Table 4).

3.6 Visualization of key findings

Figure 1 presents the most significant differences between mathematics achievement levels and sexes for three key variables: postural stability, total MET values, and sedentary behavior (sitting time). Panel A illustrates the significant differences in postural stability between excellent and good mathematics achievement groups, with both sexes in the excellent group demonstrating superior balance performance ($p < 0.001$, $\eta_p^2 = 0.137$). Panel B depicts the substantial sex-based differences in total physical activity (MET values), with males showing consistently higher activity levels across both achievement groups ($p < 0.001$, $\eta_p^2 = 0.188$). Panel C highlights the significant differences in sedentary behavior between achievement levels, with good-level students accumulating more weekly sitting time than excellent-level students ($p < 0.001$, $\eta_p^2 = 0.166$). These visualizations emphasize the magnitude of group differences and help illustrate the key patterns observed in our dataset.

4 Discussion

This study examined the relationships between out-of-school physical activity patterns and sedentary behavior, mathematics achievement level, and physical fitness parameters among Qatari schoolchildren. The results indicated substantial sex-based variations in total physical activity, with males exhibiting higher activity levels across achievement groups. Sedentary behavior significantly differed between mathematics achievement level, with lower-achieving students accumulating more sitting time. Mathematics achievement level predicted 23.7% of the

TABLE 3 Mean (±SD) physical activity in relation to mathematics achievement level and sex.

	Excellent level in mathematics		Good level in mathematics		Main effect	Interaction	
	Male (n = 25)	Female (n = 24)	Male (n = 25)	Female (n = 24)	Sex	Mathematics achievement level	Sex* mathematics level
Total MET values	2337.1 ± 996.1	1419.9 ± 801.5	1901.3 ± 1110.7	1061.4 ± 757.7	**$p < 0.001$** $\eta_p^2 = 0.188$	**$p = 0.037$** $\eta_p^2 = 0.045$	$p = 0.838$ $\eta_p^2 = 0.001$
Walking MET Min/week	553.1 ± 397.2	314.9 ± 348.0	469.26 ± 463.8	276.4 ± 201.5	**$p = 0.005$** $\eta_p^2 = 0.082$	$p = 0.412$ $\eta_p^2 = 0.007$	$p = 0.761$ $\eta_p^2 = 0.001$
Moderate MET min/week	488 ± 372.7	361.7 ± 238.7	372.80 ± 267.0	245 ± 234.8	**$p = 0.030$** $\eta_p^2 = 0.049$	$p =$ **0.047** $\eta_p^2 = 0.041$	$p = 0.990$ $\eta_p^2 = 0.001$
Vigorous MET min/week	1,296 ± 786.2	743.3 ± 501.8	1059.20 ± 706.3	540 ± 498.9	**$p = <0.001$** $\eta_p^2 = 0.155$	$p = 0.091$ $\eta_p^2 = 0.03$	$p = 0.897$ $\eta_p^2 = 0.001$
Sedentary behavior Sitting/week	2.5 ± 1.3	3.8 ± 2.2	4.2 ± 1.9	5.3 ± 1.9	**$p = 0.002$** $\eta_p^2 = 0.1$	**$p < 0.001$** $\eta_p^2 = 0.166$	$p = 0.853$ $\eta_p^2 = 0.001$

η_p^2 = Eta partial squared. Bold values indicate statistical significance with $p < 0.005$.

variance in sedentary behavior. Furthermore, significant differences between the achievement levels were observed in several parameters. Anthropometric analysis revealed that excellent-level students had significantly lower height and body mass compared to good-level students. This finding contradicts typical assumptions that taller or heavier children perform better academically. Recent research by Martin et al. (2018) indicates that lower BMI values in childhood may be associated with improved executive functioning, potentially benefiting mathematical cognition. These differences likely reflect complex developmental relationships rather than direct causal effects. Arm span also showed a significant interaction effect between mathematics achievement level and sex ($p = 0.021$, $\eta_p^2 = 0.056$), with distinctive patterns across groups. Additionally, in physical performance assessments, postural stability demonstrated marked differences between achievement levels, representing a large effect size that explains approximately 13.7% of the variance in balance performance. Excellent students maintained better balance compared to good-level students. This substantial effect underscores the potential neurophysiological connections between motor control and mathematical cognition.

TABLE 4 Regressions equations (±SEE) to estimate physical activity scores (N = 98).

Dependent variables	Regression equations	R	R^2	P
Total MET values	2997.72*sex-878.55	0.426	0.181	**<0.001**
	3594.638*group-397.949	0.468	0.219	0.36
Walking MET	726.72*sex-215.55	0.286	0.082	**0.004**
Moderate MET	557.48*sex-127.07	0.218	0.047	**0.031**
	731.34*group-115.92	0.295	0.087	**0.013**
Vigorous MET	1713.53*sex-535.93	0.389	0.151	**<0.001**
Sedentary behavior	1.490*sex+1.2	0.390	0.152	**<0.001**
	−0.30*group+1.61	0.487	0.237	**0.002**

R^2 = coefficient of determination. Bold values indicate statistical significance with $p < 0.005$.

4.1 Physical activity and sedentary behavior

In the present study, total physical activity levels reveal substantial gender-based differences ($\eta_p^2 = 0.188$, large effect size), with male students consistently showing higher activity levels regardless of academic achievement. This large effect explains nearly 19% of the variance in physical activity patterns between sexes. The lower physical activity levels among girls compared to boys of similar age have been well documented in several populations across Europe (Tobias et al., 2007; Van Stralen et al., 2014), the United States, and Australia (Olds et al., 2011). These findings are also consistent with regional studies showing consistently lower activity levels among female students in Gulf Cooperation Council countries (Zimmo et al., 2017). However, in a recent study conducted in the State of Qatar, Hermassi et al. (2024) reported no significant differences between boys and girls regarding physical activity levels, which contrasts with our current findings. This discrepancy may be attributed to several methodological and contextual factors. First, Hermassi et al. (2024) examined a broader age range (10–13 years) compared to our more narrowly defined sample (12.1 ± 0.5 years), potentially capturing different developmental stages where sex-based activity gaps may not yet be pronounced. This aligns with findings from longitudinal studies showing that sex-based differences in physical activity patterns become more evident during specific developmental windows (Soini et al., 2014; Sharara et al., 2018; Wyszyńska et al., 2020). Second, our current investigation specifically stratified participants by mathematics achievement levels, which may have revealed sex-based activity differences that were masked in the previous study's general population approach. Third, the timing of data collection differed between studies, with our current research conducted during the post-pandemic period when physical activity patterns may have undergone substantial changes due to altered school policies and recreational opportunities. Finally, the measurement tools, though similar, were administered differently, with our current protocol employing more rigorous validation procedures for the IPAQ-SF responses. These methodological refinements likely enhanced our ability to detect sex-based differences in physical activity patterns that were not apparent in the earlier investigation.

In the present study, gender-based differences were particularly evident in vigorous physical activity, possibly reflecting cultural

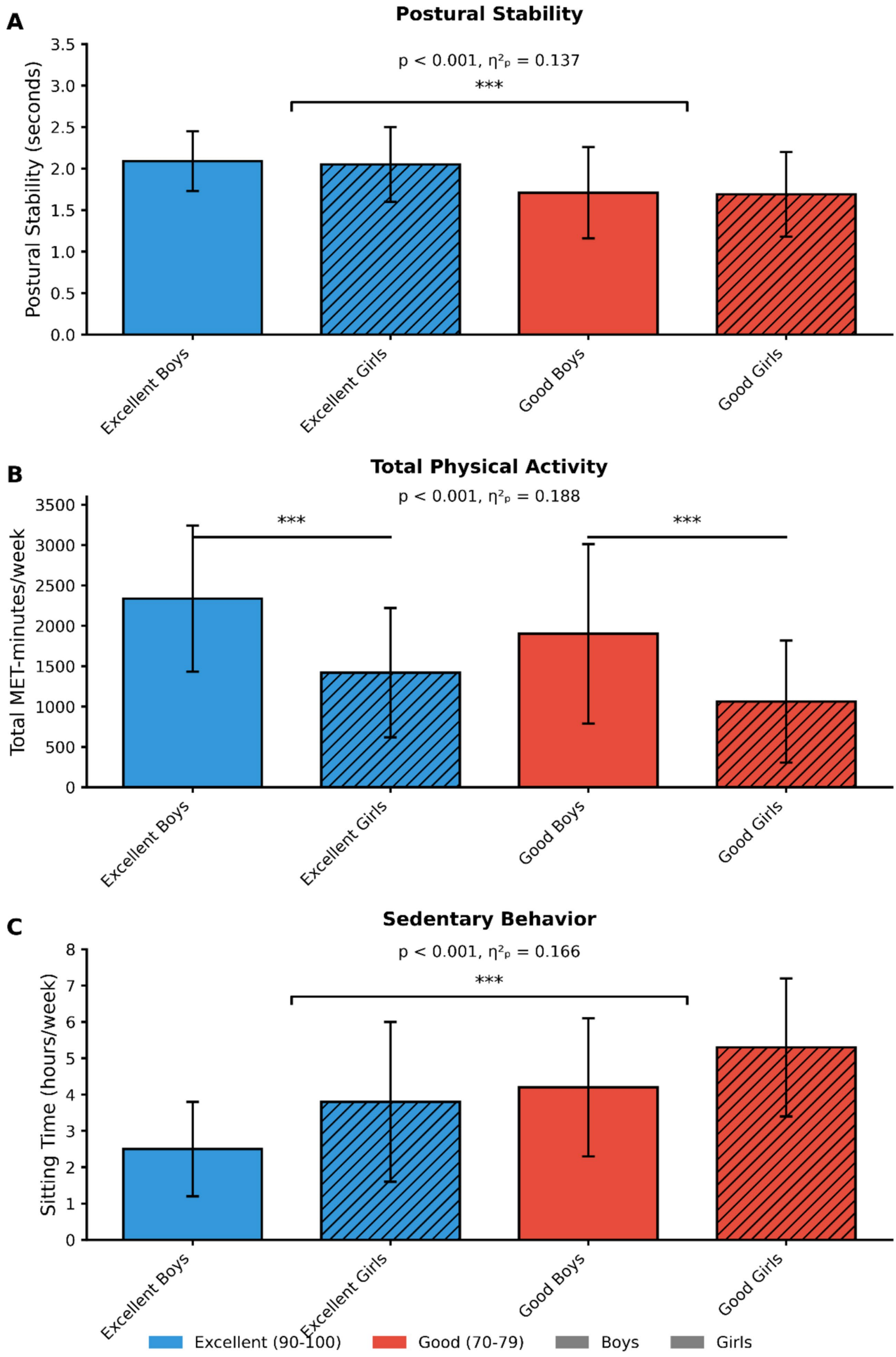

FIGURE 1
Means (standard deviation) of key physical parameters between mathematics achievement groups and sexes. **(A)** Postural stability, **(B)** total physical activity and **(C)** sedentary behavior (weekly sitting time). ***Indicates significant differences between these variables.

influences on physical activity participation among Qatari youth (Sharara et al., 2018). This is in line with previous studies suggesting that boys engage in more moderate-to-vigorous physical activity (MVPA) than girls (Soini et al., 2014; Wyszyńska et al., 2020). Furthermore, the regression analyses in the current study identified gender as the primary predictor of physical activity patterns (Table 4). These findings emphasize the need for targeted interventions that consider gender-specific factors in Qatari educational settings. The results support previous regional studies highlighting the influence of cultural factors on physical activity participation patterns (Al-Thani et al., 2018).

However, there are some limitations of self-reported physical activity IPAQ-SF to mention. First of all, the true value of PA is unknown and each measure is just an estimate of PA as, for example, no 24-h measurements of energy expenditure via indirect calorimetry or throughout observation of activity patterns have been recorded (Burchartz et al., 2020). Evaluating the relationship between the different parameters is even more complicated as most questionnaires and PA diaries only ask to report PA with a duration of at least 10 min (or even asking for PA over or under 60 min) (Prochaska et al., 2001). Furthermore, it is crucial to use standardized reporting to enhance the comparability of self-reported measures can offer additional contextual information of PA in a timely manner by using, e.g., ecological momentary assessments (Sattler et al., 2021) using of accelerometers to further refine our understanding of PA in the future.

Previous studies have reported a significant correlation between physical activity and academic achievement, particularly in mathematics (Rasberry et al., 2011; Sneck et al., 2019). A recent meta-analysis of Xu et al. (2024) reported that classroom-based physical activity (CBPA) interventions have been found to significantly improve overall academic performance, from 10 studies involving 2,481 participants, CBPA interventions significantly improved performance in mathematics, interventions show promise in enhancing overall academic and mathematics performance, their impact on reading and spelling performance appears to be minimal. In addition, Rasberry et al. (2011) found that half of the 50 studies they reviewed demonstrated a positive relationship between school-based physical activity and children and adolescents' mathematics achievement level. More recently, systematic reviews by Sneck et al. (2019) and James et al. (2018), examined physical activity interventions in relation to children and adolescents' academic achievement and concluded that they had no detrimental effects on mathematics achievement level. In this context, Álvarez-Bueno et al. (2017) showed that physical activity improves classroom behavior and contribute positively to domains of academic achievement, reading, calculation, and composition among young people. Zhou et al. (2022) found that physical activity can reduce arithmetic anxiety, leading to improved mathematics achievement level, both in boys and girls. Similarly, Shin et al. (2024) observed that moderate to vigorous physical activity levels are positively correlated with arithmetic proficiency.

Longitudinal research indicates that executive function plays a crucial role in contributing to academic achievement, rather than the other way around (Aly et al., 2024a; Aly et al., 2024b). Additionally, executive function has been associated with academic success in children of various ages, both with and without specific learning disabilities (Cancela et al., 2019). Specifically, performance on tasks involving inhibition and working memory consistently correlates with mathematics performance (Passolunghi et al., 2016). The review and meta-analysis by Cortés Pascual et al. (2019) highlight the multifactorial nature of executive functions, revealing that working memory is the most extensively researched component and a stronger predictor of academic performance than inhibition. Furthermore, the behavior of executive function components varies depending on the subject studied, particularly in the context of the relationship between mathematics and the visuo-spatial aspect of working memory. Similarly, most executive function components are more closely related to performance in mathematics than in language.

The inverse relationship between sedentary behavior and mathematics achievement represents a crucial finding. Lower-achieving students demonstrated significantly higher sitting time, supporting previous research linking excessive sedentary behavior to reduced cognitive performance (Wu et al., 2017). The large effect size observed for differences in sedentary behavior between mathematics achievement levels ($\eta_p^2 = 0.166$) is particularly noteworthy, as it indicates that achievement groups differ substantially in their sitting time, with this factor explaining approximately 16.6% of the variance. This robust relationship aligns with Ekelund et al. (2016), who found that extended sedentary time significantly impacts cognitive processes related to academic performance. This relationship may be particularly relevant in Qatar, where students spend approximately 194 ± 38 min in sedentary behavior during a six-hour school day (Zimmo et al., 2017). However, it is important to acknowledge that not all sedentary activities are detrimental. For instance, activities such as reading can be productive, whereas excessive screen time may have negative effects (Adelantado-Renau et al., 2019). To address this limitation, future studies should separate productive sedentary behaviors, like reading, from non-productive ones, such as prolonged screen time, to provide a more nuanced understanding of their distinct impacts on academic achievement.

Previous reviews and cross-sectional studies have shown that prolonged sedentary behavior, particularly screen-based sitting time, is associated with unfavorable brain microstructure, reduced levels of brain-derived neurotrophic factor, and poorer cognitive and academic achievements outcomes (Yang et al., 2022; Felin Fochesatto et al., 2023). Bueno et al. (2022) reported that different patterns of sedentary behavior, such as bouts (uninterrupted amount of time during the behavior) and breaks (interruption of the behavior with at least light physical activity), may influence mathematics achievement in children (Howie et al., 2015). However, the association between the duration of bouts or the frequency of breaks in sedentary behavior in free-living conditions and mathematics achievement remains unclear and has not yet been explored among adolescents. The association between sedentary behavior and mathematics achievement level requires careful interpretation, as it often fails to account for specific types of sedentary activities. Rather than evaluating distinct domains of sedentary behavior, such as doing homework, using a computer, or reading for pleasure, it tends to encompass the entire spectrum of sedentary behavior that schoolchildren engage in (Kirby et al., 2012). This broad categorization presents a challenge, as current findings, based on self-reported measures, indicate that different types of sedentary behavior may have contrasting effects on academic performance. For example, certain sedentary activities, such as searching the internet, listening to music, or sitting idle, may have negative effects, whereas others, such as studying without a computer or reading for pleasure, may enhance it. This complexity highlights a significant limitation in interpreting the relationship between sedentary behavior and mathematics performance, as the nuanced effects of different sedentary activities are not fully captured. Furthermore, the existing literature emphasizes that while SB negatively affects certain aspects of youth health outcomes, it may not have uniform effects across all domains, including academic achievement (Ekelund et al., 2016).

4.2 Health-related fitness parameters

The relationship between postural stability and mathematics achievement observed in our study warrants particular attention. The significant difference in balance performance between achievement groups suggests shared neural substrates between mathematical cognition and motor control, as both functions rely on cerebellar and prefrontal cortical networks (Cadenas-Sanchez et al., 2020; Raghuveer et al., 2020). Recent neuroimaging studies have demonstrated overlapping activation patterns during complex mathematical operations and fine motor control tasks (Felin Fochesatto et al., 2023). In child development, the ability to maintain postural control plays a crucial role, serving as a fundamental prerequisite for performing complex motor skills and a variety of physical movements (Esmaeilzadeh and Kalantari, 2013; Dhahbi and Saad, 2024). In the present study, a key finding was the robust relationship between postural stability and mathematics achievement, characterized by a large effect size ($\eta_p^2 = 0.137$). This substantial effect indicates that 13.7% of the variance in balance performance is explained by mathematics achievement level. Students exhibiting excellent mathematics achievement demonstrated superior balance control, maintaining stability longer compared to lower-achieving peers. The magnitude of this effect suggests meaningful neurophysiological connections between systems supporting motor control and mathematical cognition. This relationship aligns with recent neurophysiological research suggesting shared neural networks between mathematical processing and motor control systems (Raghuveer et al., 2020). Enhanced executive functioning may serve as the common mechanism benefiting both cognitive tasks and motor control (Cadenas-Sanchez et al., 2020).

Medicine ball throwing performance revealed significant sex-based differences, reflecting established physiological distinctions. These differences persisted across mathematics achievement levels, suggesting independent developmental trajectories for upper body strength and academic capabilities (Hermassi et al., 2023). In fact, strength and power are considered important factors for throwing velocity, and the medicine ball throw is a valid test for predicting upper limb power (Hermassi et al., 2010; Hermassi et al., 2019).

4.3 Limitations

This study has several limitations that should be considered. Firstly, the cross-sectional design limits the ability to establish causality between the variables studied. Secondly, the reliance on self-reported data introduces the potential for biases, such as social desirability bias and recall bias. Thirdly, the lack of socioeconomic data means that important contextual factors that could influence the results were not accounted for. Lastly, the study was conducted with a single-school sample, which may limit the generalizability of the findings to other populations. Future longitudinal studies should examine the temporal relationships between these variables while considering maturational factors. In addition research should address these limitations by employing longitudinal designs, incorporating objective measures, including socioeconomic data, and using larger, more diverse samples.

4.4 Practical applications and recommendations

The study's findings highlight the need for sex-specific physical activity interventions in schools, especially in Qatar, where boys tend to be more active than girls (Dhahbi et al., 2024). Programs should address cultural factors that influence physical activity participation and focus on balance and coordination to improve both physical fitness and academic performance, particularly in mathematics.

Given the inverse relationship between sedentary behavior and mathematics achievement, reducing sitting time is essential. Schools can integrate more active breaks and physical activity into the curriculum. Regular monitoring of physical activity and sedentary behavior will help tailor interventions, particularly for lower-achieving students. Furthermore, enhancing postural stability through targeted physical activity programs can support both physical fitness and cognitive function, benefiting students' academic performance.

5 Conclusion

This study demonstrates significant associations between mathematics achievement, health-related fitness, and physical activity patterns among Qatari schoolchildren, with particularly noteworthy relationships between postural stability, sedentary behavior, and mathematical performance. The findings support an integrated approach to educational and physical development, emphasizing the importance of reducing sedentary behavior, while promoting active learning strategies. Sex-specific differences in physical activity patterns highlight the need for targeted interventions considering cultural contexts. These results provide an evidence-based foundation for developing effective educational and physical programs in Qatar's educational system.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The studies involving humans were approved by the Institutional Review Board of Qatar University (QU-IRB 1544-FBA/21). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

SH: Conceptualization, Data curation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. WD: Formal analysis, Methodology, Visualization, Writing – review & editing. NJ: Writing – original draft, Writing – review & editing. AA: Funding acquisition, Resources, Writing – original draft. SK: Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. RT: Funding acquisition, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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